

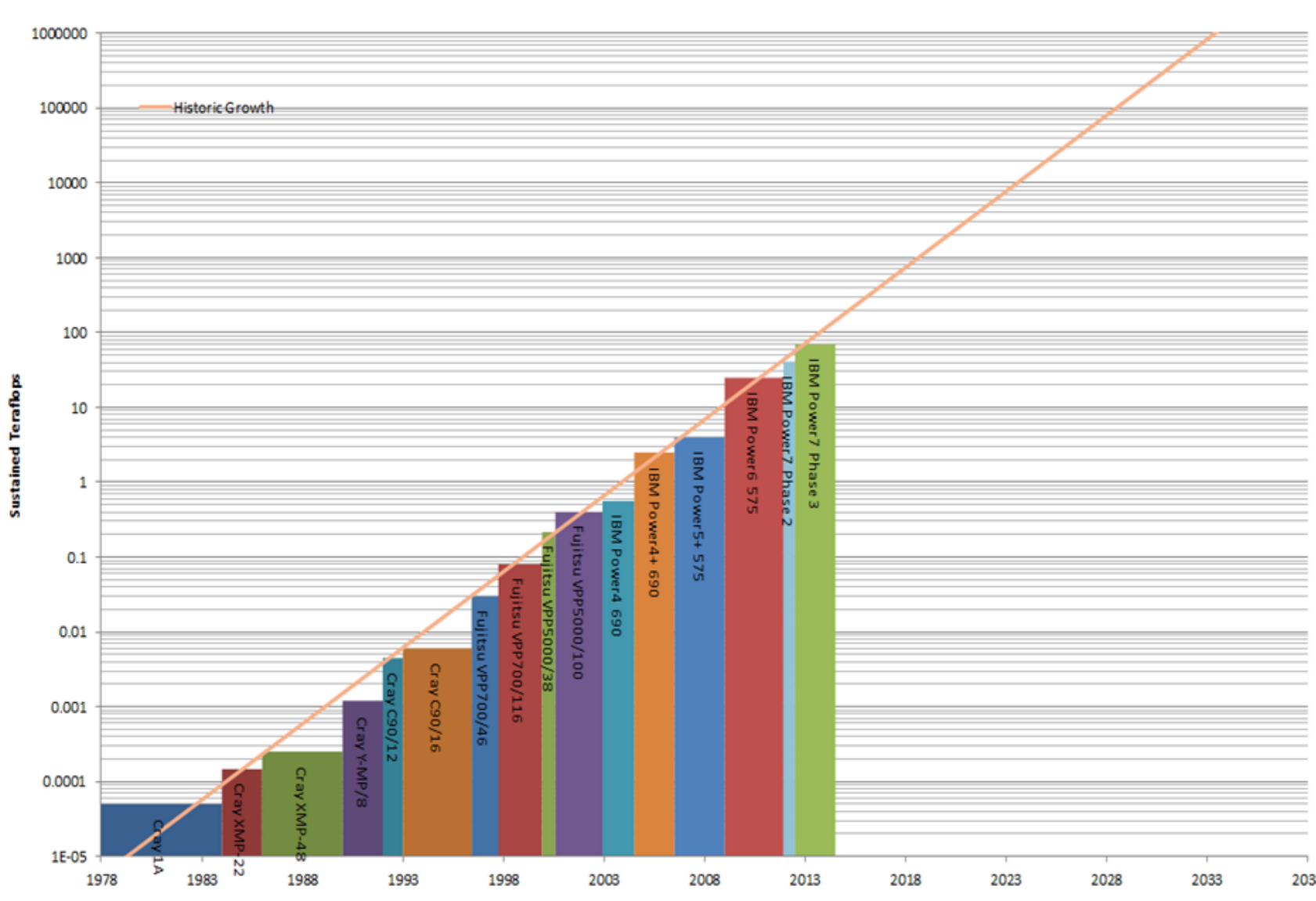
# A Massively-Parallel Framework for Finite-Volume Simulation of Global Atmospheric Dynamics

