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E3SM: Performance of spectral element dycore on Summit at scale

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EXASCALE COMPUTING PROJECT

E3SM Energy Exascale Earth System Model

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U.S. DEPARTMENT OF ENERGY

A performance-portable nonhydrostatic atmospheric dycore for the Energy Exascale Earth System Model running at cloud-resolving resolutions.

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L. Bertagna et. al., SC ‘20: Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis, 2020

SCREAM: Simple Cloud-Resolving E3SM Atmosphere Model

Simple code is faster, easier to port, and provides results which can be easily understood

Because very high resolution is the most obvious use of GPUs for climate modeling

Complete rewrite in C++/kokkos, allows us to escape from 40 yrs of legacy Fortran code

Lead: Peter Caldwell (LLNL)

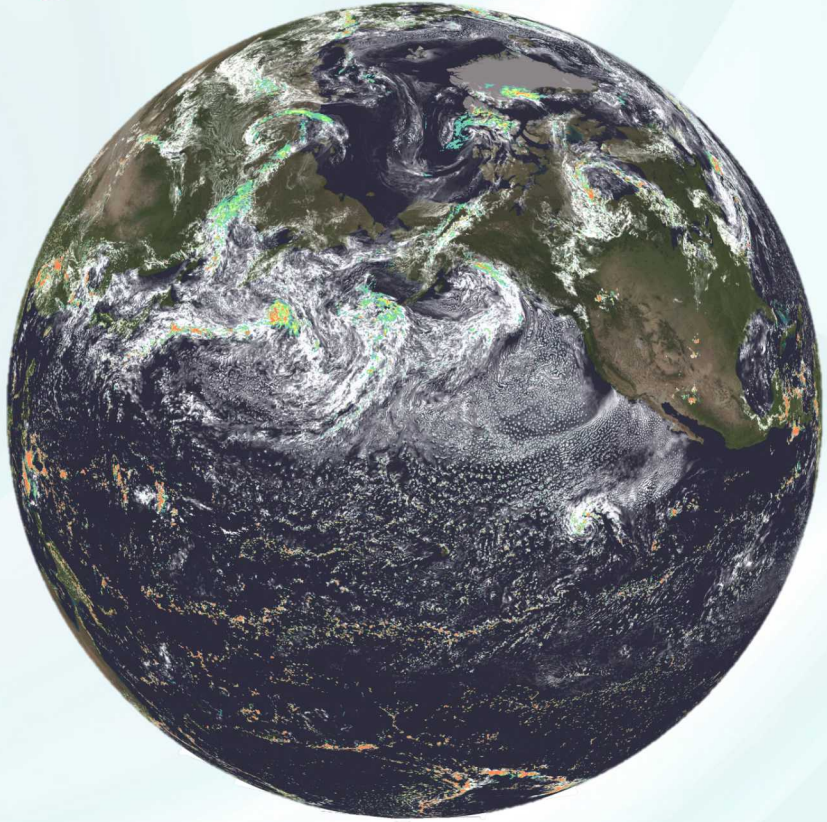
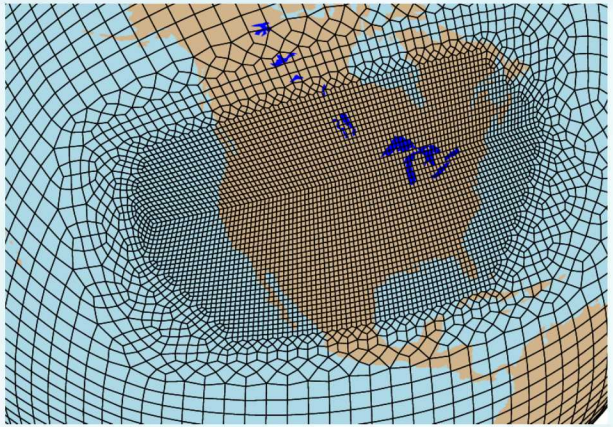


