G8 ICOMEX: ICOsahedral-grid Models for Exascale Earth System Simulations

Japan, UK, France, Germany, Russia

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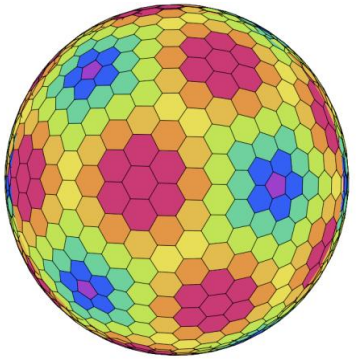


Objective: Prepare 4 advanced Earth system models based on icosahedral grids but *differences in numerics and grid structure*

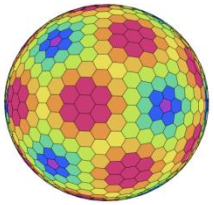
- NICAM, Structured hexagonal A-grid
- ICON, Unstructured triangular C-grid
- MPAS, Unstructured hexagonal C-grid
- DYNAMICO, Structured hexagonal C-grid

- Exascale computing required

Basic strategy

- Address selected key problems on the way to exascale and derive generic solutions
- WPs focus on optimization of computational performance and parallelization of I/O
- Complemented by a regular model intercomparison exercise

Intercomparison and evaluation of models



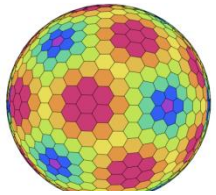
Goal: Model intercomparison on K computer

Lessions learned:

- Porting the model codes to K computer turned out to be difficult
  - Non-standard software stack (e.g. MPI library)
  - Initially, remote memory access did not work
  - OpenMP is not supported, instead the compiler supports auto-parallelization
  - Using the available auto-parallelization requires code refactoring at a level that is not feasible for the non-Japanese groups

→ *Thus, only a limited performance comparison could be conducted so far*

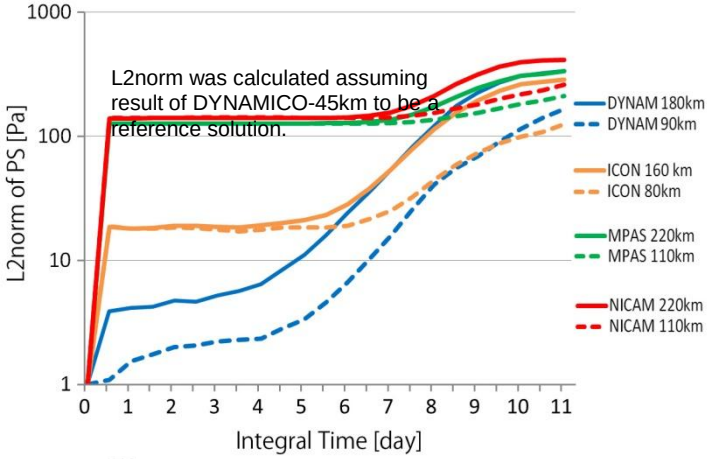
Intercomparison and evaluation of models



Deterministic Test (Jablonowski and Williamson 2006)

→ *All four models show improvement of error assessed in surface pressure.*

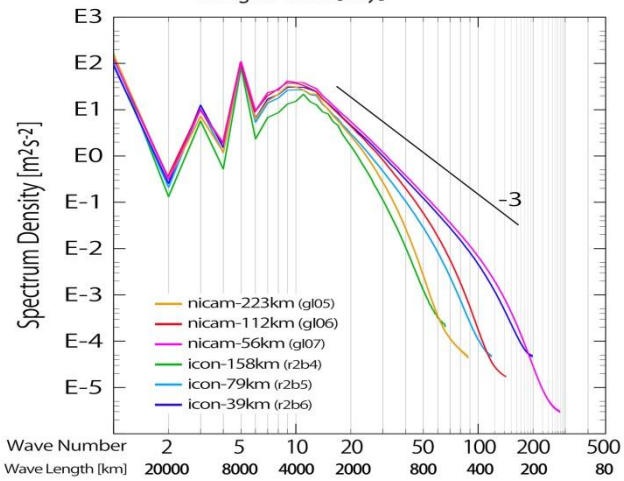
- Error rises just after an integration start in non-hydrostatic models; the degree of error is different among models.
- Most of the initial error can be solved by refinement of a vertical grid; it has been checked by changing number of vertical layers and its level.
- ICON model shows smaller error than that of the other non-hydro models; vertical discretization in ICON model seems to work well in this experiment.



Statistical Test (Held and Suarez 1994)

→ *An energy peak is found at wave number 7-10; both models simulated waves reasonably.*

- An energy slope obtained in higher horizontal grid-space is similar k^{-3} power spectra.
- An advantage of grid-space on ICON seems to be little comparing among same grid-levels (i.e. gl06 and r2b6).

