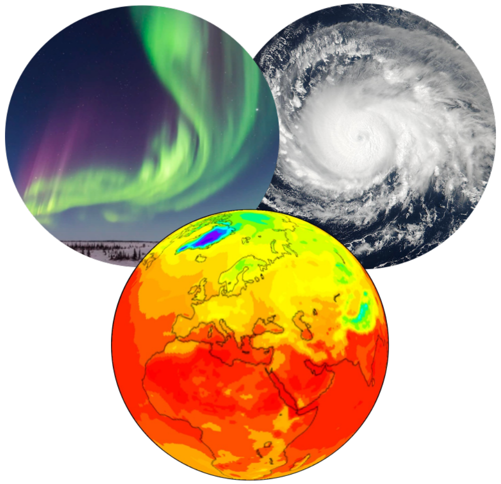
MPAS-Atmosphere in SIMA and CESM-CAM Preliminary Results

Bill Skamarock, Peter Lauritzen, Michael Duda, John Truesdale, Miles Curry



MPAS-Atmosphere in an Earth Systems Model

SIMA – System for Integrated Modeling of the Atmosphere

EarthWorks

EarthWorks (lead PI: Dave Randall CSU)

- A high resolution CESM configuration.
- A single ~4 km global grid for the atmosphere, ocean, and land.
- Exascale technology - GPUs

The SIMA Vision

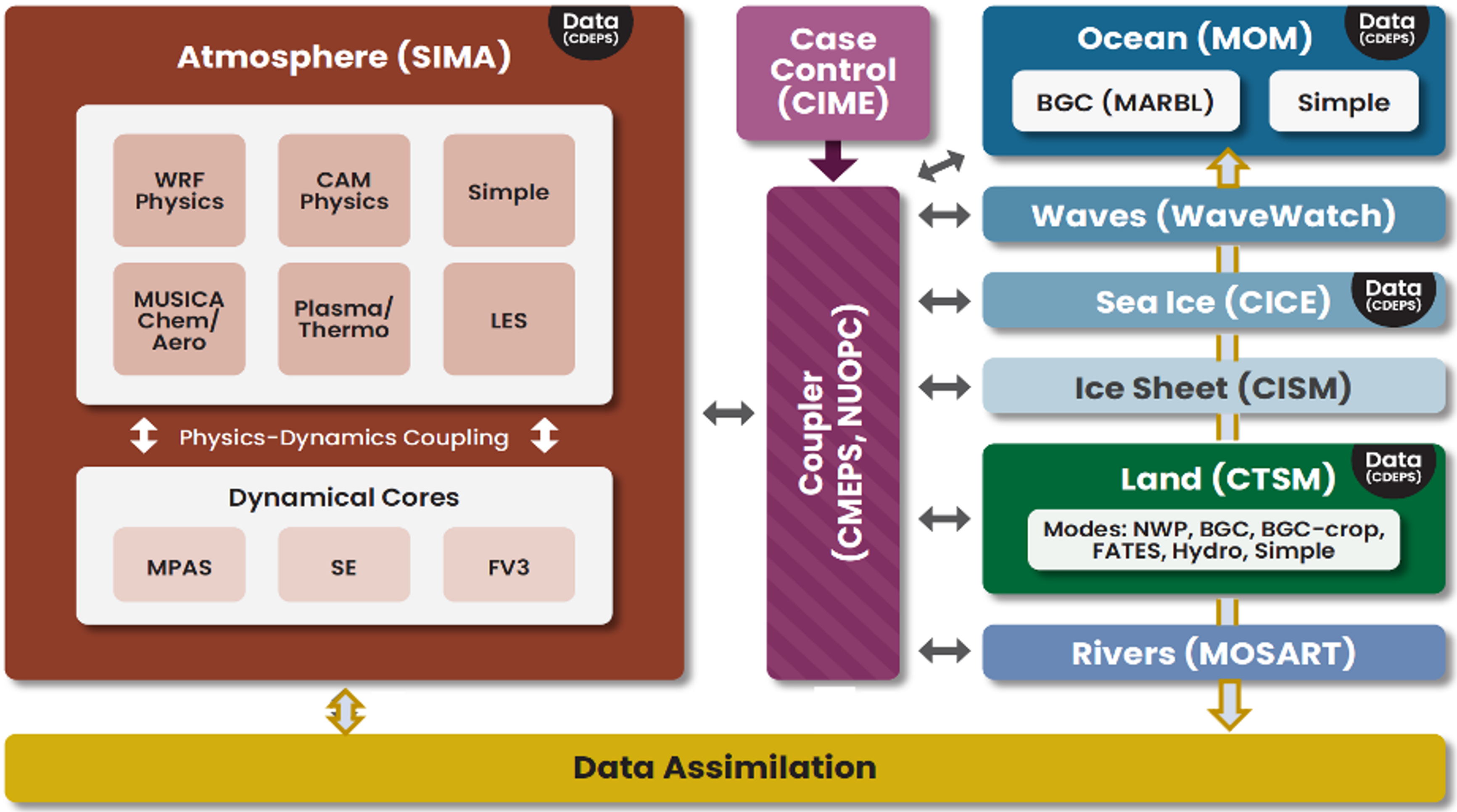
SIMA is the effort to unify NCAR-based community atmospheric modeling across Weather, Climate, Chemistry, Geospace

SIMA developed and defined with the community (vision results from a community workshop in June 2020) https://wiki.ucar.edu/display/SIMA

SIMA Vision:

- A configurable *system*, *not* a single model
- Atmospheric models *within* an Earth System Model (CESM)
- A minimal set of interoperable components
    - Physical/Chemical/Upper Atmosphere Parameterizations, Dynamical cores
- Common *infrastructure* and methods
    - Share and extend Diagnostics, Education/Tutorials, etc
    - Reduce duplication of effort
- *Community* working together towards frontier applications

