HOMME: Towards a Scalable High Order Atmospheric Dynamical Core

Richard Loft

Computational Science Section
Scientific Computing Division
National Center for Atmospheric Research
Boulder, CO USA

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Some Thoughts re Indo-US Collaboration

- Accuracy, mass conservation & scalability are important ingredients in future dynamical core evolution
- CSS @ NCAR has a focus in this area
- There as many aspects to explore.
- We are building a strong visitor program.
- We have a prototype code: **http://www.homme.ucar.edu**

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Advantages of Spectral Element Methods

- h-p finite element method (Ne x N)
- Exponential convergence in p (N)
- Naturally cache-blocked NxN computations
- Nearest-neighbor communication
- Well suited to highly parallel µprocessor systems

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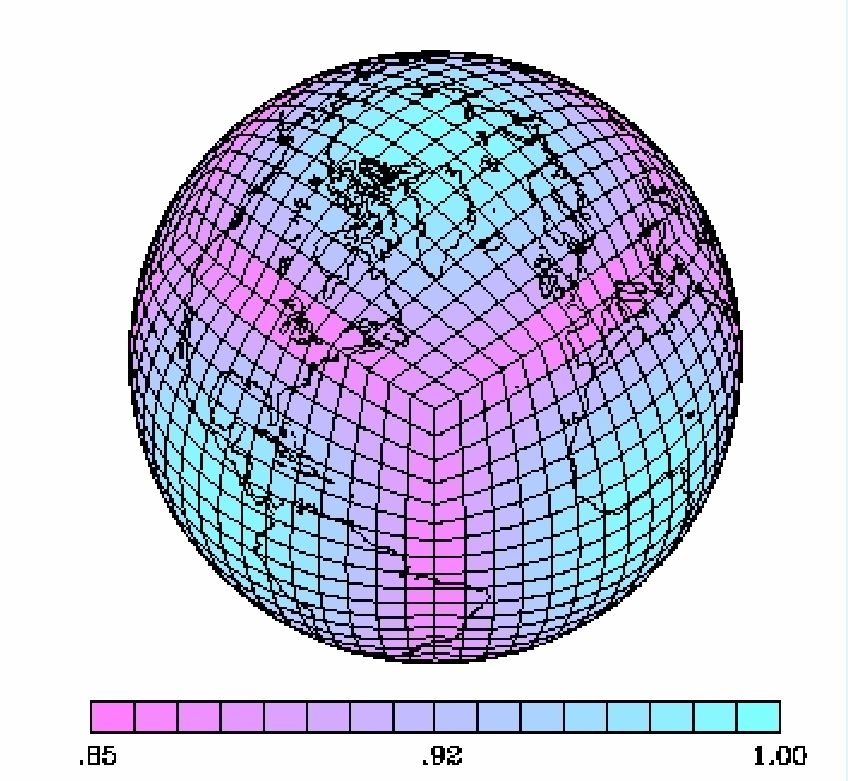
The Cubed-Sphere



- Equal angular grid
  - Rancic et al (1996)
- Quasi-uniform
- Avoids pole problems
- Curvilinear coordinates: metric terms
- Ne=12 6^{th} order elements approximates a T85 grid (current operational resolution)

