Development of Global Cloud Resolving Model

Tests with 3D elliptic solver

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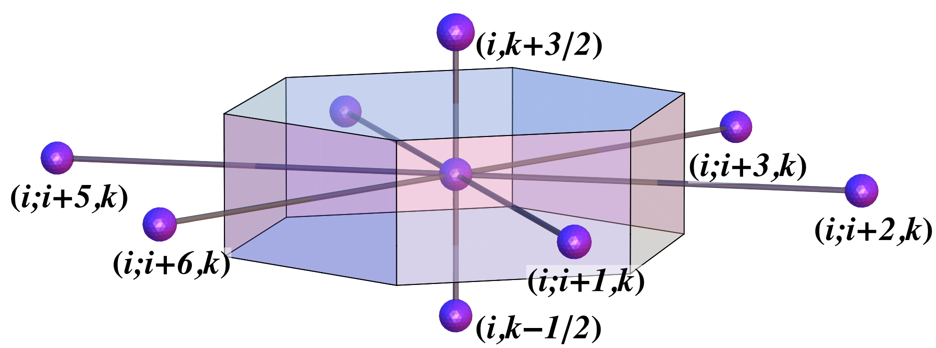
Development of a 3D poisson solver

- Based on Arakawa, Jung and Konor
- The continuous equation

$$\nabla^2 w + \frac{\partial}{\partial z}\left[\frac{1}{\rho}\frac{\partial}{\partial z}\left(\rho w\right)\right] = rhs$$



- The discrete equation

$$\frac{1}{A_i}\sum_{i'}\frac{w^{(\kappa)}_{i+i',k+1/2} - w^{(\kappa+1)}_{i,k+1/2}}{L_{i;i+i'}} l_{i;i+i'}$$

$$+\frac{1}{\delta z_{k+1/2}}\left[\frac{1}{\rho_{k+1}\delta z_{k+1}}\left(\rho_{k+3/2} w^{(\kappa+1)}_{k+3/2} - \rho_{k+1/2} w^{(\kappa+1)}_{k+1/2}\right) - \frac{1}{\rho_k \delta z_k}\left(\rho_{k+1/2} w^{(\kappa+1)}_{k+1/2} - \rho_{k-1/2} w^{(\kappa+1)}_{k-1/2}\right)\right] = rhs_{i,k+1/2}$$

where (κ) denotes an iteration index.

Development of a 3D poisson solver

- Re-arrange to form an implicit tridiagonal system in the vertical

$$\frac{\rho_{k-1/2}}{\delta z_{k+1/2}\rho_k \delta z_k} w_{k-1/2}^{(\kappa+1)} - \left[\frac{1}{A_i} \sum_{i'} \frac{l_{i;i+i'}}{L_{i;i+i'}} + \frac{\rho_{k+1/2}}{\delta z_{k+1/2}} \left(\frac{1}{\rho_{k+1}\delta z_{k+1}} + \frac{1}{\rho_k \delta z_k} \right) \right] w_{i,k+1/2}^{(\kappa+1)} + \frac{\rho_{k+3/2}}{\delta z_{k+1/2}\rho_{k+1}\delta z_{k+1}} w_{k+3/2}^{(\kappa+1)}$$

$$= rhs_{i,k+1/2} - \frac{1}{A_i} \sum_{i'} \frac{l_{i;i+i'}}{L_{i;i+i'}} w_{i+i',k+1/2}^{(\kappa)}$$

- A straightforward modification of the relaxation operator within the 2D multigrid.
- With the current domain decomposition the entire vertical column is local information. Scaling results of the 2D solver will indicate the scaling of the 3D solver.