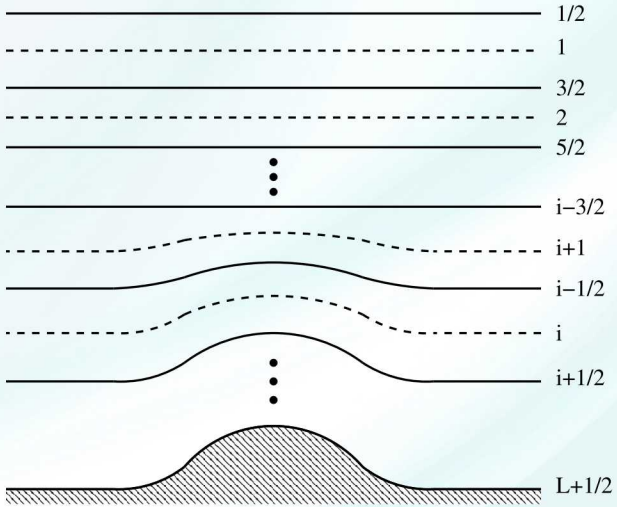
Fig: Snapshot of precipitation (color) and liquid water path (opacity with opaque white = 200 g m^{-2}) after 2.5 simulated days.

HOMME NH Dycore

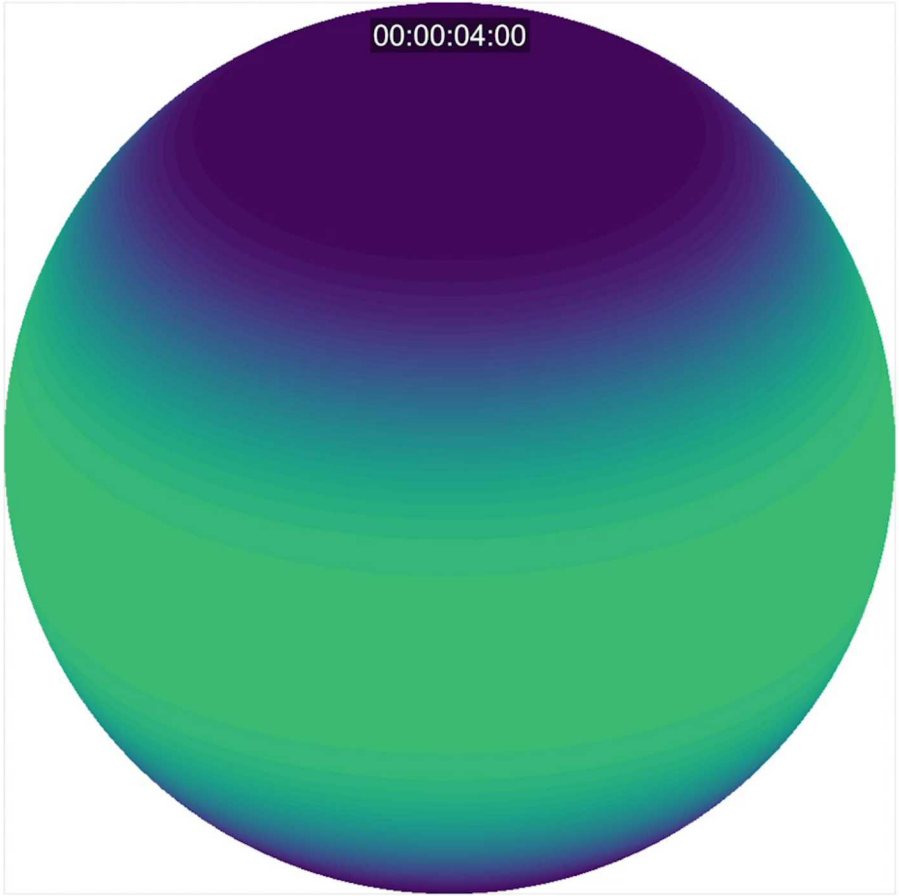
SCREAM Atmosphere model uses the HOMME nonhydrostatic dynamical core

- Euler equations + hyperviscosity, shallow atmosphere approximation, rotating reference frame
- Hamiltonian structure-preserving discretization
- Laprise mass coordinate formulation
- Lorenz staggering in the vertical
- Mimetic vertical differencing (Simmons & Burridge MWR 1981, Taylor et al. JAMES 2019)
- **Spectral Element** mimetic horizontal differencing (Taylor & Fournier, JCP, 2010)
- Vertically Lagrangian (SJ Lin, MWR 2004)