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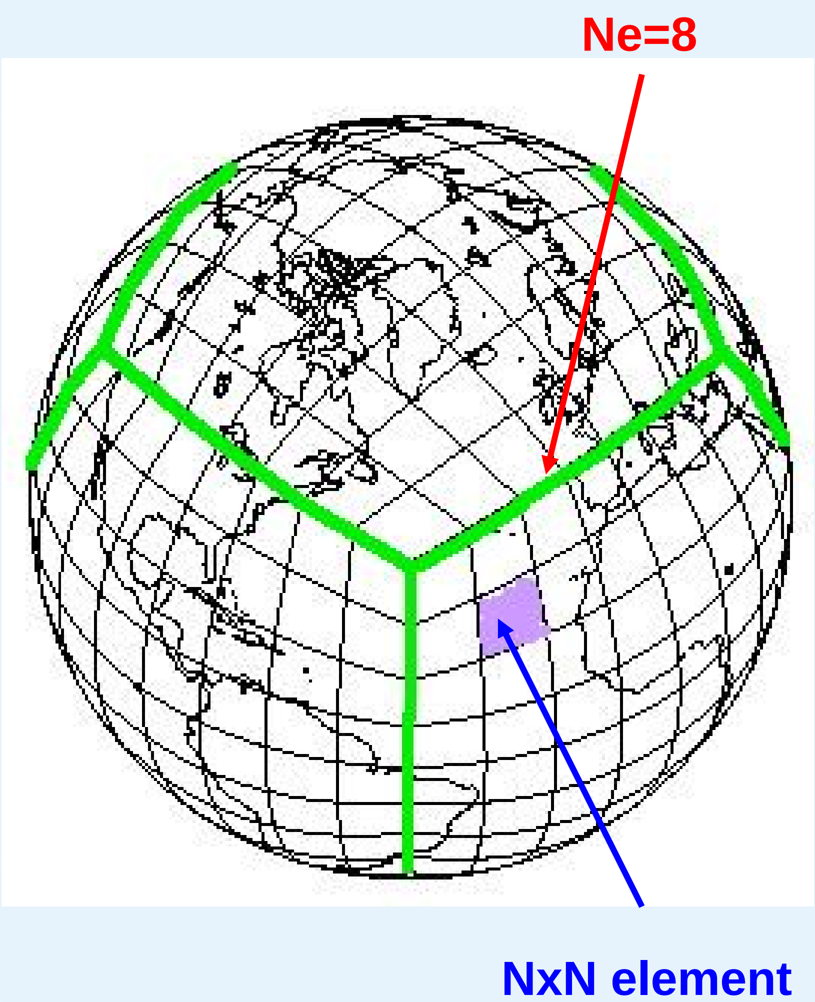
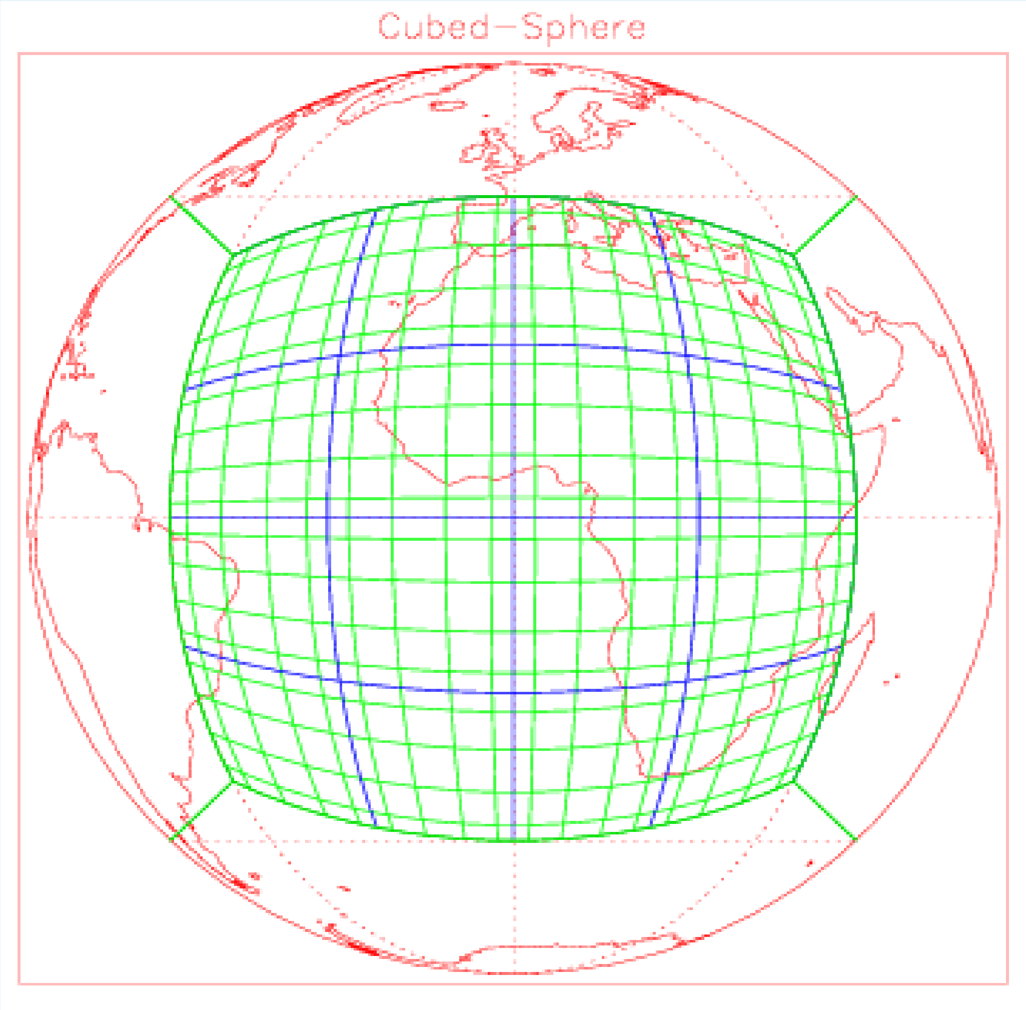
The Spectral Element Computational Mesh: the "Cube-Sphere"