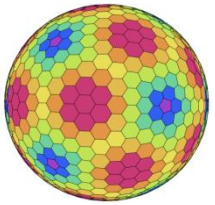


Aqua Planet Experiment (Neale and Hoskins 2000)

→ *Equatorial Kelvin waves were simulated reasonably in ICON model and NICAM.*

- In Hovmoller diagram of OLR, one or two clear line per one month (eastward propagation of cloud system) can be found in NICAM without CP.
- In ICON model, many lines can be found; it would be a characteristic of models with CP.

Abstract model description scheme



Goal: Improving portability of computational efficiency and productivity

- Development of a source-to-source compiler
- Abstraction of memory datatypes (and loop structures)
- Prototype available adapting the memory layout to a given computing platform
- For the ICON dynamical core, changing the memory layout from (cells, levels, blocks) to (levels, cells, blocks) yields a speedup between 11% and 17% on IBM Power 6 and Intel Westmere

Lessons learned:

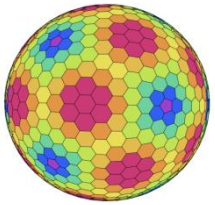
- Limited tool support for Fortran code (that works on non-toy examples)
  - Workarounds for source-to-source compiler (Rose) required
- Application/analysis even on a (stripped) climate model too time consuming

Ongoing work: Bottom-up approach to investigate kernels with alternative memory layout to derive best-practices for the model development and DSL requirements

Future work: Assessing potential of using accelerators

- Uses DYNAMICO code as work base; OpenACC directives will be considered

Implicit solvers for massively parallel computing platforms



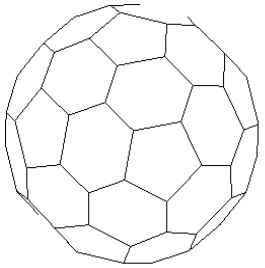
Goal: Development of an implicit Multigrid Helholtz solver

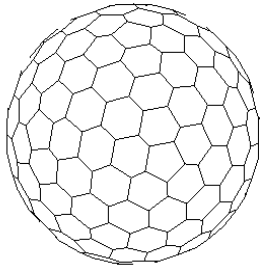
Implicit solver avoids global communication and does not inhibit bit-reproducibility

→ Results from Gung-Ho project indicate competitive computational performance and scaling

→ Development of a semi-implicit version of MPAS

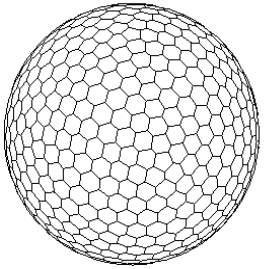
- Grid generation code has been adapted to build and write the multigrid hierarchy.
- Restriction/prolongation operators for the Hex C-grid have been tested in 2D.
- A semi-implicit time integration scheme has been formulated and the Helmholtz problem derived. Coding in MPAS is under way.

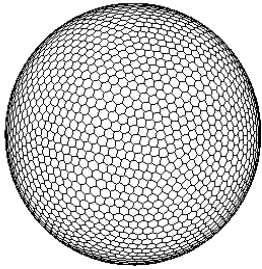




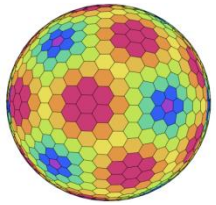
Lessons learned:

- Working remote from the core developers is suboptimal
  - Face-to-face speeds up development





Parallel I/O and internal postprocessing



Parallel internal postprocessing

Goal: Extent the XIOS I/O servers to support unstructured grids

- A second-order accurate, conservative, scalable and efficient remapping scheme for arbitrary grids has been developed and successfully tested

I/O benchmarking and optimization

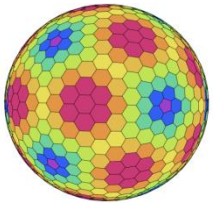
Goal: Analyze and suggest improvements for the (parallel) I/O scheme

- Analysis revealed performance degradation (Blizzard + NFS)
  - A patch circumventing the NetCDF cache speeds up serial write by a factor of 3
  - MPI-IO layer on DKRZ supercomputer required major performance fix
  - Embarrassingly parallel output (one file per task) continues to be fastest (A patch for HDF5 has been developed in the WP – 10x improvement)
  - Abstract I/O schemes and implied performance model have been developed

Lessions learned:

- Performance loss due to suboptimal interactions/replication: file systems <-> I/O layers
  - There are many pitfalls to extract best performance
- A generic performance optimized interface is needed to reduce optimization effort!

Lessions learned during the project



- International communication and coordination is important
  - Huge potential to share/re-use approaches and results
  - Unfortunately, this did not work perfectly for ICOMEX
  - Potential reason: the loose coupling of WPs in the proposal and late starts of several WPs

- Interdisciplinary effort involving computer science is helpful

- Challenges to overcome
  - Code portability
  - Performance portability
    - Inefficiencies in deployed software stack
  - Find the appropriate abstraction to formulate models
    - Improves portability and productivity

- Opportunities
  - Joint development of standards avoids re-development of software

Disclaimer: The views of the speaker do not necessarily reflect the views of the consortium.