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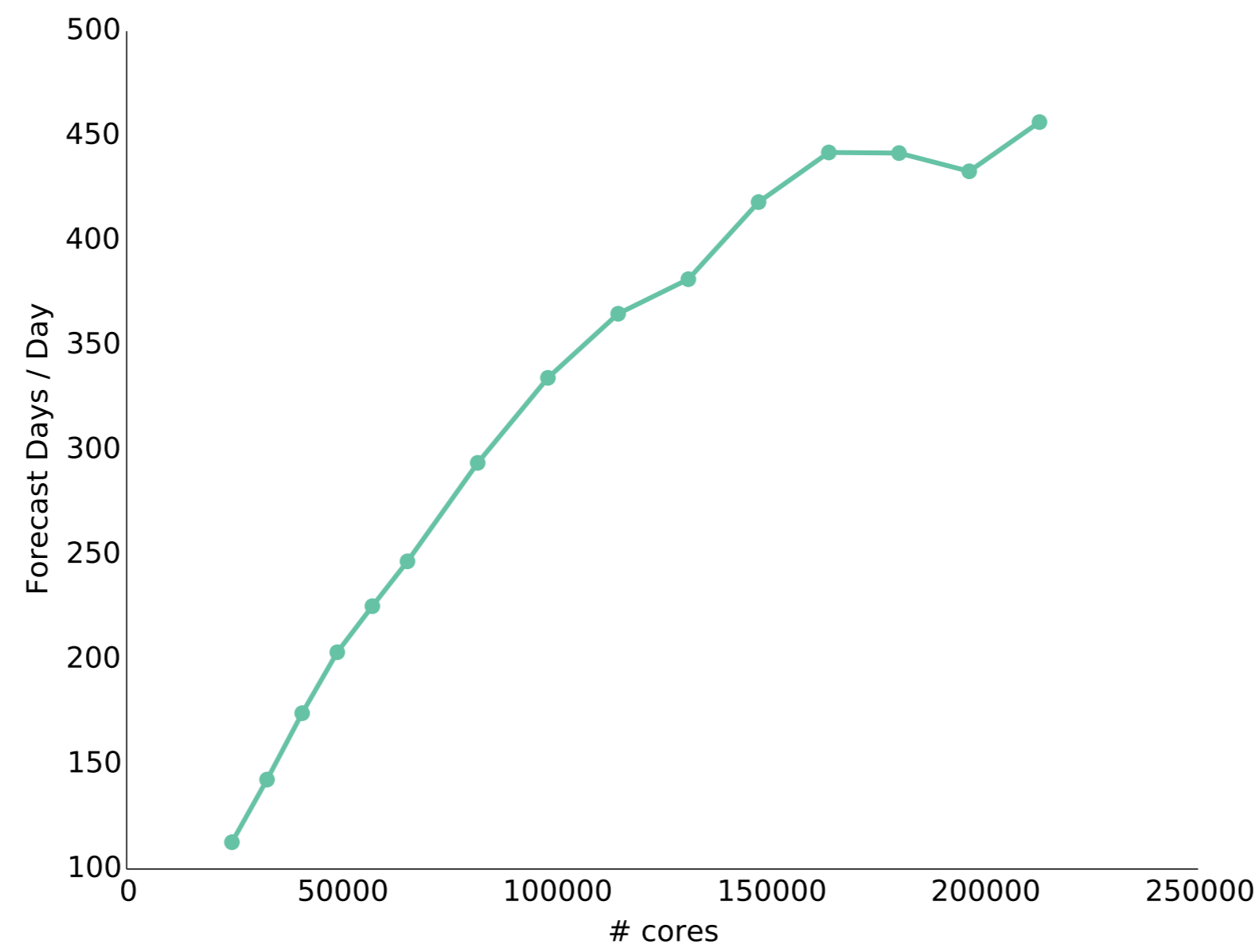
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## Scalability of Current IFS Dynamical Core