Planned framework for unified ESM

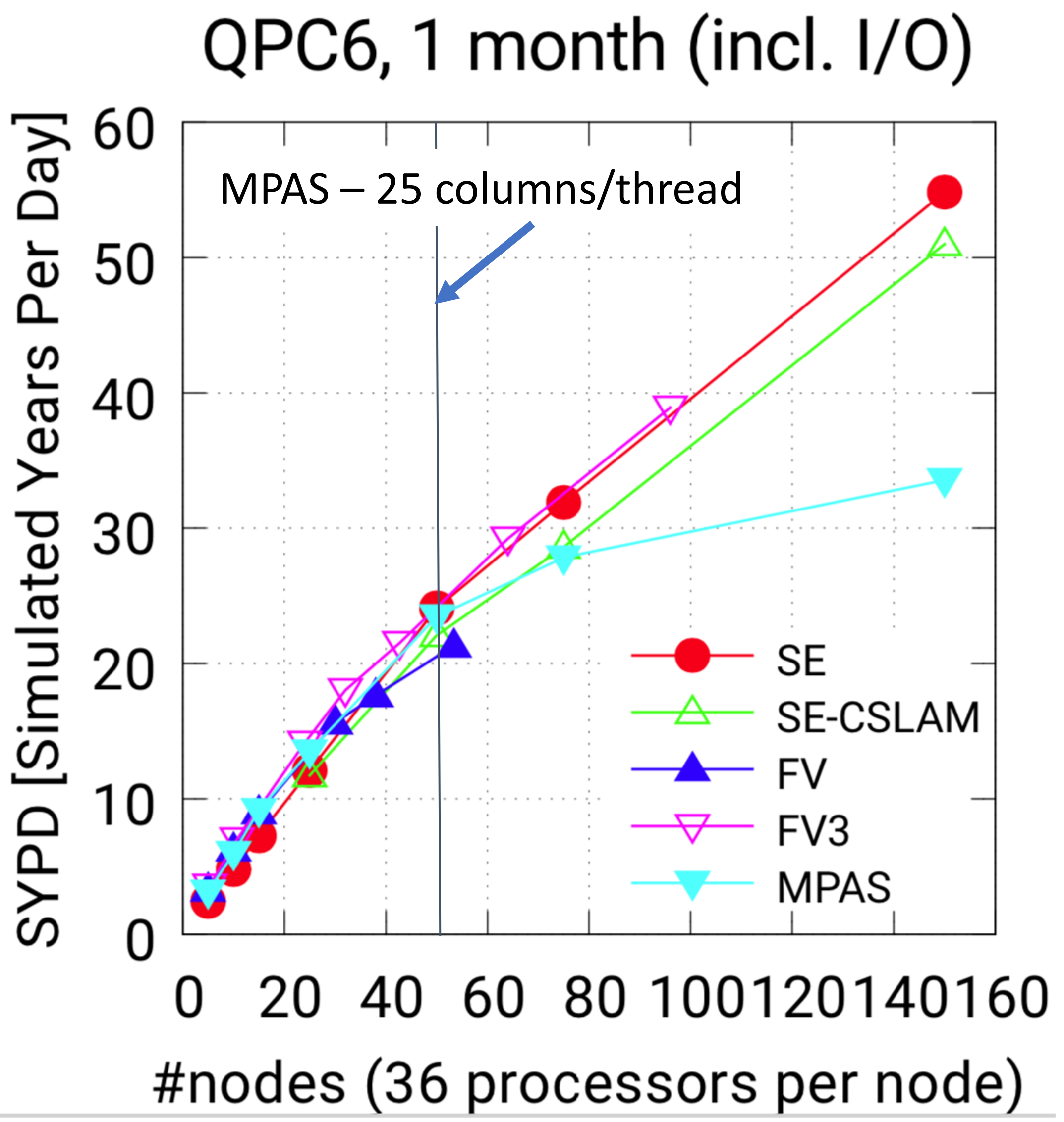


Preliminary performance data

Setup: CAM6 physics (Aqua-planet)

- Timings include history I/O, writing restart file, etc.
- 33 tracers (=CAM6 #tracers)

- With 1800 processors (typical core count for development runs) all cores are within ~4 SYPD of each other!
- Only at scaling limit there are large differences



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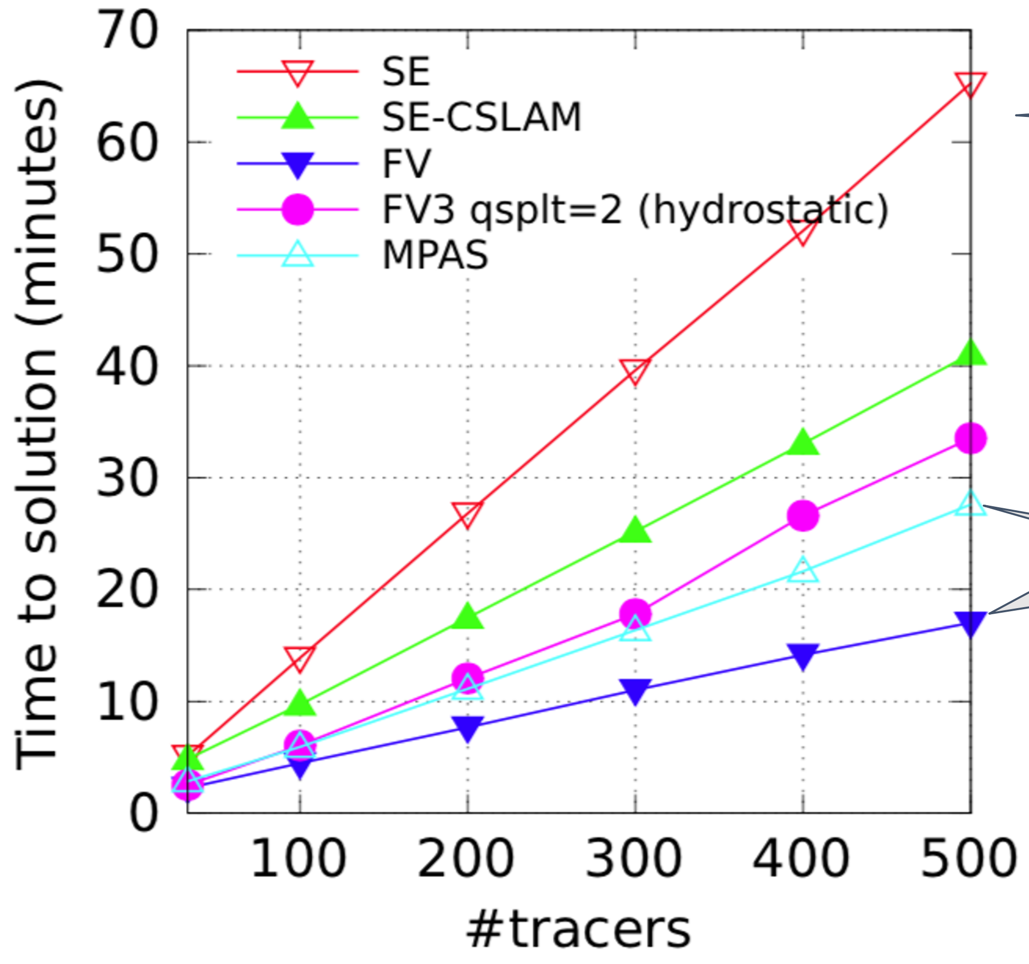
Preliminary performance data

FKESSLER, 1 month (no I/O), 900 cores



Spectral-element advection is the slowest in terms of cost per additional tracer

FV and FV3 use dimensionally split advection schemes (computationally cheaper than fully 2D schemes such as CSLAM)

FV lat-lon advection algorithm cheaper than cubed-sphere version

MPAS fastest among next-generation cores

Note: This plot would look different at large core counts ("just" 900 cores used here) ...
(MPAS – 45 columns/thread)

