E3SM-MMF

Energy Exascale Earth System Model

Multiscale Modelling Framework

A Multiscale Modelling Framework for E3SM

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EXASCALE COMPUTING PROJECT

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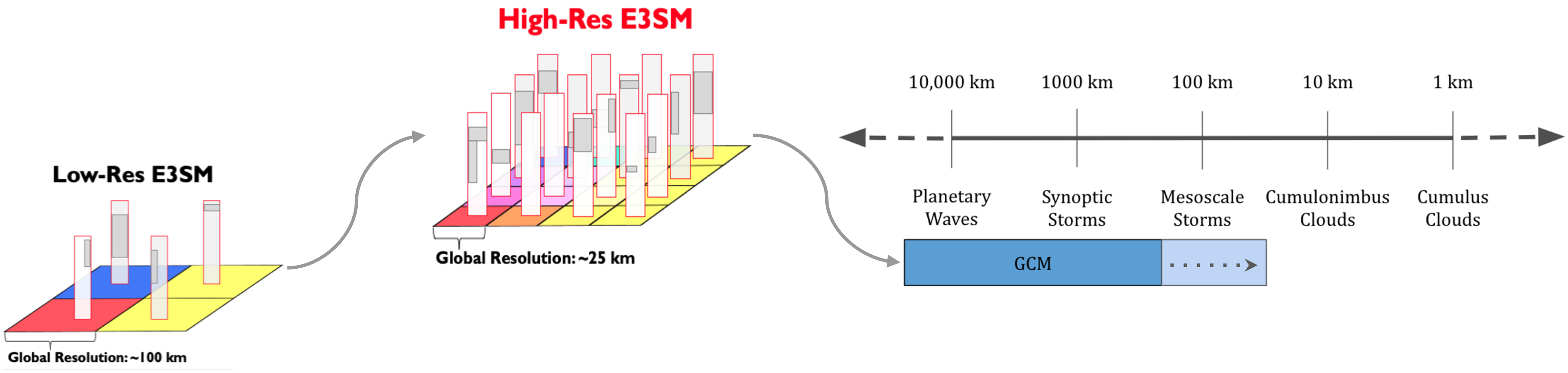
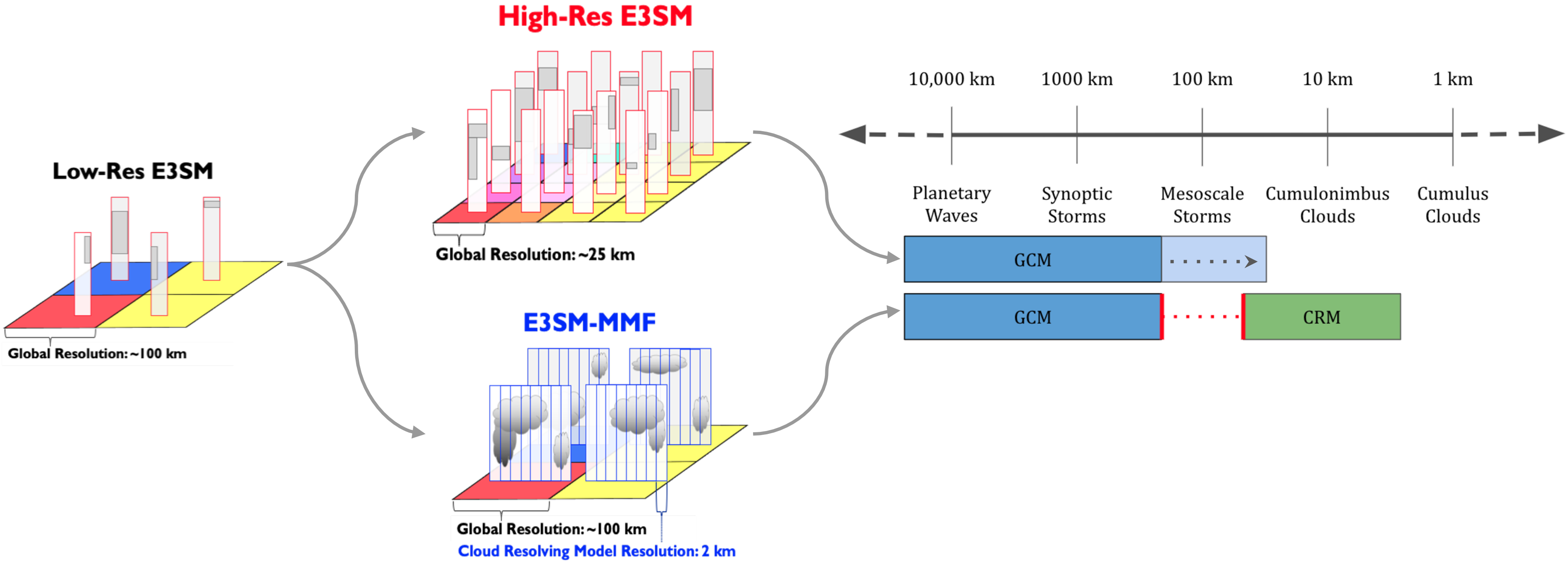
U.S. DEPARTMENT OF ENERGY