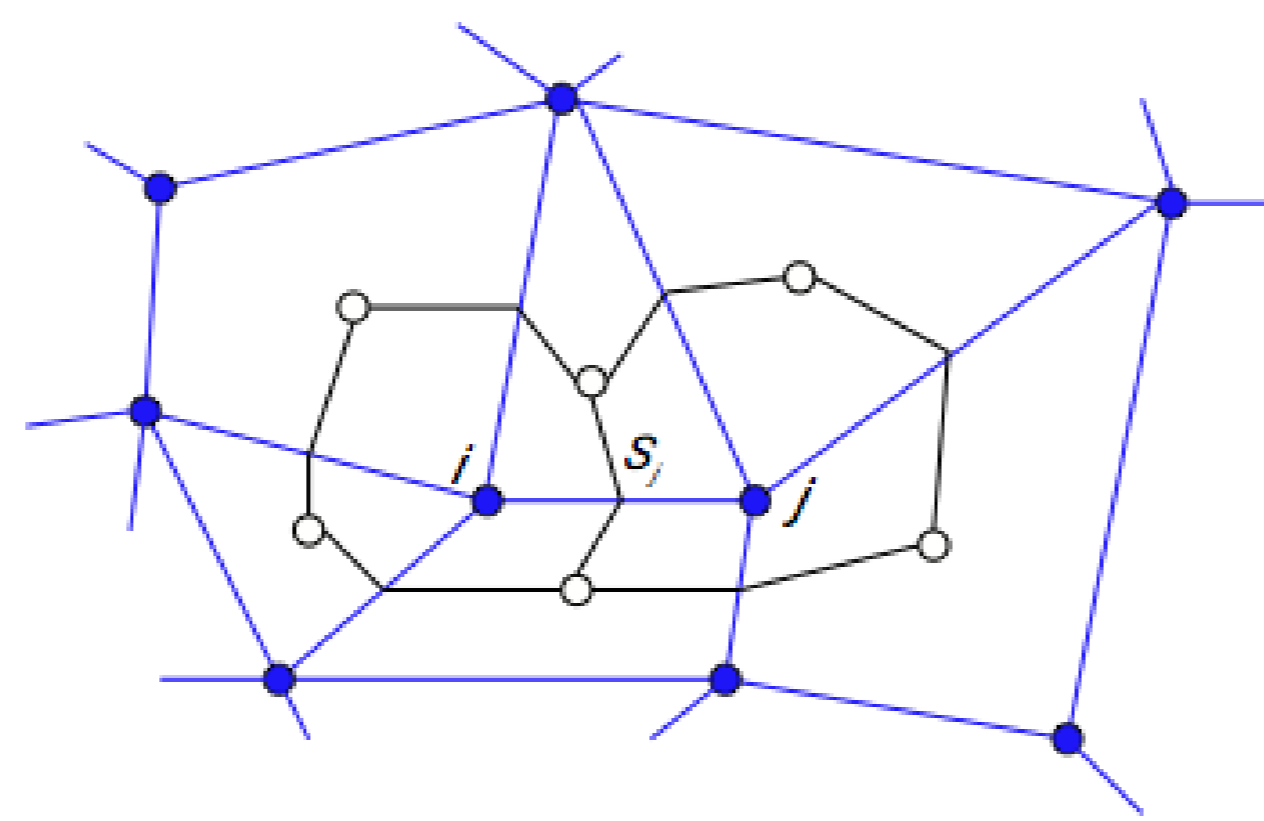
5km horizontal resolution with 137 levels



- ▶ We will reach Exa-scale in ~2030
- ▶ Spectral Transform Method does not scale to Exa-scale because of **global communications**
- ▶ Semi-Lagrangian time-stepping implementation is non-conservative

## Alternative Dynamical Core: Unstructured Edge-based Finite Volume MPDATA

- ▶ Non-oscillatory forward-in-time scheme, capable of accommodating a wide range of scales and conservation problems
- ▶ Unstructured prismatic meshes allow irregular spatial resolution and enhancement of polar regions.
- ▶ Formulation for time-dependent non-orthogonal curvilinear coordinates on the manifold.

