Non-hydrostatic dynamics: Algorithms, software, and high-resolution science

SciDAC PI Meeting
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Outline

• **Primary results & impact**
  – Performance & accuracy improvements to E3SM Atmosphere (EAM) transport
  – Fully integrated into E3SM v2
  – New diagnostic methods for high-resolution experiments

• **Methods and highlights**
  – Algorithms and software
  – High-resolution science: Non-hydrostatic dynamics

• **Ongoing & proposed work**
  – Leveraging EAM results for MPAS Ocean
  – Model fidelity improvements with minimal performance impact
  – High resolution science campaigns

**Also at this meeting**

• **Poster (Tuesday)**: Characterizing Non-Hydrostatic Effects in the Next-Generation E3SM Atmosphere Model

• **Poster (Thursday)**: Algorithms and Software for Fast E3SM Atmosphere Tracer Transport
SciDAC Pilot Phase 1: Before & after

- Transport speedup (0.25 deg, 40 tracers): ~6x
- Dynamical core (v1 dynamics + transport, no physics) speedup: ~3x
- Full atmosphere model speedup: ~2.1x

2019: EAM/SL ready for v2
E3SM Atm. Dycore Performance

- SYPD (higher is better)
- Solid: Eulerian SE transport w/lim9
- Dashed: Pointwise SL + QLT
- Red: Cori (KNL)
- Green: Edison (HSW)

**6x transport speedup**
- **3x from SL:** larger time step, smaller data movement requirements
- **2x from MPI (NGD):** Reduced communication volume

**3x atm. dycore speedup**
- At scale
- Appx. same for KNL

**2x full atm. Speedup**
- Physics now largest component

3.2x speedup (Edison)

HOMME v1 1/4 Degree

- 40 tracers
- 25 km res.
- 72 vertical levels
Full EAM (dyn., trans., & phys.) performance

(a) $\Delta \lambda = 1^\circ$, 5 years

(b) $\Delta \lambda = 0.25^\circ$, 5 days

2.1x speedup (Anvil, 2700 ranks)

Unexpected result: ~10% to ~20% speedup in dynamics solver
- Better use of fast memory (L3 cache)
- procs. spend less time in MPI_Wait

More details in Thursday’s poster session
- Comparison of costs vs. resolution
- And more!

E3SM
Energy Exascale Earth System Model
U.S. DEPARTMENT OF ENERGY
Algorithms & software development

- Cell-integrated remap SL transport

**Highlight:**

**Insight:** High-order, remap SL …
- Requires at least 1 global collective per timestep to achieve tracer consistency and shape preservation
- Still lower communication volume than SL flux-form
- Can efficiency be improved further?

![Graph showing normalized wall time vs. NQ with 2.24x speedup (2400 ranks, Mutrino)]
## Cell-integrated SL vs. Pointwise interpolation SL

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![Diagram](Diagram.png)
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**Claim 1:** An algorithm that provides locally bounds-preserving shape preservation is sufficient to also provide tracer consistency.

**Claim 2:** Solving **Problem A** without losing conservation is equivalent to solving **Problem B**.
Algorithms & software

- Stabilized interpolation SL transport with Communication-efficient Density Reconstruction (CDR)

Highlight:
- Mass conservation, tracer consistency, and shape preservation solved in smallest possible number of global collectives

Verification:
- Improved accuracy in space
- Convergence in time with simplified physics

3.2x speedup (Edison)
Algorithms & software

- **Highlight:**
  - Software release
  - COMPOSE: Library for communication-efficient, property-preserving, semi-Lagrangian tracer transport

- **Climate validation**
- **Integration for E3SM v2**
  - CDR/ISL transport
  - Time step coupling
  - Already in E3SM Master
Hi-res science: Physics for hi-res

- BER Call for Proposals
  March 2019
  - Aerosol & aerosol-cloud interaction identified as “crucial” for E3SM v3, v4
  - Accurate representation may require additional tracer species
  - Multi-tracer efficiency of new SL methods provides significant advantages over E3SM v1
Hi-res science: Quantifying non-hydrostatic effects

• Vertical resolution requirements in hydrostatic vs. non-hydrostatic models (right)
• Multiscale interactions
  – Physically accurate or numerical artifacts?
• Results: EAM v3, v4 may require increased number of levels to reduce numerically-triggered small-scale features
Symmetric instability

- Small-scale process
- Intensifies rain bands in extratropical cyclones
  - Large effects on regional precip.
- Diagnosed by change in sign of EPV (right)
  - EPV now in EAM
- Results: EAM-NH capable of representing sym. inst., EAM-H is not

More details in Tuesday’s poster session
- Comparison of NH to H with baroclinic instability
- And more ...
Proposed for Phase 2

- Algorithms/Software
  - SL Trans. for MPAS Ocn (right)
    - No degradation in accuracy, conservation, consistency
    - Significant performance gains, esp. BGC
  - High-order tracer transport
    - Improved resolution of small scales
    - No timestep penalty

- NH Science
  - Radiative-Convective Eq.
    - RCEMIP contribution
  - Tropical cyclone climo.
  - Condensate loading
Summary

• Phase 1 impacts:
  – Model speedup @ 0.25 deg: Transport up to 6x, Dycore 3x, EAM 2x
  – EAM v2 with 120 tracers now runs as fast as v1 with 40 tracers
  – Aerosol modeling no longer constrained by transport
  – Flexible time-step coupling methods
  – COMPOSE Software already employed by other projects (LDRD, SciDAC)
  – Better understanding of NH effects in EAM, how to diagnose them

• Phase 2 impacts:
  – Transfer algorithms & tailor an implementation for MPAS Ocean
  – Improve perf. of BGC campaign
  – Add resolution to tracers without time step penalty
  – RCEMIP experiments
  – Hi-res climatology