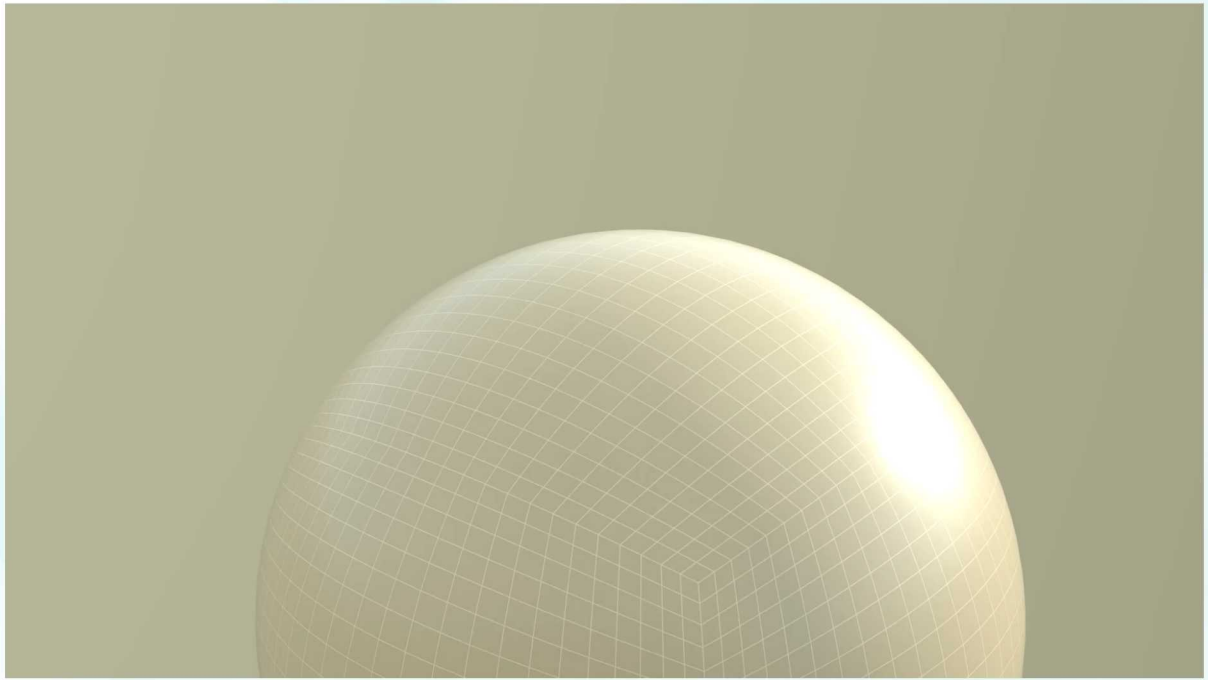


DCMIP Baroclinic Instability Test Case



- Specific humidity at ~500 mb. (0..7 g/kg)
- Idealized moist baroclinic-instability test case: geostrophically balanced initial state + small perturbation in the northern hemisphere
- 3 km horizontal resolution (average grid spacing at the Equator) for 40 days.
- 30 layers in the vertical (50km top)
- Instability grows exponentially to day 9, eventually spreading to the southern hemisphere. Fully turbulent around day 30.

DCMIP Supercell Test Case

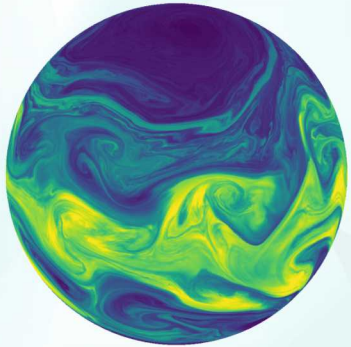


- Supercell test case on reduced-radius sphere used to test global models at nonhydrostatic scales with moist physics and turbulence.
- Kemp et al., MWR 2007, JAMES 2015 supercell test with warm-rain Kessler physics
- Rendered isosurfaces of cloud water + cloud rain
- Small Planet (x120), with 120m horizontal resolution
- Model top at 20km. 128L equally spaced in z (~156m)
- NERSC Cori, 1024 nodes, 64x2
- 2 hour simulation, 5s snapshots

NGGPS Dynamical Core Evaluation

https://www.weather.gov/sti/stimodeling_nggps_implementation_atmdynamics

- 13km and 3km benchmarks of several non-hydrostatic models (dynamical core) on cubed-sphere, icosahedral and geodesic grids
- All models originally run on NERSC Edison (Xeon Ivy Bridge)
- Precise documentation, easy to reproduce with any model.
- Baroclinic instability flow with 10 tracers, 128L
- E3SM HOMME dycore results.
  - **Non-Hydrostatic version**
  - 3km and 1km horizontal resolution
  - 128 vertical layers
  - 40s timestep
  - Monotone conservative transport
  - Report wall clock time for 2h simulation
  - No I/O