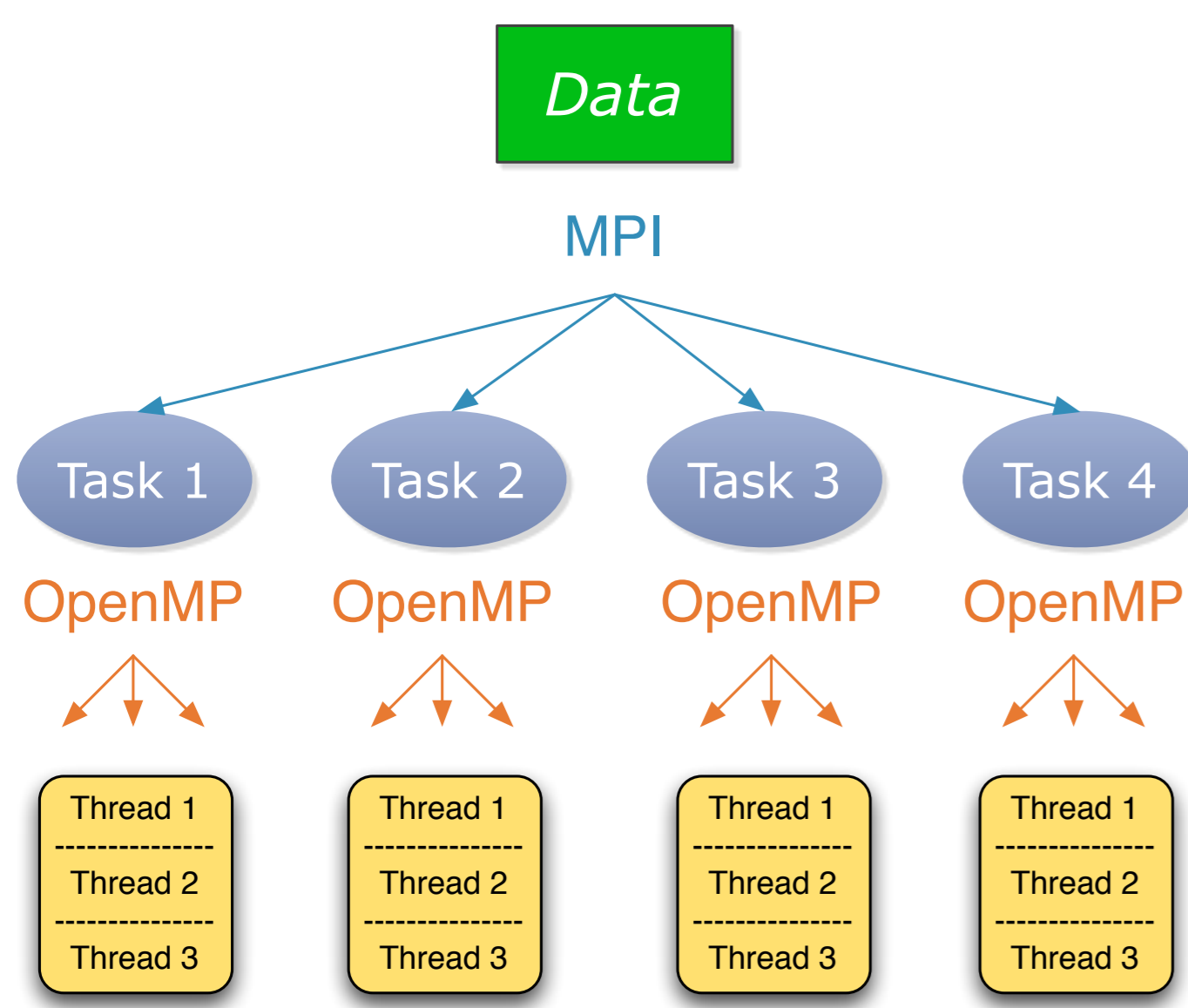


$$\frac{\partial G\psi}{\partial t} + \nabla \cdot (G\mathbf{v}^*\psi) = GR$$

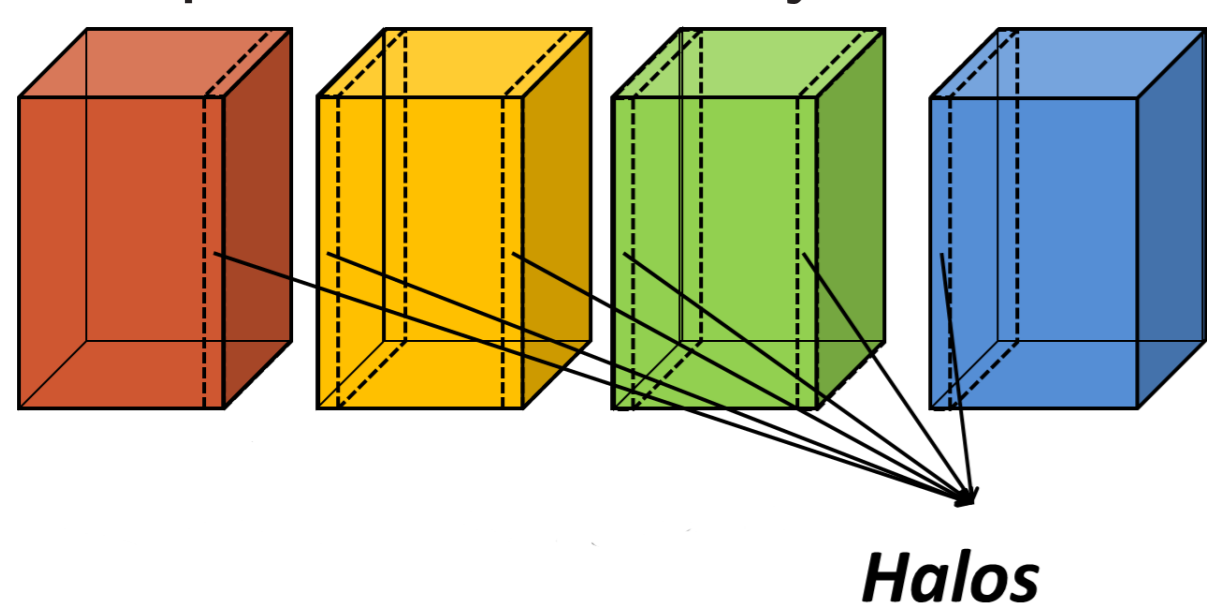
See Szmelter and Smolarkiewicz (2010, JCP), for further discussion.