- Spectral Elements:
  - A quadrilateral "patch" of gridpoints **N x N**
  - Gauss-Lobbattto Grid
  - N=8 is optimal (Taylor)
- Cube
  - **Ne** = Elements on an edge
  - 6*Ne*Ne elements total
- Cube Partitioning
  - Metis
  - Space filling curve partitioning algorithm
- Ne=8 shown ~180 km

6th Order Spectral Elements on the Ne=4 Cube Sphere



Moist Semi-implicit Spectral Element Hydrostatic Primitive Equations

- ✓ Crank-Nicholson time integration scheme
- ✓ CAM hybrid vertical discretization
- ✓ Non-staggered Gauss-Lobbatto grid
- ✓ Scalable preconditioned CG solver for semi-implicit
- ✓ Preconditioner limits iteration count to 3 iterations - 4-5 x faster than explicit.

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Methodology for Testing the Moist Primitive Equations with Physics

- ✓**Moist Held-Suarez** diagnostic
  - ✓Developed by Galewski, Sobel, Held
  - ✓Completed successfully - matches GSH paper
- ✓**Aqua-Planet** Tests (Neale & Hoskins)
  - ✓Emanuel physics (well into testing)
  - ✓CAM Physics (software integration begun)

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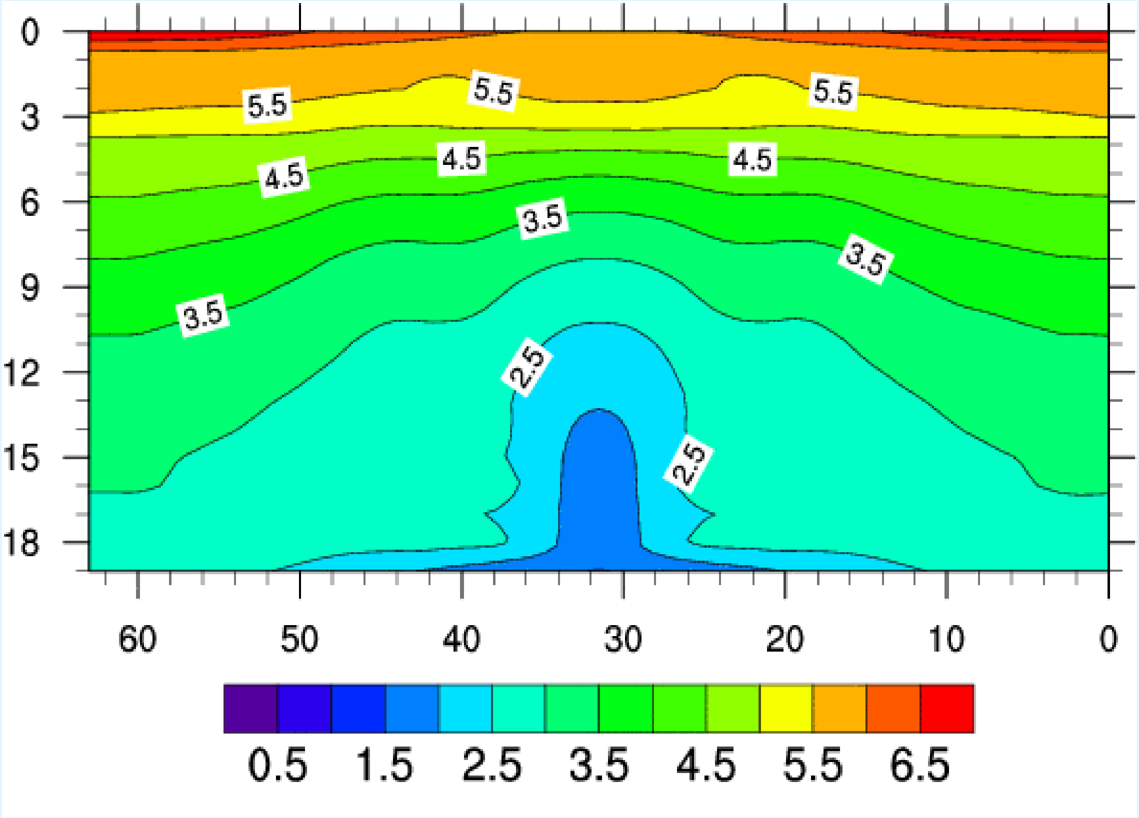
Moist Held-Suarez Test Case: Temporally and Zonally Averaged Log of the Mixing Ratio