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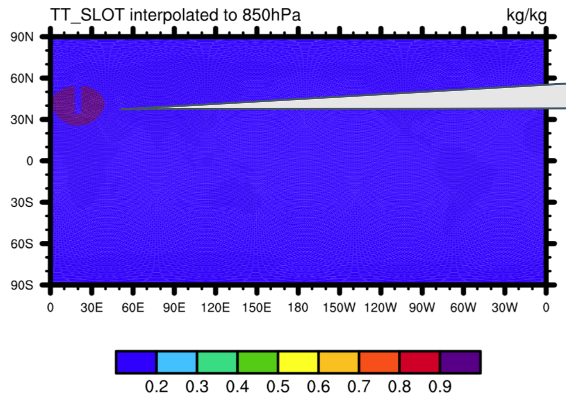
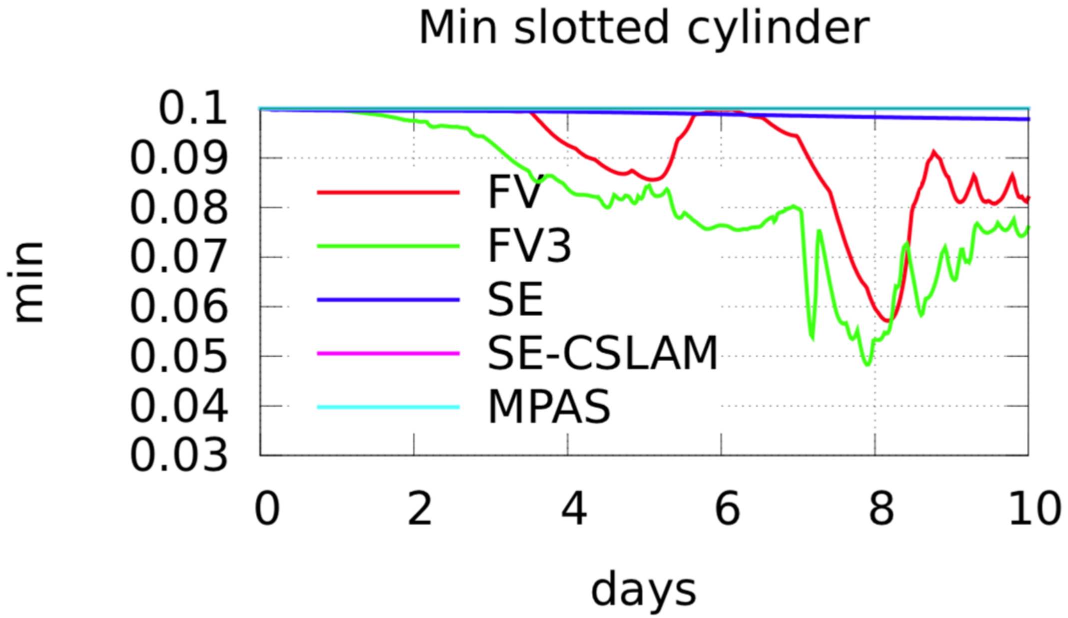
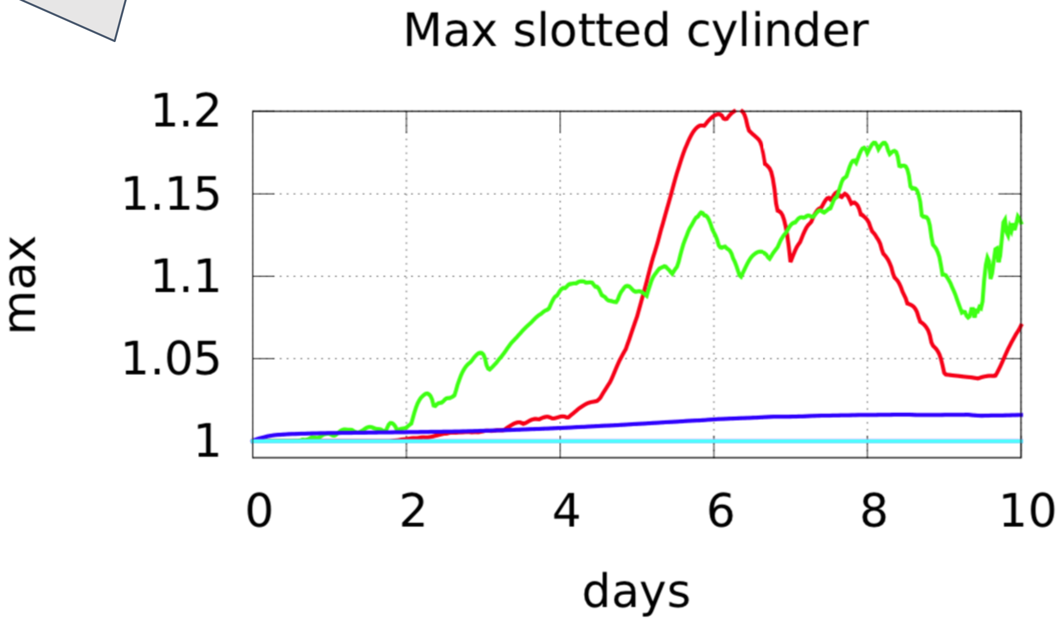
Shape-preservation



Min (=0.1) and max (=1.0) should be preserved and, in particular, range should not be expanded

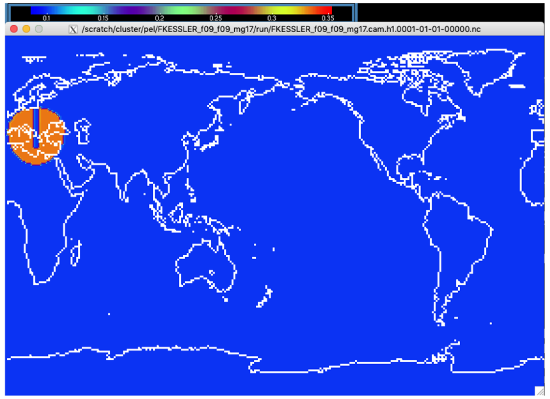
FV and FV3 produce large errors!
Could be remedied with more restrictive limiters, however, not entirely due to dimensionally split scheme (limiters **limit only** in coordinate directions!)

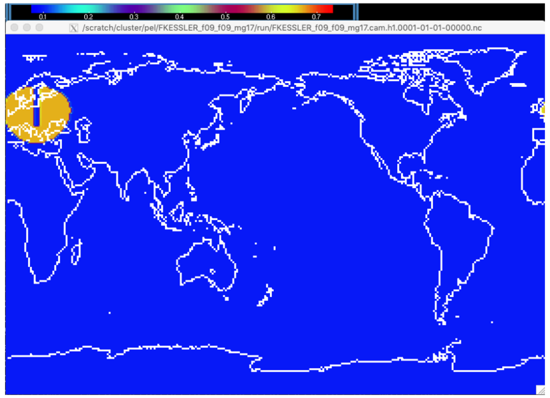


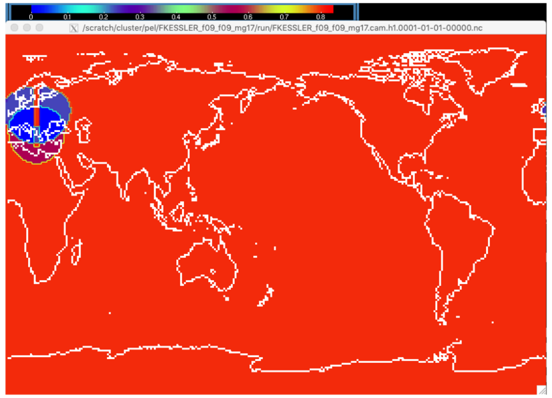


Three tracers adding to a constant

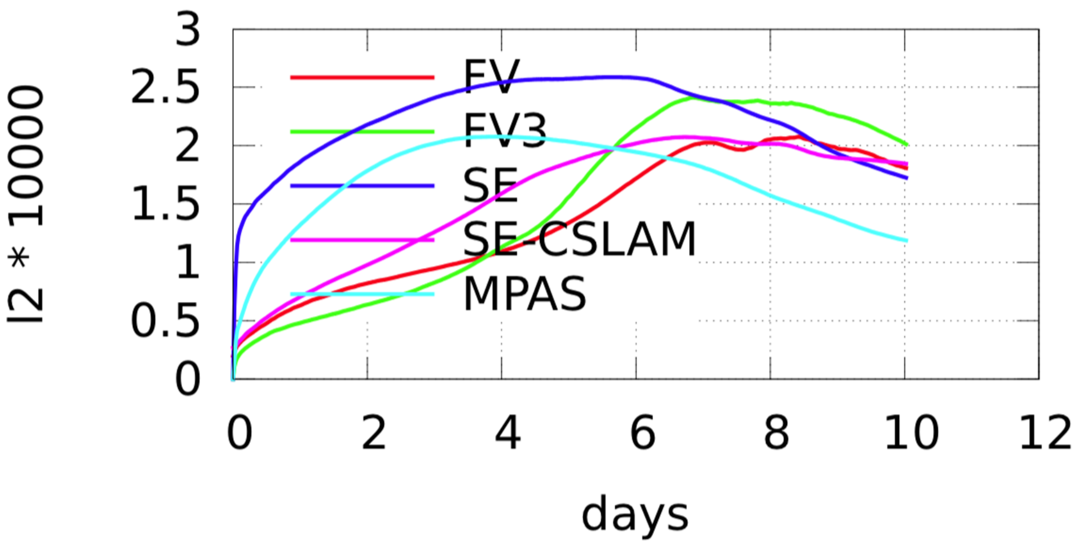
Lauritzen and Thuburn (2012)