## Massively Parallel Implementation

- ▶ Multiple levels of parallelism
- ▶ Optimal Equal-Area Domain decomposition



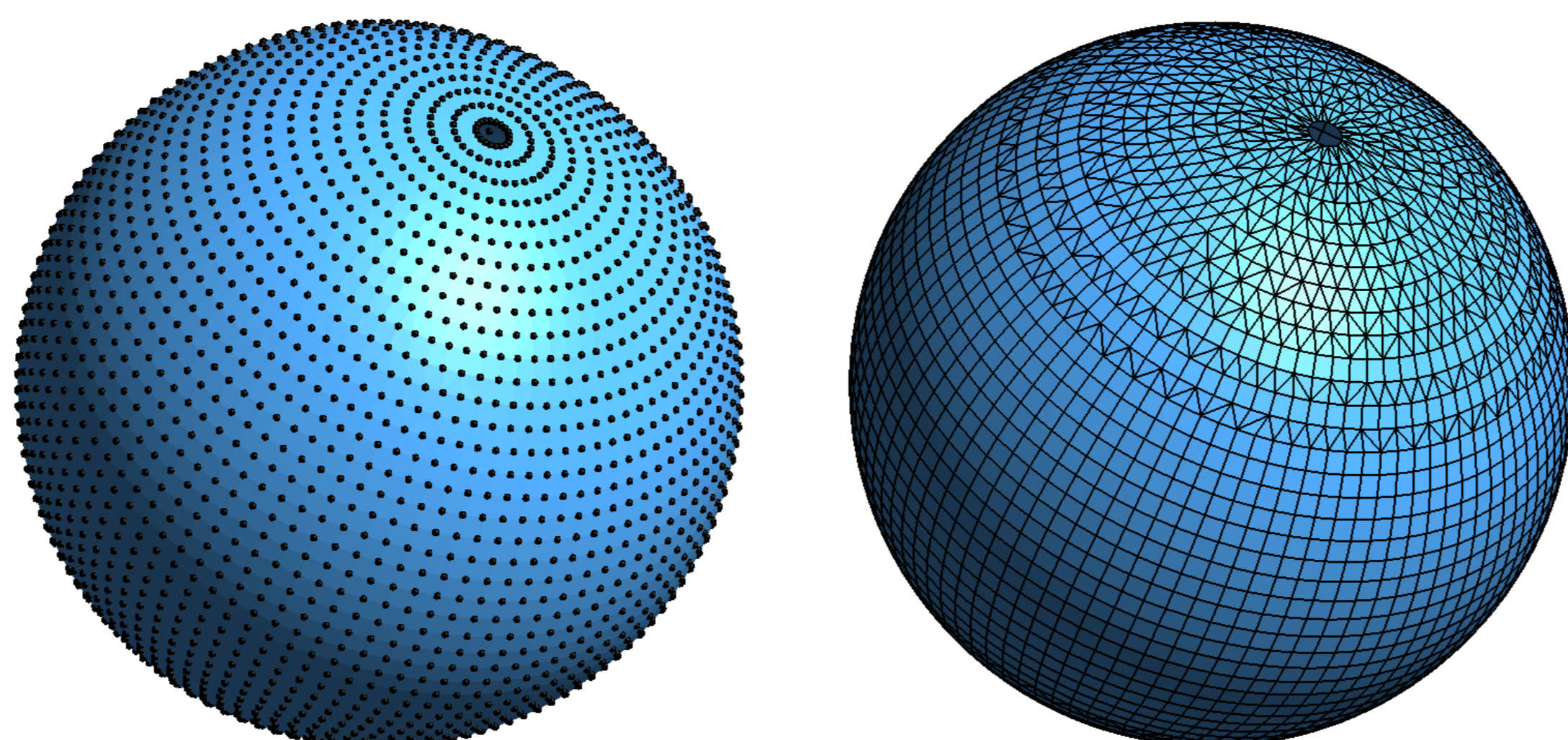
- ▶ Local computations in every subdomain