Testing HOMME Scalability

Blue Gene/L @ NCAR

"Frost"

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Details of the NCAR/CU "Frost" Blue Gene/L

- 2048 processors, 5.73 Tflops peak
- 2 processors per node
- Torus Interconnect Network
- 32 I/O nodes
- 6 Tbytes of high performance disk
- Delivered to NCAR: March 15, 2005

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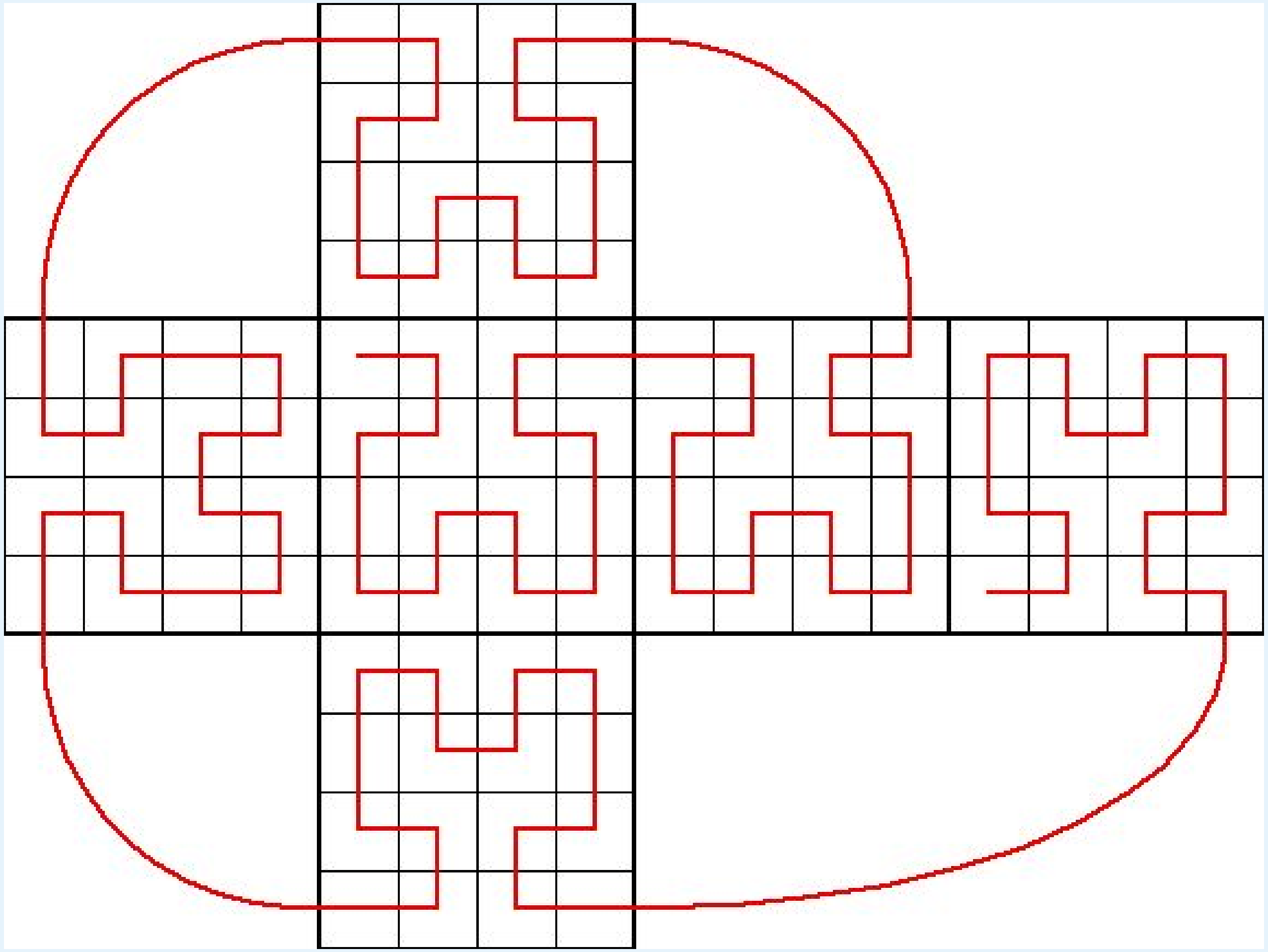
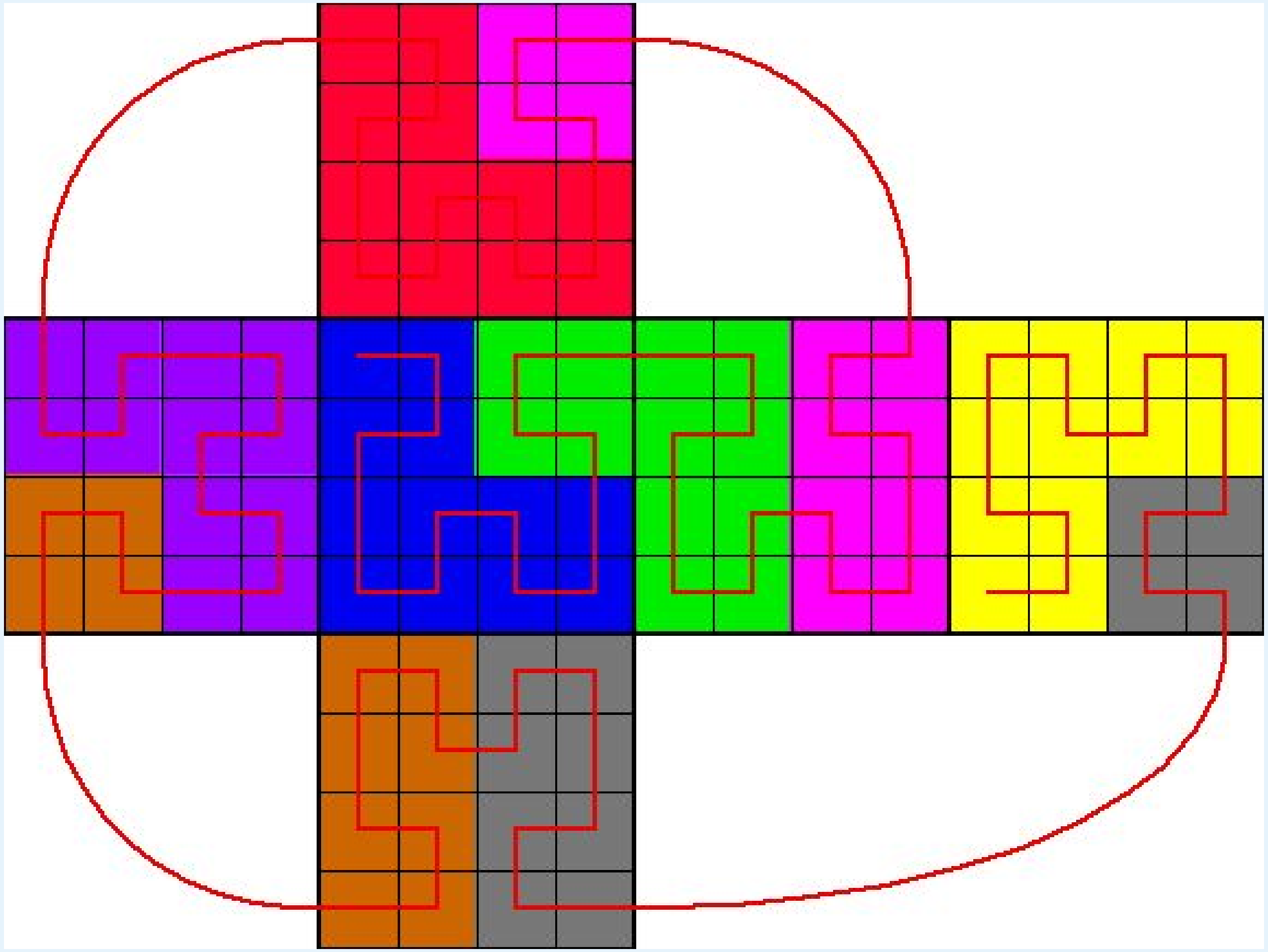
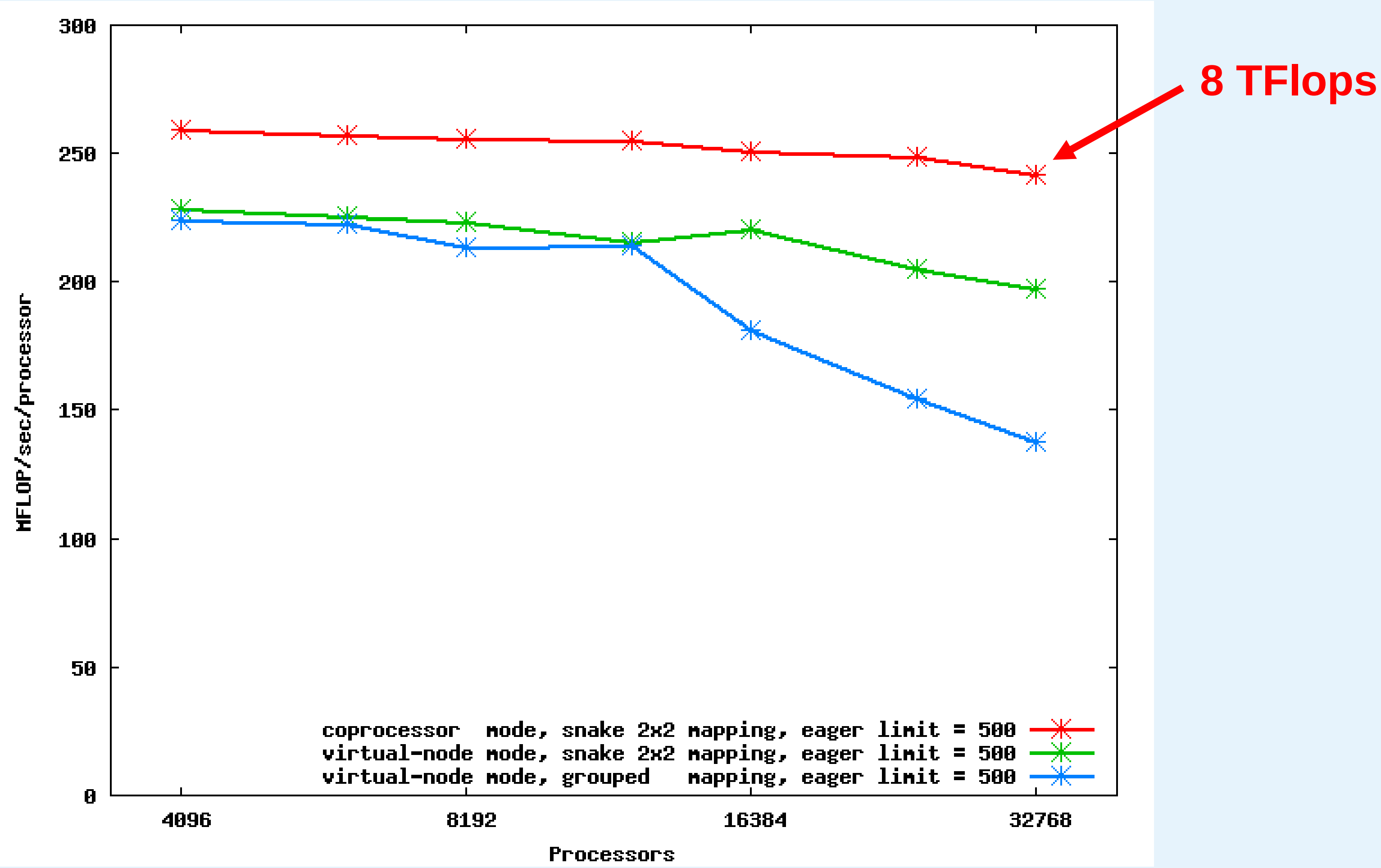
Partitioning a cube-sphere on 8 processors