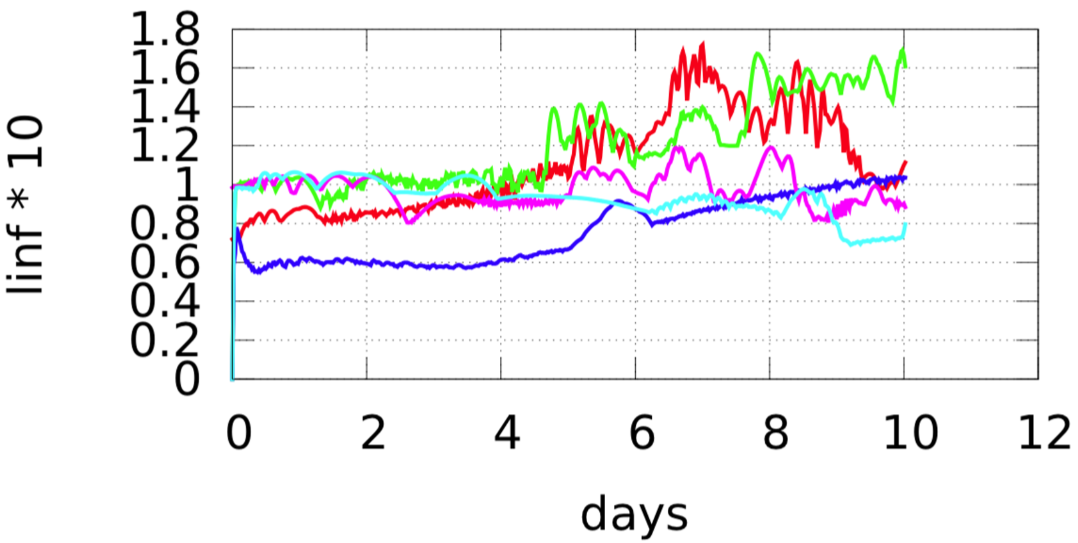




Three-tracer correlation test



Three tracer correlation test



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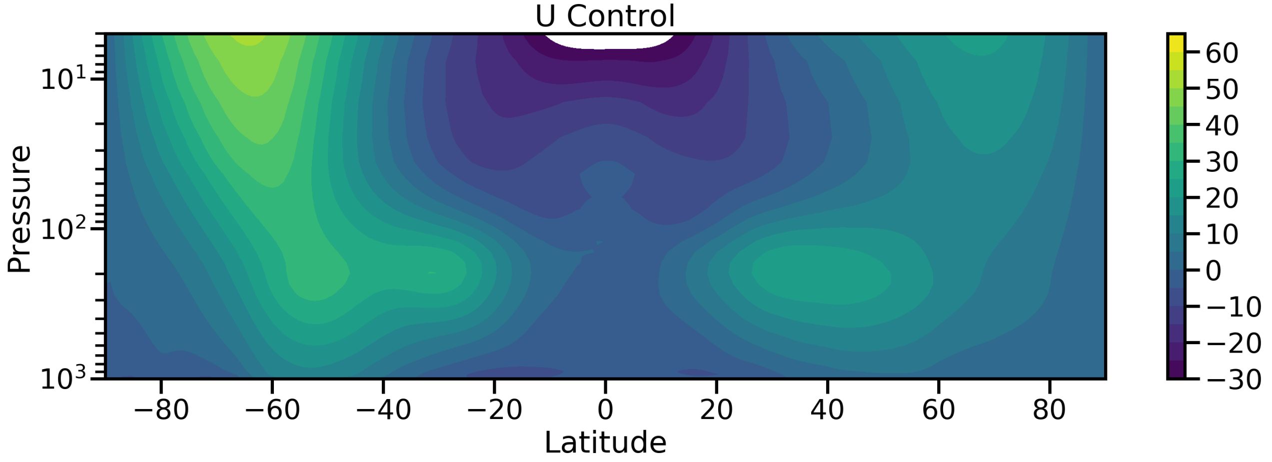
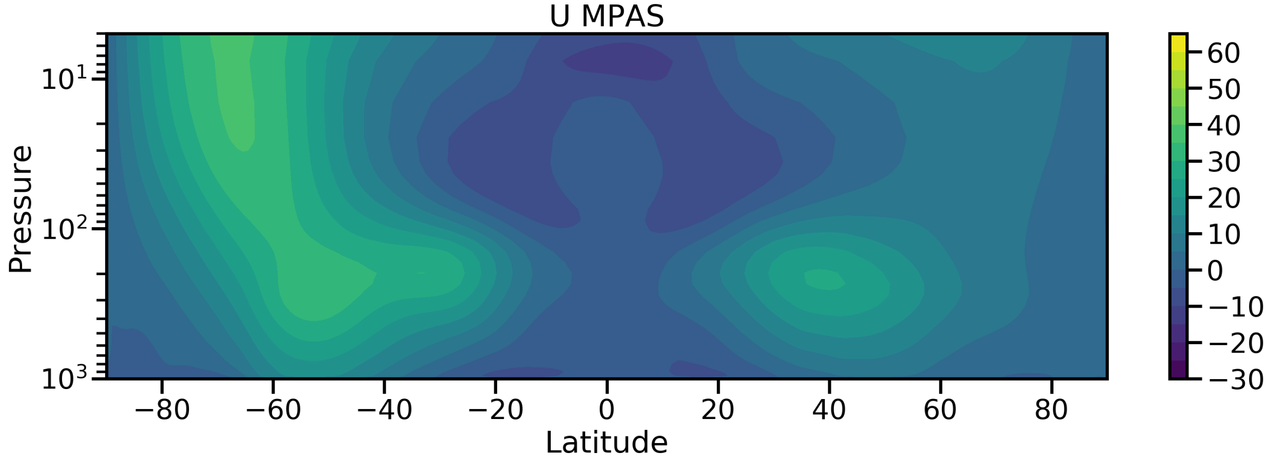
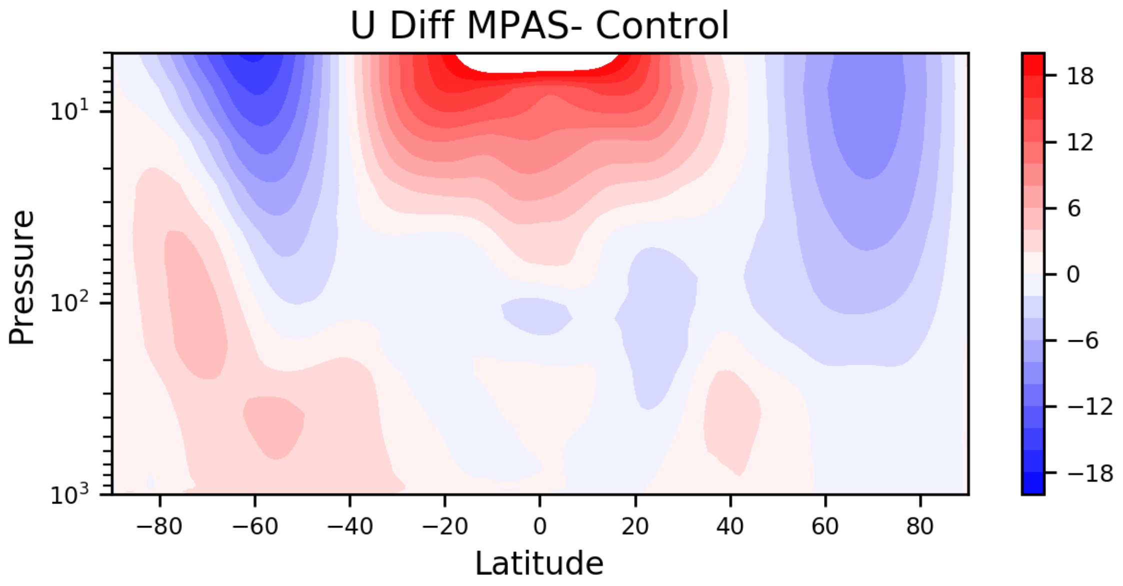
F2000 CAM simulation (year 2000 repeated), 120 km MPAS and control (FV) results, CAM6 physics
6-year simulation, results are 5-year average (years 2-6)
Zonally averaged zonal wind (m/s)