Enhancing the Resolved Scales



Enhancing the Resolved Scales



MMF Pros and Cons

Promising

- Explicit representation of clouds and cloud-radiative feedbacks
- Explicit (3D) or semi-explicit (2D) moment feedback (i.e. CMT)
- Semi-explicit cloud-aerosol feedbacks
- MMFs have a history of improving convectively coupled phenomena (ex. MJO)

Mixed

- The scale gap provides “computational leverage” that can be exploited for performance
- Precipitation and turbulence statistics are sensitive to CRM domain size and grid

Problematic

- Higher cost makes development/testing difficult, especially climate reproducibility
- The scale gap stops small scale variance from being transported on the global grid

The Exascale Computing Project

We are focused on making E3SM-MMF viable for climate simulations by making it *faster*

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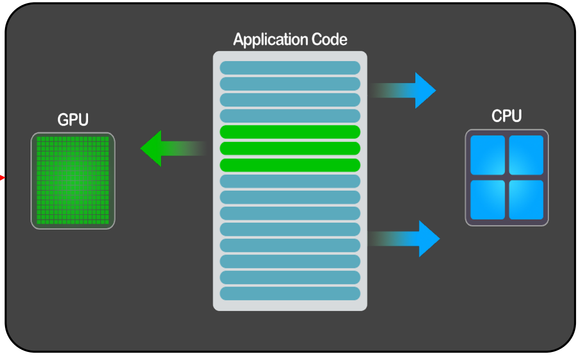
- The CRMs are independent so they can be offloaded to a GPU
- Radiation can be similarly accelerated



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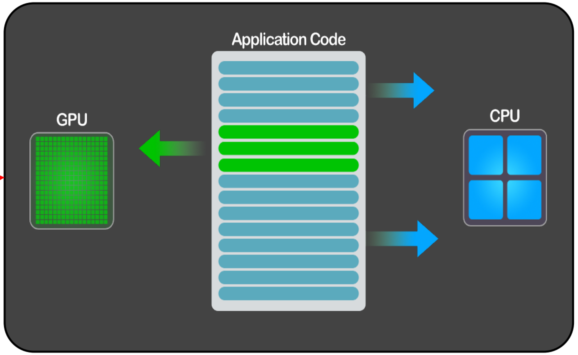
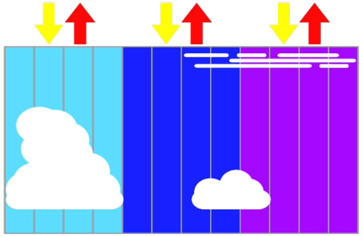


Algorithmic Acceleration

- The scale separation of the models can be exploited to reduce the number of CRM time steps
- Radiation is done on groups of columns to reduce the workload, and aerosol optics are done once per physics column