- ▶ Small halo needs to be exchanged with surrounding subdomains for **Distributed Memory** algorithms
- ▶ **Shared Memory** parallelisation avoids further subdivision of subdomains
- ▶ Structured treatment of vertical direction discounts cost of horizontal indirect addressing

## Evolutionary Introduction into IFS

- ▶ Construction of unstructured mesh using same data points as used by IFS' Spectral Transform Method
- ▶ Integration with ECMWF's infrastructure for archiving, post-processing, visualisation



## Flexible Dynamic Framework

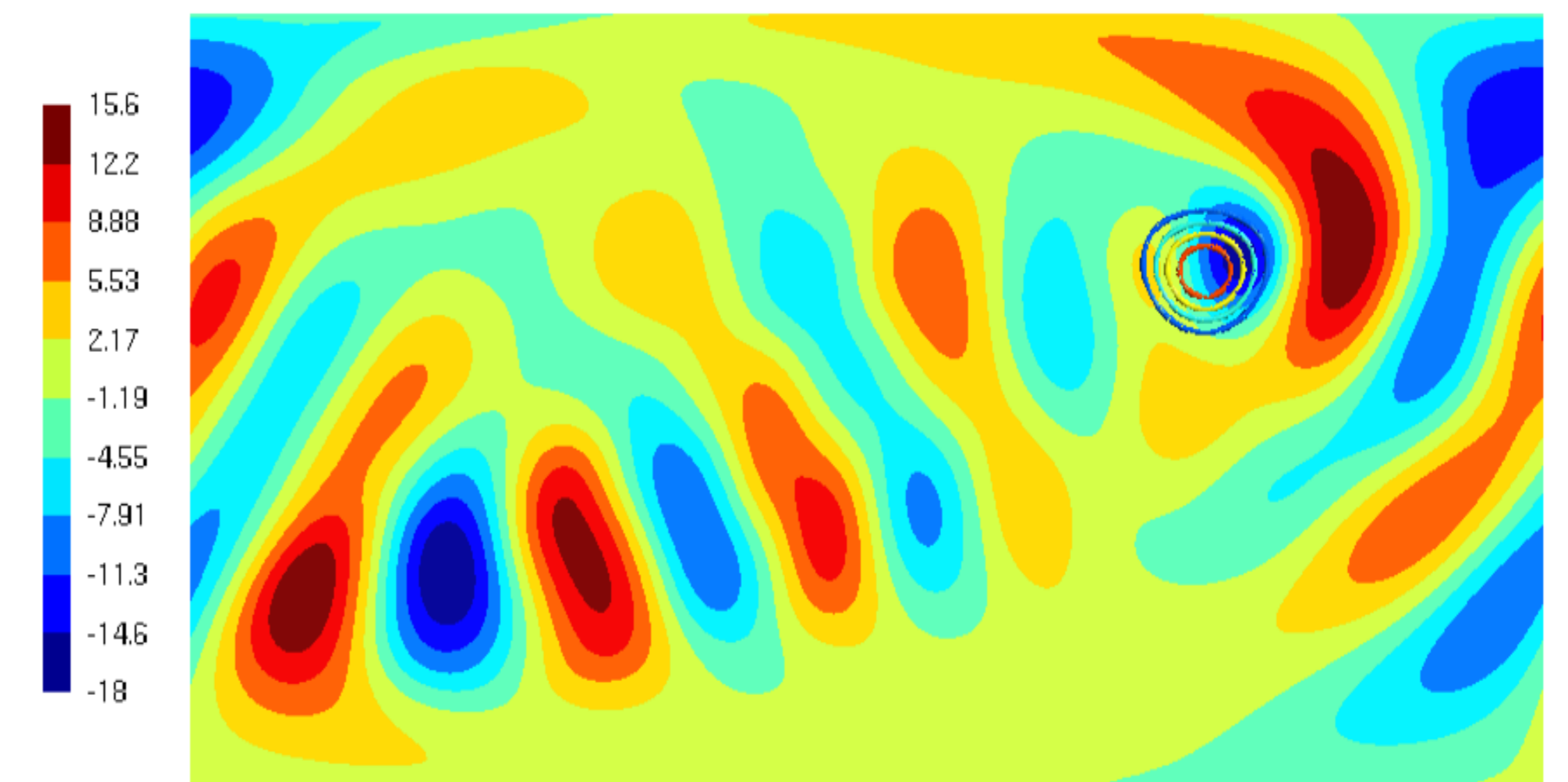
- ▶ Complex requirements for unstructured meshes
- ▶ Handling of distributed memory parallelisation
- ▶ Mesh specific routines: construction of dual mesh, periodicity, reading/writing fields, interpolation
- ▶ Multiple meshes to handle multigrid implementations
- ▶ **Object Oriented Design** using C++:
  - ▶ Hierarchical nesting of topological objects
  - ▶ Meshes, Field Sets, Fields
  - ▶ Multiple Halo-Exchange patterns
- ▶ **Fortran Interface** allows direct access to internal data