Partitioning a cubed-sphere on 8 processors



BG/L HOMME - Moist Held-Suarez



Sustained MFLOP per second per processor for moist Held-Suarez.
Explicit integration Δt = 4 seconds.

6 X 128 X 128 elements, 96 vertical levels.

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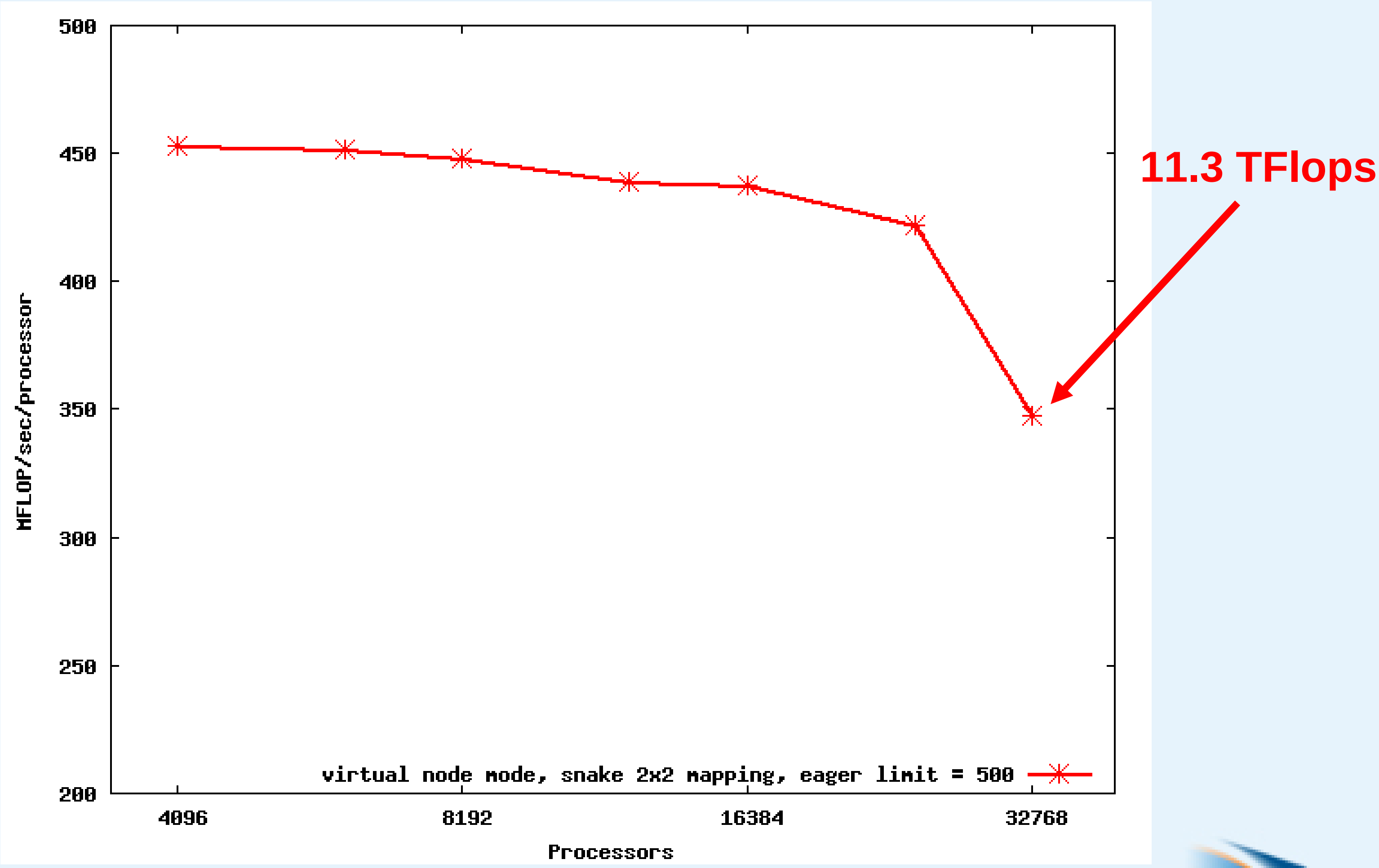
BG/L HOMME - Aquaplanet with Emanuel Physics