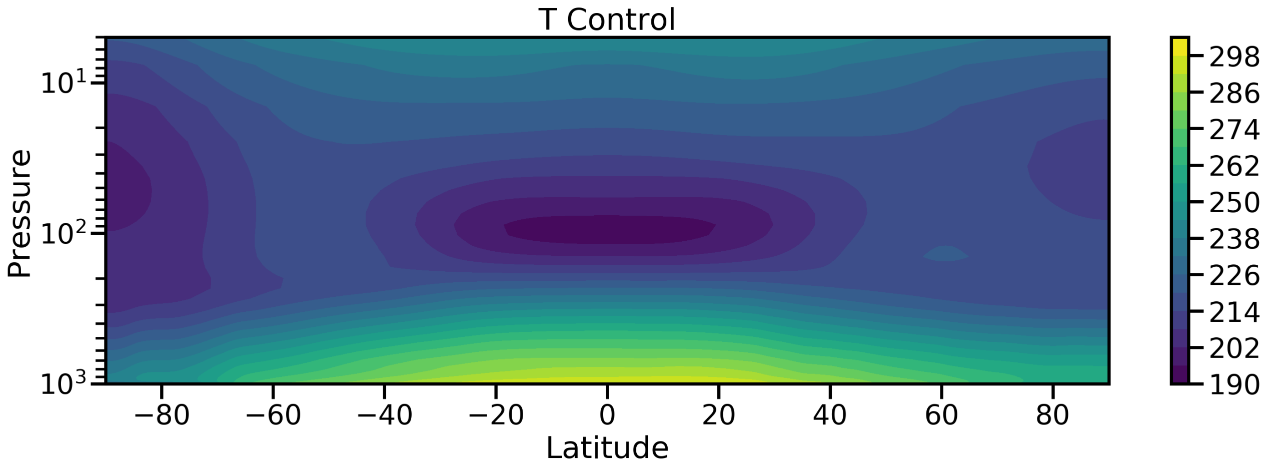


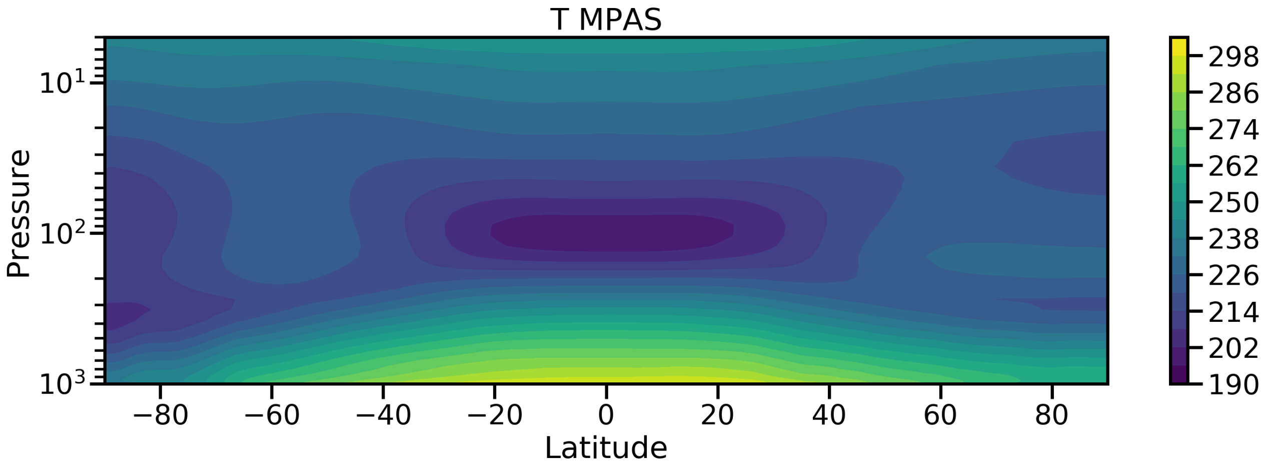


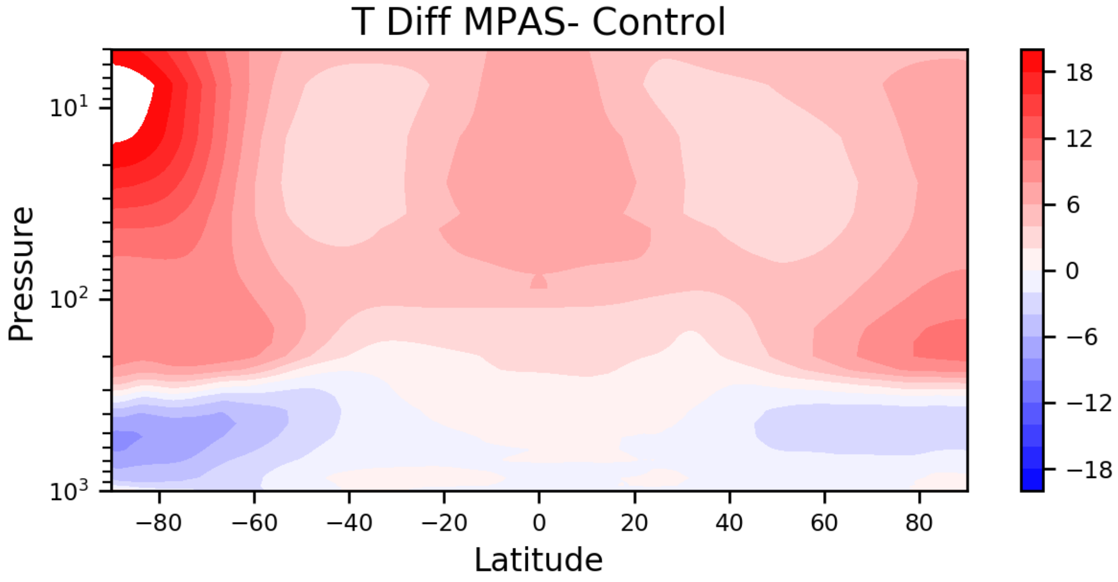


MPAS – stronger mid-latitude tropospheric jets, weaker midlatitude stratospheric jets, weaker easterlies in the upper stratosphere in the tropics.