Performance Portability Challenges

OpenACC vs **C++** vs **OpenMP**

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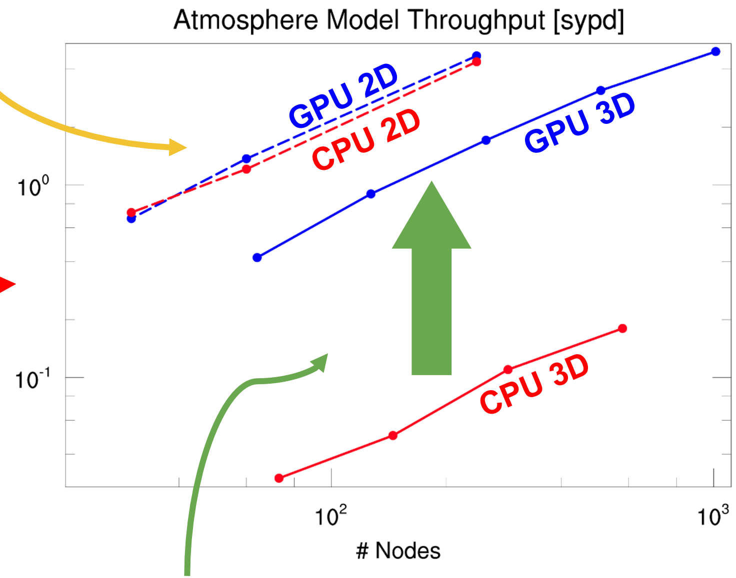
- The CRM was rewritten in C++ and has good performance on Summit GPUs

GPU speed-up of 2D CRM (32x1) masked by radiation



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- An OpenMP version of the Fortran CRM is also being pursued

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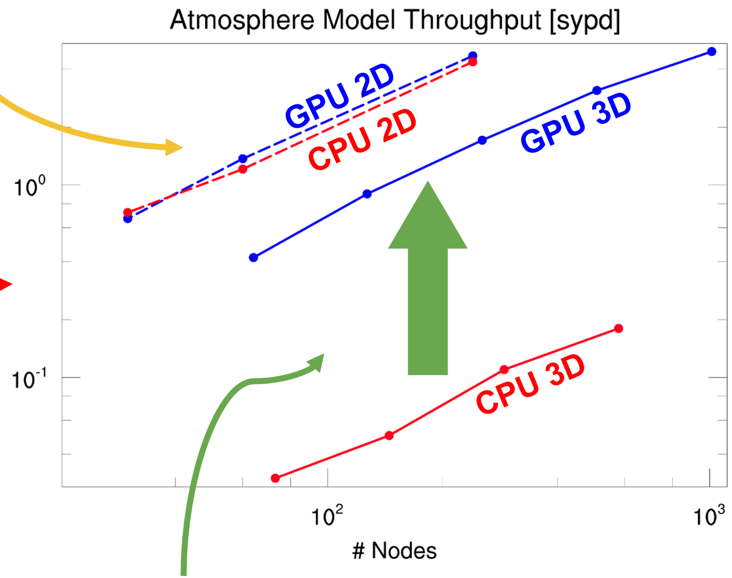

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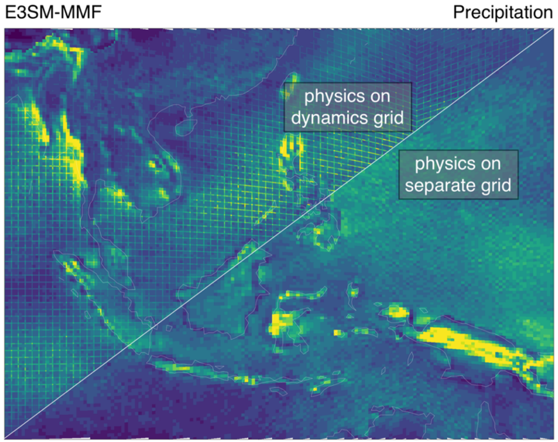
Early Problems (and Solutions)

The code was ported from SP-CAM and we immediately ran into problems using the SE dycor and finer vertical grid of E3SM

- Instability in the CRM turbulence scheme → Resolved with turbulent CFL
- Enhanced “fog” bias due to thinner levels → Resolved with stronger mixing
- Grid imprinting from spectral GLL grid → Resolved with new FV physics grid