## Shallow Water Equations on the Sphere

$$\frac{\partial GD}{\partial t} + \nabla \cdot (G\mathbf{v}^*D) = 0$$

$$\frac{\partial GQ_x}{\partial t} + \nabla \cdot (G\mathbf{v}^*Q_x) = G \left( -\frac{g}{h_x} D \frac{\partial H}{\partial x} + f Q_y - \frac{1}{GD} \frac{\partial h_x}{\partial y} Q_x Q_y \right)$$

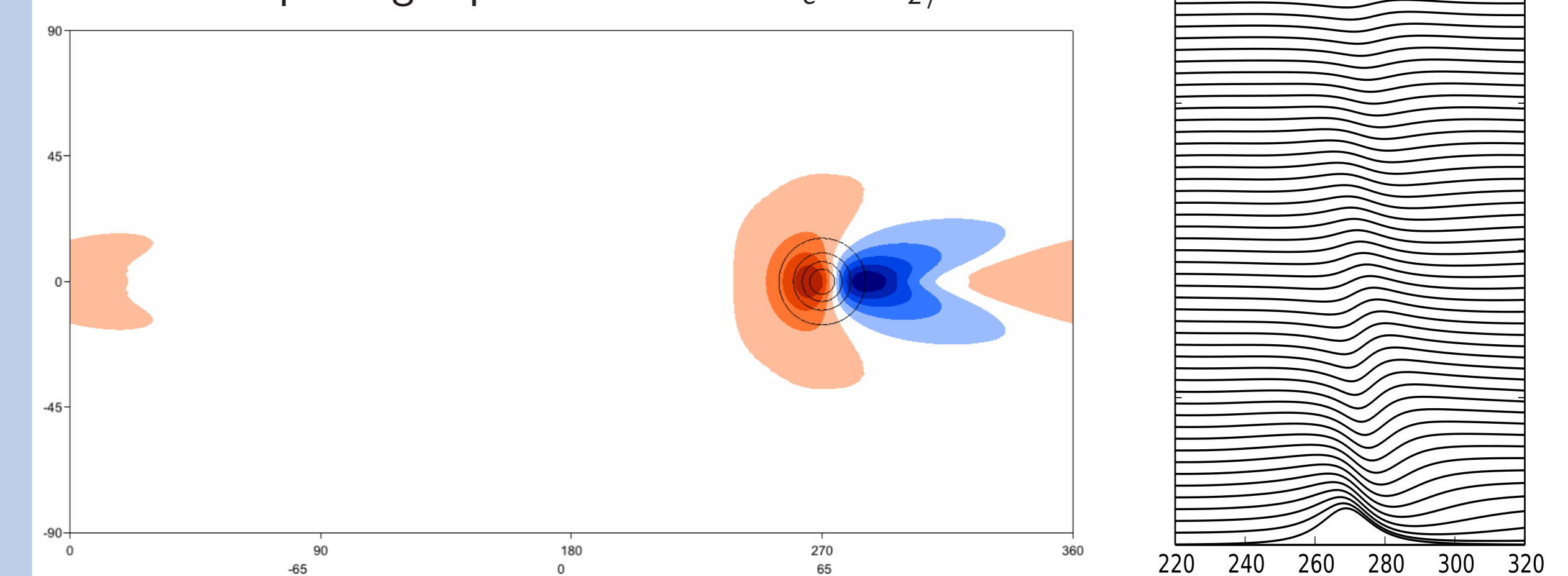
$$\frac{\partial GQ_y}{\partial t} + \nabla \cdot (G\mathbf{v}^*Q_y) = G \left( -\frac{g}{h_x} D \frac{\partial H}{\partial x} + f Q_y - \frac{1}{GD} \frac{\partial h_x}{\partial y} Q_x Q_y \right)$$



Meridional wind-component for flow over 2km mountain at mid-latitudes; result obtained using Reduced Gaussian mesh with 16km resolution.