F2000 CAM simulation (year 2000 repeated), 120 km MPAS and control (FV) results, CAM6 physics
6-year simulation, results are 5-year average (years 2-6)
Zonally averaged temperature

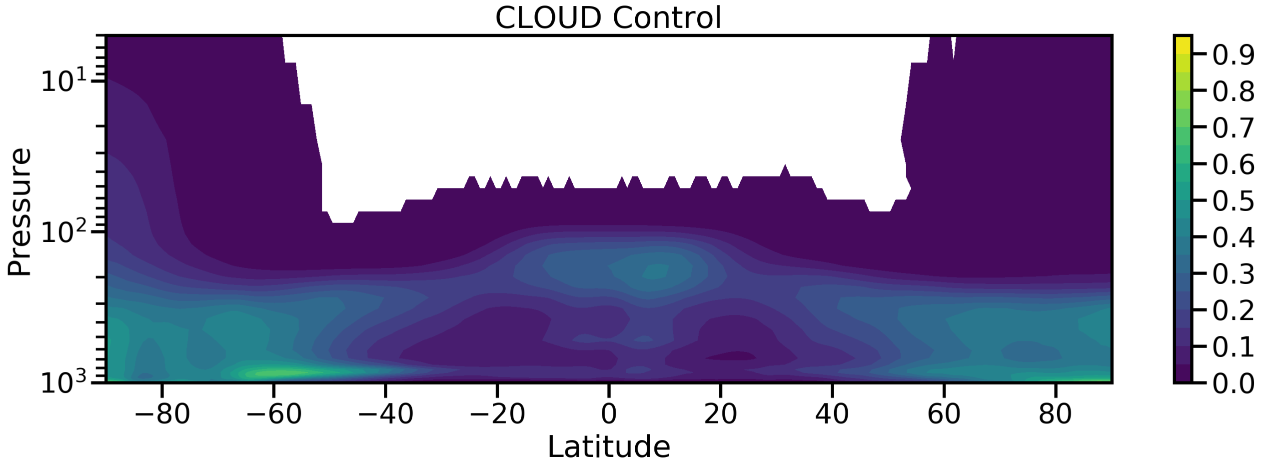


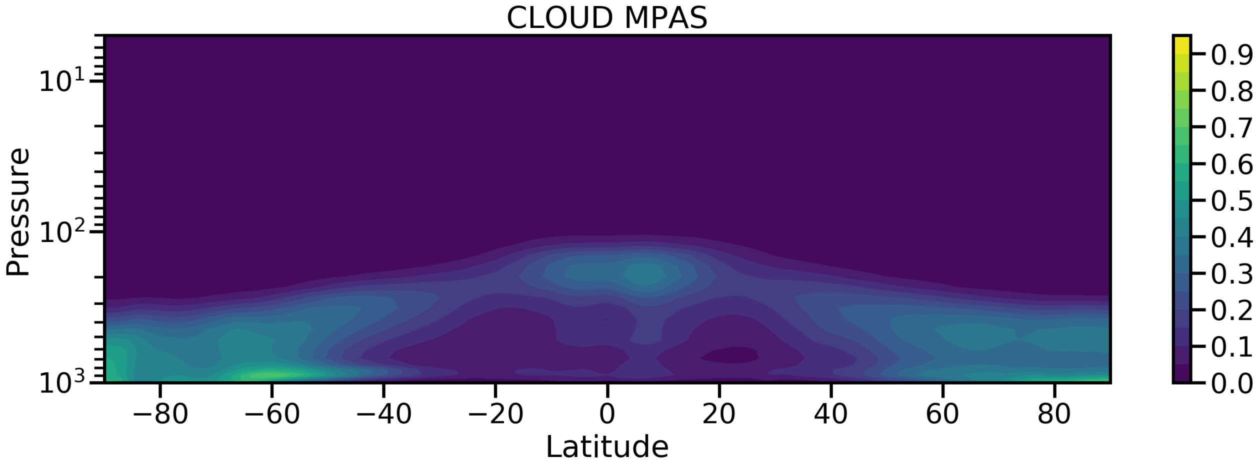


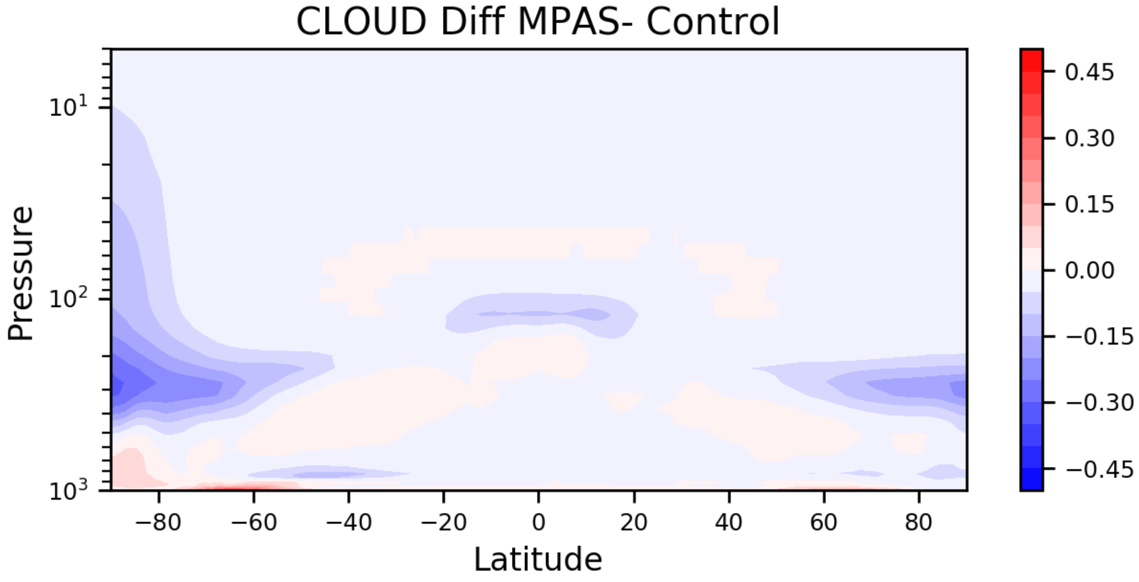


MPAS – warmer in the stratosphere, cooler in the troposphere.

F2000 CAM simulation (year 2000 repeated), 120 km MPAS and control (FV) results, CAM6 physics
6-year simulation, results are 5-year average (years 2-6)
Zonally averaged cloud fraction





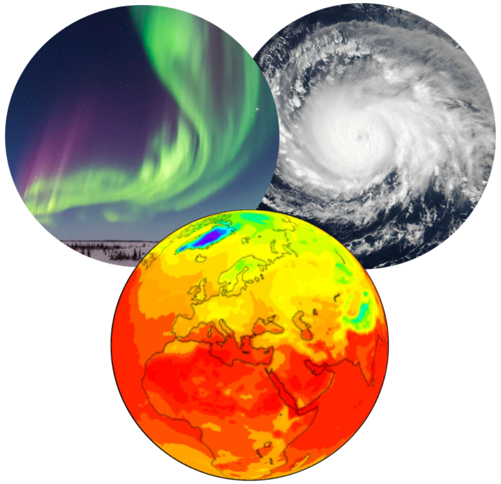


MPAS – fewer clouds in the upper troposphere / lower stratosphere in the polar regions.