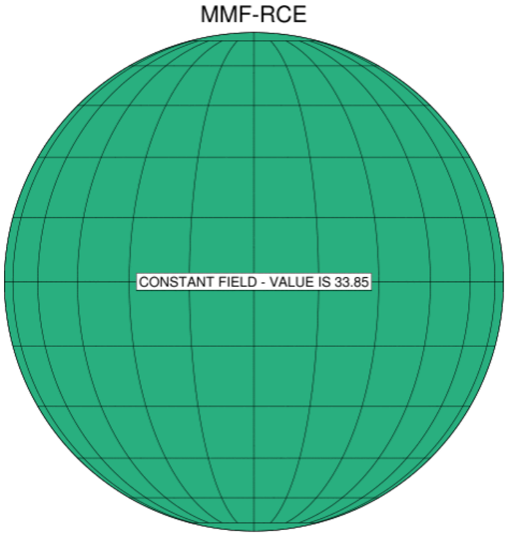


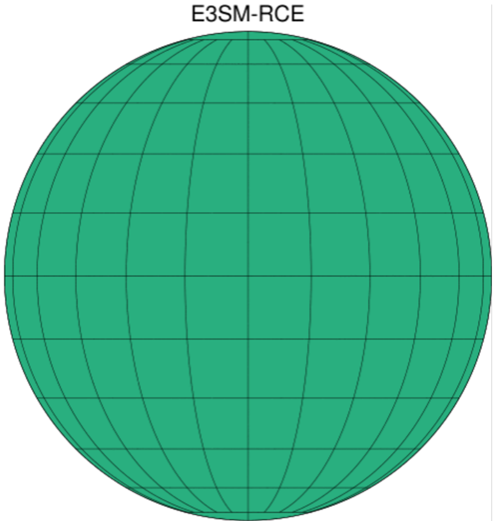
The grid imprinting problem motivated the new FV physics grid, which resolves the imprinting and improves performance

Feedbacks to E3SM

The unique problems we encountered with the MMF have led us to contribute to E3SM development:

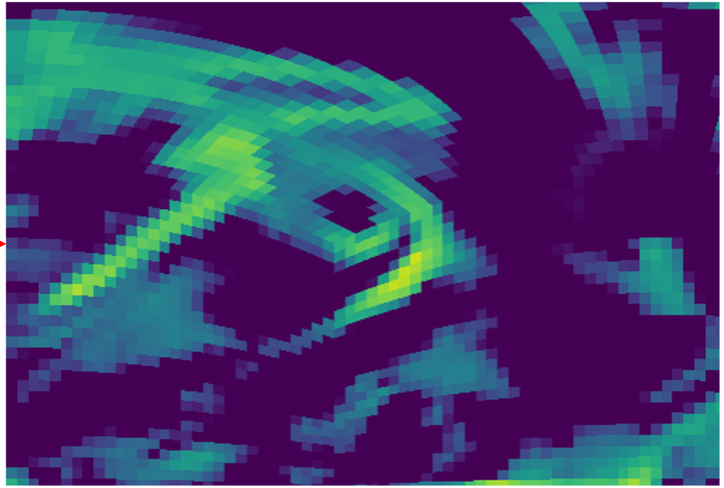
- Aquaplanet and RCE compsets
- C++ and GPU porting of RRTMGP
- Finite volume physics grid
  (i.e. physgrid)
- New tool for hindcast initial conditions
  (i.e. HICCUP)
- YAKL for performance portability
  (temporary alternative to Kokkos)