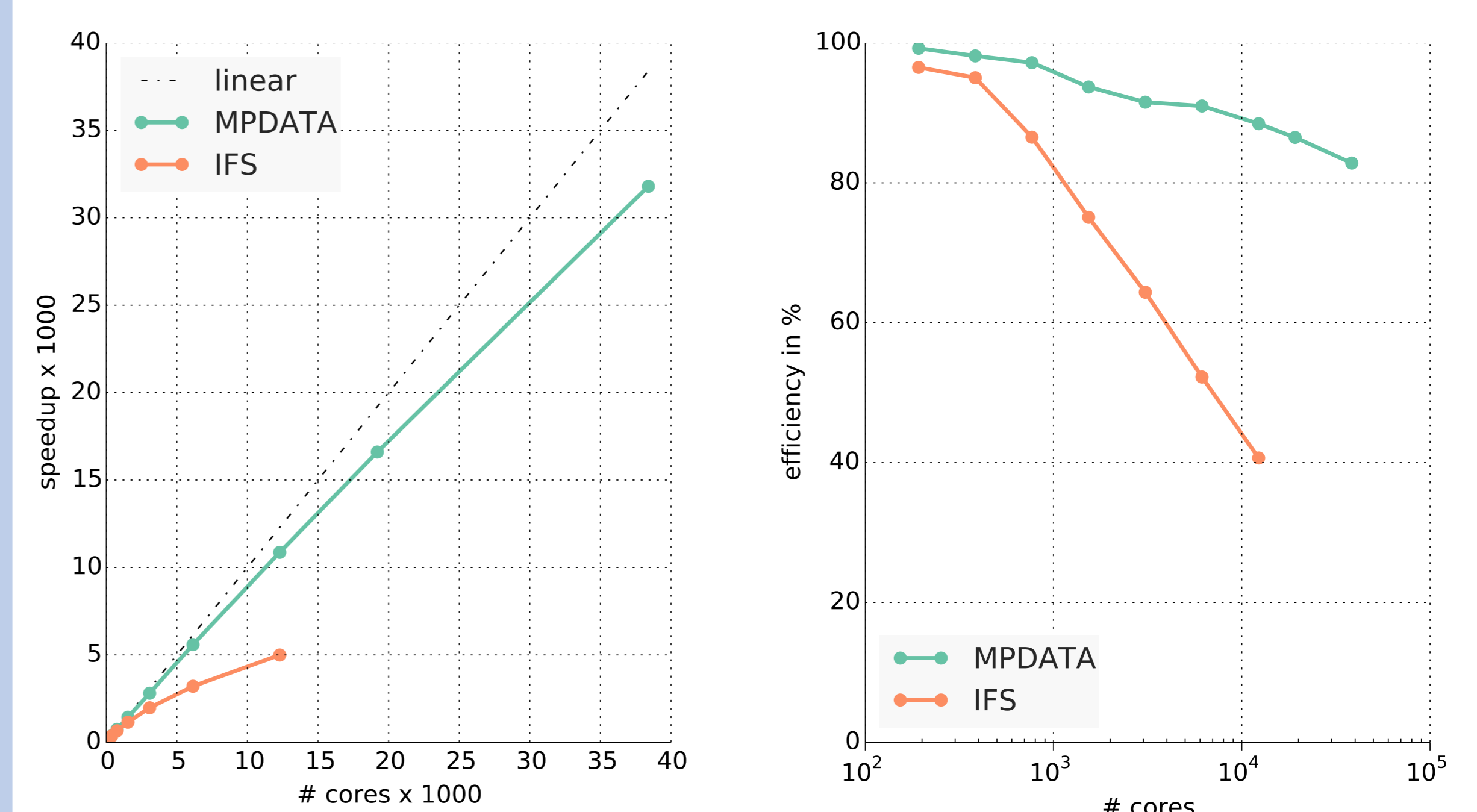
## 3D Hydrostatic Equations in Isentropic Coordinates

Froude Number = 2, Zonal wind  $U = 10 \text{ m/s}$ ,  
Brunt-Väisälä frequency = 0.04  
Isentropes in a vertical plane at the equator  
Isentropes height perturbation at  $H_e = \lambda_z/8$



Result obtained using Reduced Gaussian mesh with 1km horizontal resolution, and 40m vertical resolution on a small planet with radius 64km.

## Parallel Scaling results



Scaling results obtained with 10km Reduced Gaussian mesh and 137 Levels.

## Acknowledgements