Clouds and moist processes are a major tuning parameter in CAM6 physics.

SIMA and MPAS: Weather in an ESM

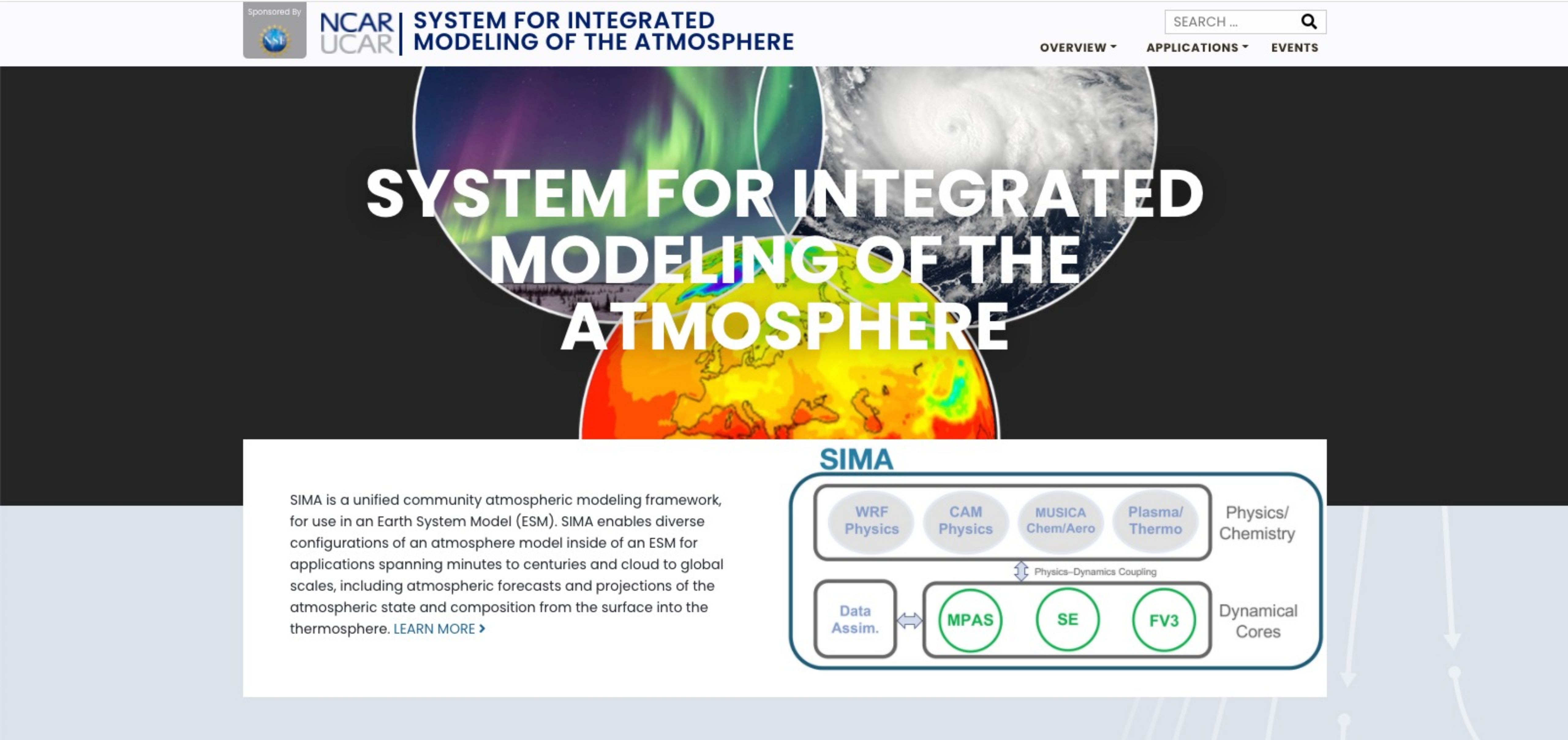
- We are bringing in other MPAS meshes into CAM (60, 30 15 and 15-3 km meshes).
- We are developing workflows for initializing CTSM, topography and GWD, and mesh mapping to other CESM components.
- We expect to encounter problems with CAM6 physics at convection permitting resolutions. Also, no scale-aware physics in CAM6 at present.



We expect to have a SIMA-Version 1 release sometime this fall.

We will have a fall tutorial with this release, likely virtual.

https://sima.ucar.edu/



EarthWorks

Five-year project led by
CSU: Randall PI, Hurrell
NCAR: Gettelman, Loft, Skamarock
with participation by 3 NCAR labs.
Funded by NSF CSSI.

EarthWorks

Science Drivers

- 4-km grid permits fine scales of motion. Topography and cities resolved
- No deep convection or gravity-wave drag parameterizations needed
- Resolved stratosphere
- Extreme events (e.g., Boulder flood and tropical cyclones) directly simulated
- Enables new science for both weather and climate, in a unified framework
- Critical for guiding adaptation at global, regional and local levels

Model architecture

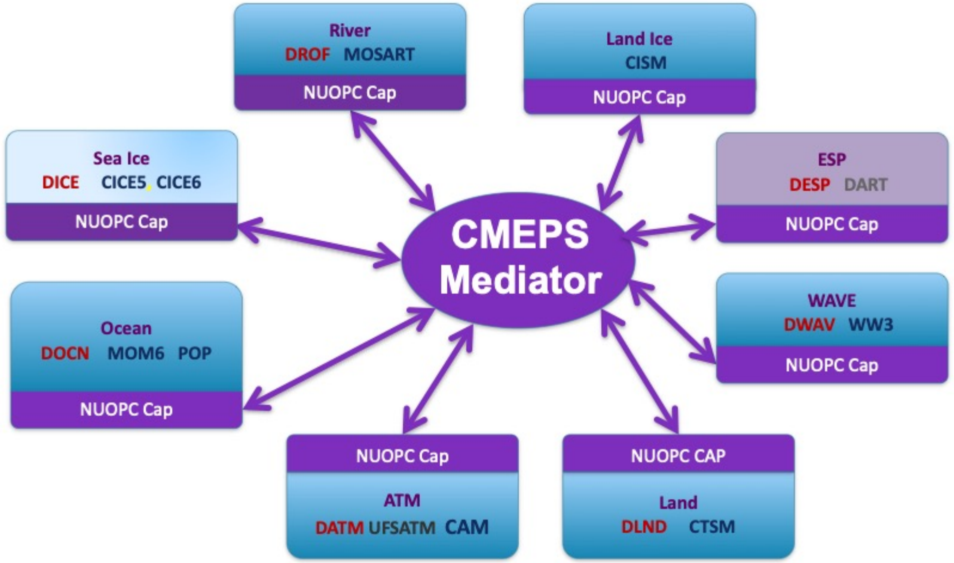
- A global coupled configuration of CESM
    - A single ~ 4 km global grid for the atmosphere, ocean, and land (no interpolation)
- Based on CESM infrastructure, including the CESM CMEPS Coupler & the Community Physics Framework
- MPAS Atmosphere (via SIMA) & MPAS-Ocean dynamical cores