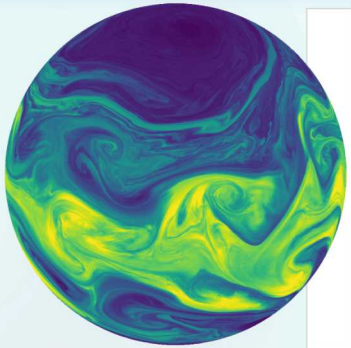


NGGPS 3km benchmark results

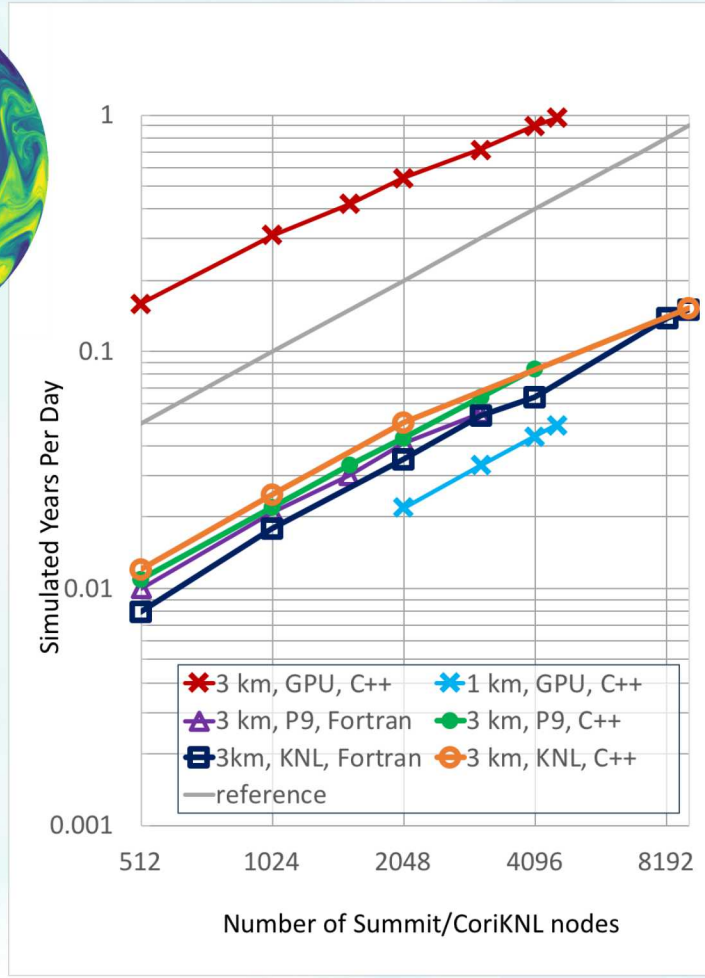
- Highlights from several generation of computers and GCRMs
- Double precision results (reported real*4 results ~1.6x faster)
- Modern Exascale architectures moderately outperform Edison (2012-2019)
- Not surprising, based on Linpack/HPGC comparison

GCRM Model	Computer (Linpack rating)	NGGPS 3km Benchmark
FV3	Edison (2.6PF)	0.16 SYPD
HOMME	TaihuLight (125 PF)	0.34 SYPD
HOMMEXX_NH	Summit (200 PF)	0.97 SYPD

NGGPS 3km Benchmark: Strong scaling (per node)



- C++/kokkos and Fortran codes competitive IBM P9
- C++/kokkos code has hand-vectorized every loop, leading to excellent KNL performance.
- Summit node with 6 V100s obtains ~ 12x speedup (for ~6x more power)
- 1km resolution also running well, but throughput is impractically low



Summary

- E3SM is developing SCREAM, a cloud resolving atmosphere model written from scratch in C++/Kokkos
- HOMMEXX-NH dynamical core for SCREAM is completed and running will on V100 GPUs, KNL and CPUs
- Physical parameterizations (P3, SHOCK, RRTMGP) are in progress
- Target for full model running on GPUs: mid-2021

Thanks!