Sustained MFLOP per second per processor for Aquaplanet with Emanuel physics.
Explicit integration Δt = 4 seconds.

6 X 128 X 128 elements, 40 vertical levels.

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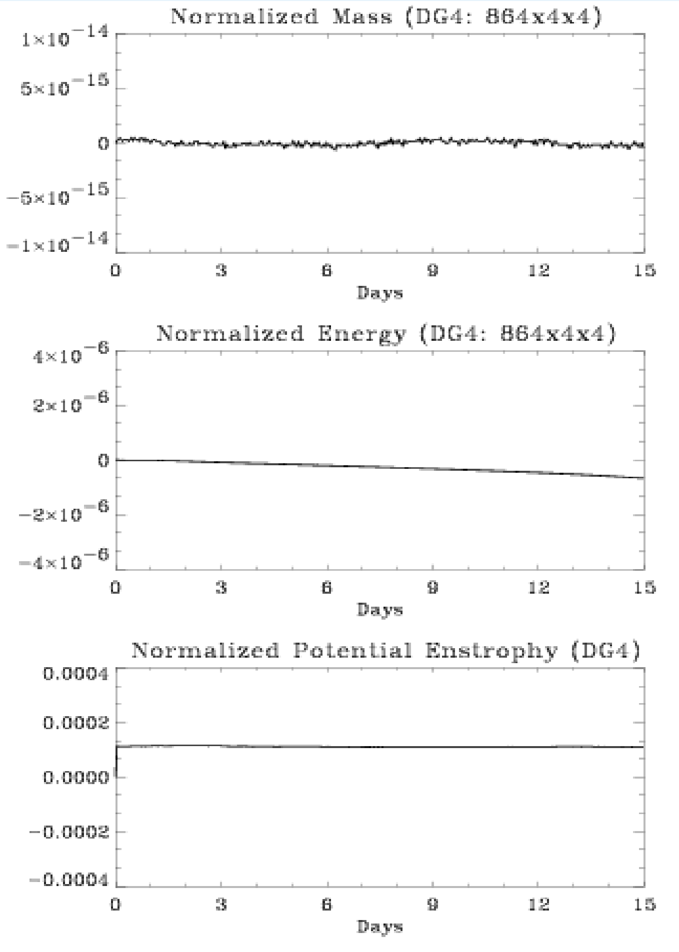
Discontinuous Galerkin Method

Discontinuous Galerkin

- **Discontinuous Galerkin**
  - A hybrid of finite-element and finite-volume methods
  - Known to capture discontinuities without spurious oscillations
- **Advantages**
  - – Better numerical results than spectral elements
  - – Mass conservation to machine precision.
  - – Good conservation of energy and potential enstrophy.
  - – Inherently scalable

Mass Conserving DG Scheme



- Shallow water equations (test case 5)
- Mass conservation to machine precision…
- Good, but not perfect, energy and potential enstrophy conservation…
- Conservative DG recently added to SE primitive equations model with standard CAM finite difference vertical coordinate scheme.

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Future Plans and Collaboration Areas

- Model Development
  - Integrate DG into moist primitive equations
  - Fully 3-D conservative schemes (vertical)
  - Complete Aqua Planet testing/validation
  - Complete integration into CAM model
    - Interface to physics packages
    - Add boundary data sets (land surface,etc)
    - Coupling cube sphere to other grids via **SCRIP**
  - Non-hydrostatic equations/meteorological applications?

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Future Plans and Collaboration Areas

- Applied Mathematics
  - solvers
  - Preconditioners
  - Time integration schemes (OIFS)
- Computer Science
  - Parallel domain decomposition
  - Process mapping
  - Optimization/ Portability-performance

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Questions?

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