Computational Aspects

- GPU-based
- 2025 Performance goal is ~0.5 SYPD for the coupled system

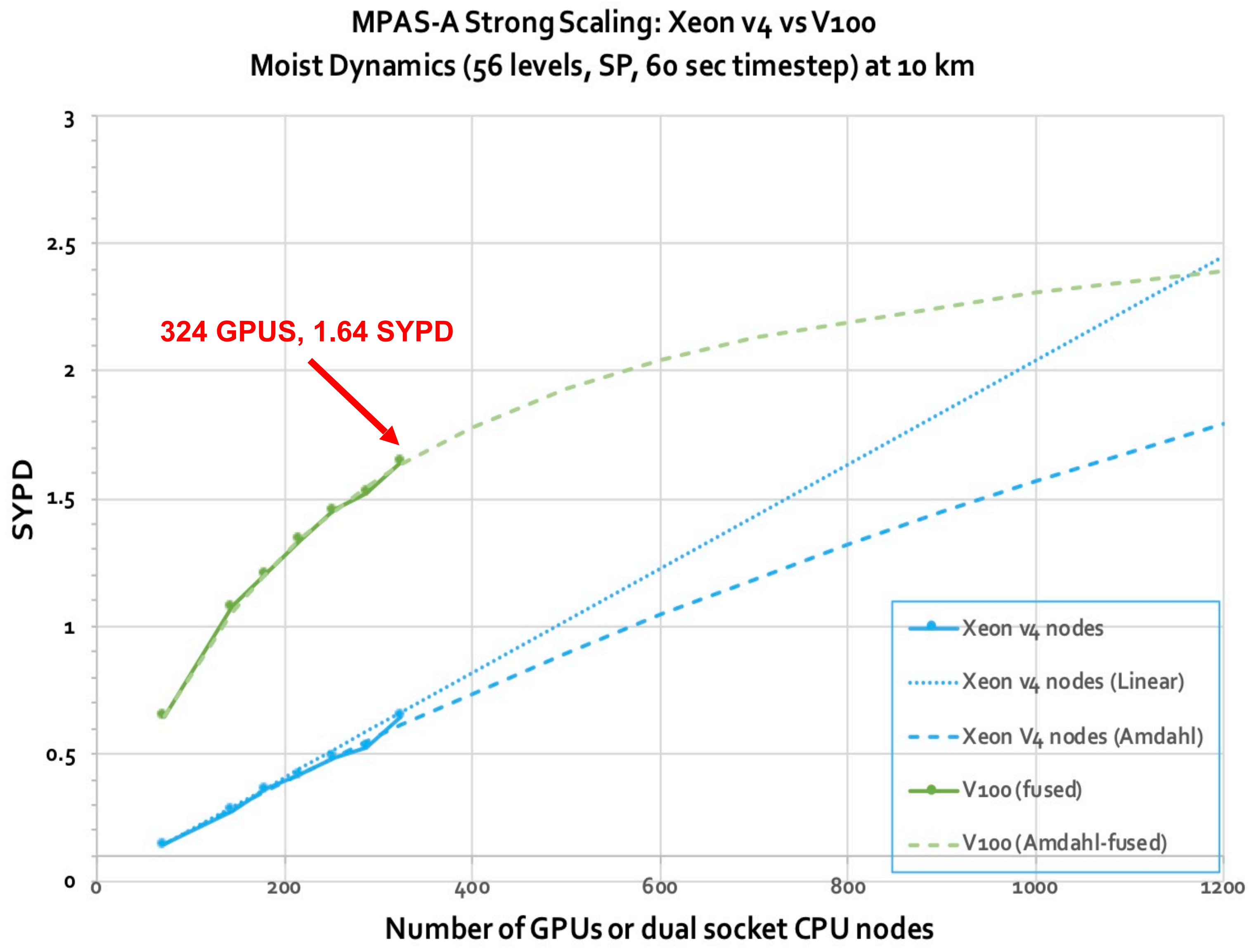
EarthWorks components

- The atmosphere model: A modified version of CAM6
  - MPAS atmosphere non-hydrostatic dynamical core, developed by MMM
  - A resolved stratosphere
  - High-resolution CAM-ish physics
  - The Community Physics Framework (CPF, a.k.a. CCPP)
- The MPAS ocean model developed at Los Alamos and used by E3SM
- The MPAS sea ice model, which is based on CISE and designed to work with the MPAS ocean model
- The Community Land Model (CLM)
- The Community Mediator for Earth Prediction Systems (CMEPS)



Is 0.5 SYPD at 4 km in 2025 feasible?

- Short answer: Yes, with caveats
- We have to extrapolate from moist MPAS tests
  - 10 km shows 1.64 SYPD on 324 GPUs.
  - Adjust to 4 km climate timestep (2.5x - CFL) ;
  - Adjust to 100 levels (1.8x - observed)
  - Physics overhead (2x - measured);
  - SP->DP (1.5x- measured)
- Answer: 0.12 SYPD
- Cost of additional tracers (6->??) not included.
- Can 4x come from better GPU hardware?
- Close. Both GPU floating point and memory performance is improving ~1.5x every 2 years, and we're due for a refresh this year.



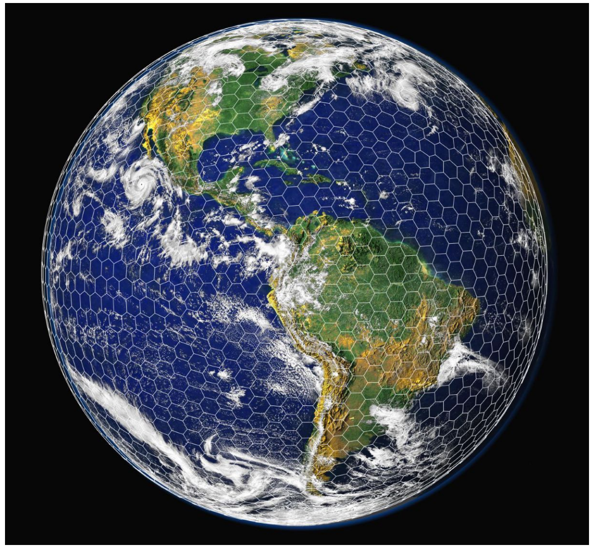
What do we get on a 4 km mesh for all components in an Earth System Model?

For the atmosphere and land surface:

- Thunderstorms & mesoscale convective systems
- Hurricanes of realistic intensity
- Individual large mountains and valleys
- Gravity waves
- Coastlines
- Many lakes, and large rivers
- Cities

For the ocean:

- The most energetic eddies
- Deep convection
- Bottom topography
- Gravity waves
- Estuaries



EarthWorks

Colorado State University

NCAR | NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Community-Based Weather and Climate Simulation With a Global Storm-Resolving Model

Learn more about EarthWorks

Papers & Talks	Datasets & Output	Education

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Phil Jones, Los Alamos National Laboratory
AJ Lauer, NCAR

Earthworks is funded by this NSF program. Alan Sussman, Program Director.

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http://hogback.atmos.colostate.edu/earthworks/

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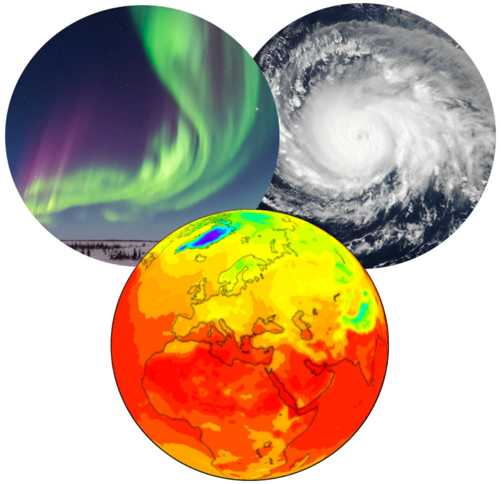

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