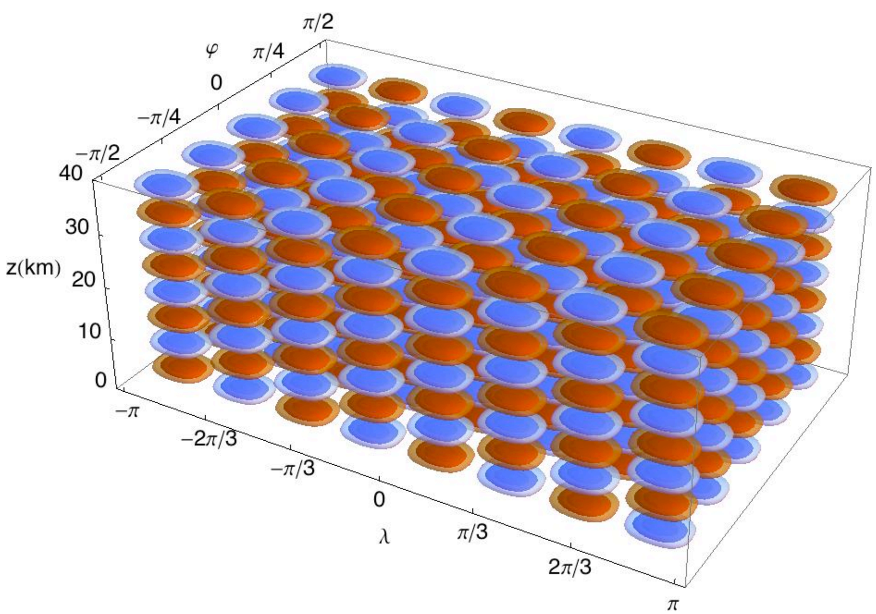
Convergence of 3D-multigrid -- analytic test 3

- Solve the Poisson equation:

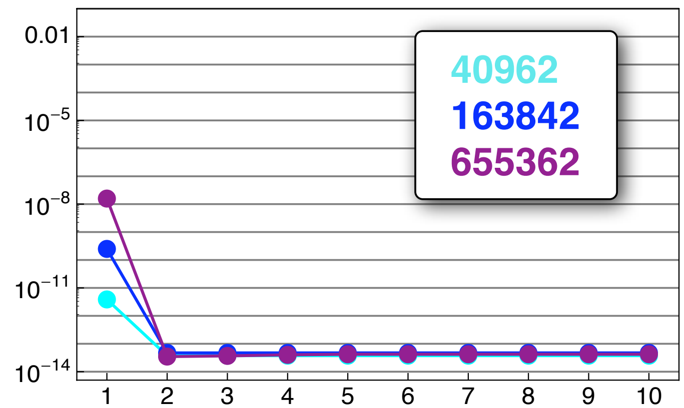
$$\nabla^2 w + \frac{\partial}{\partial z}\left[\frac{1}{\rho}\frac{\partial}{\partial z}(\rho w)\right] = rhs$$

- We can *make-up* an analytic test case and numerically differentiate to form *rhs*

$$w(\lambda,\varphi,z) = 4\sin(4\lambda)\cos^2(5\varphi)\sin^3\left(8\pi\frac{z}{z_T}\right)$$



- Infinity-norm of the difference between the true and numerical as a function of V-cycles



- 40 layers

Franklin (2D multigrid, 20 V-cycles, 20 layers)

The **NERSC Cray XT4** system, named **Franklin**, is a massively parallel processing (MPP) system with **9,660 compute nodes**. Each node has quad processor cores, and the entire system has a total of **38,640 processor cores**.

Each compute nodes consists of a **2.3 GHz** single socket **quad-core AMD Opteron processor (Budapest)** with a theoretical peak performance of 9.2 GFlop/sec per core (4 flops/cycle if using SSE128 instructions). **Each compute node has 8 GB of memory (2 GB of memory per core)**, and each service node (e.g. login node) has 8 GB of memory. Each compute node is connected to a dedicated **SeaStar2** router through Hypertransport with a 3D torus topology.

Time (s)		Number of cores					
		640	1280	2560	5120	10240	20480
Grid resolution	2,621,442 **(9)** (15.64km)	0.563	0.368	0.276	0.220		
	10,485,762 **(10)** (7.819km)	2.306	0.953	0.545	0.386	0.265	
	41,943,042 **(11)** (3.909km)	9.434	4.447	2.281	0.968	0.595	0.411
	167,088,642 **(12)** (1.955km)	insufficient memory per core	18.163	9.427	4.420	2.359	1.005
	671,088,642 **(13)** (0.977km)	insufficient memory per core	insufficient memory per core	insufficient memory per core	18.235	9.405	4.427

Current status and work

- Much of the computational infrastructure of the baroclinic model can be reused. e.g. parallel domain decomposition and communication
- Parallel 3D multigrid methods work well for elliptic equations on the icosahedral grid. 2D multigrid scales well to large numbers of processes.
- The stretching and tilting terms in the vorticity equations are straightforward and use many of the grid metrics developed for other operators.
- Advection is defined at cell centers, corners and edges:
  - Centers. 3rd-order upstream biased. Done
  - Corners. 3rd-order upstream biased. Done
  - Edges. Currently being developed.