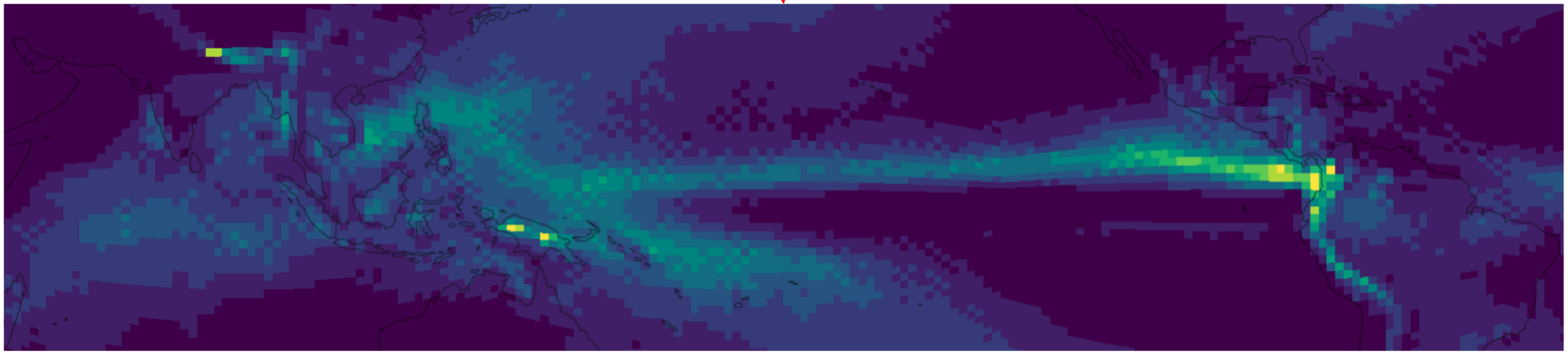


The Variance Trapping Problem

After we started running on the physgrid we started noticing oddly "*stuck*" pixels in animations on the native grid...



We also noticed some "*checkerboard*" noise was present in the precipitation climatology



The Variance Trapping Problem

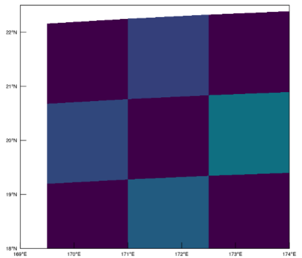
The MMF coupling only considers the CRM domain mean, so smaller scales cannot be advected on the global grid

Convective circulations can become "*trapped*" at the largest scales locking the CRM in an **active state**

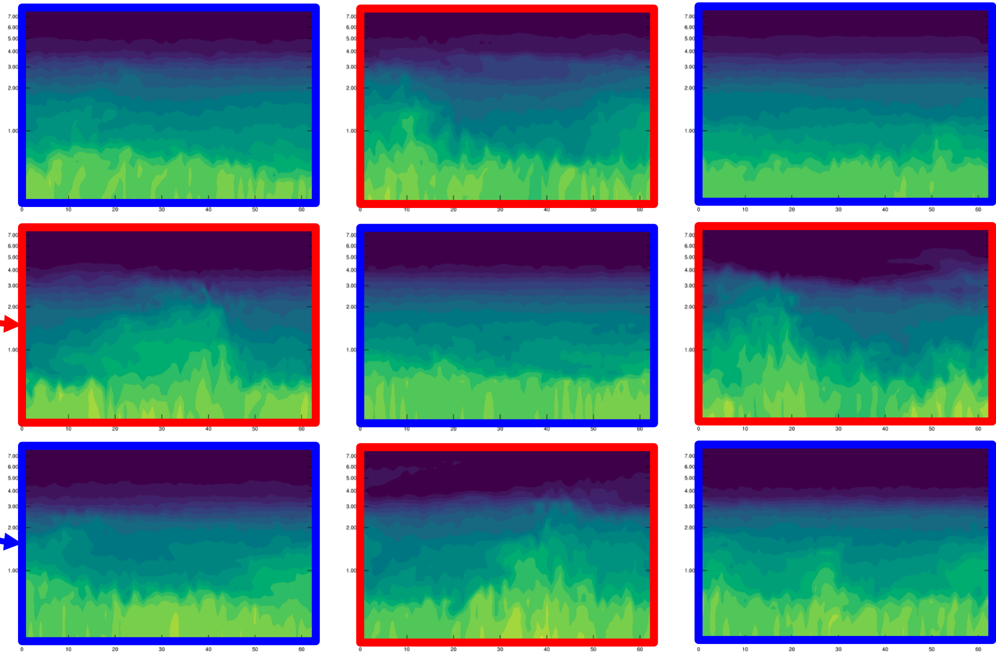
Large-scale dynamics causes downstream CRMs to become locked in a relatively **quiescent state**

Note that the issue is relatively "*small*" when compared to typical biases

GCM grid liquid water path



CRM grid water vapor

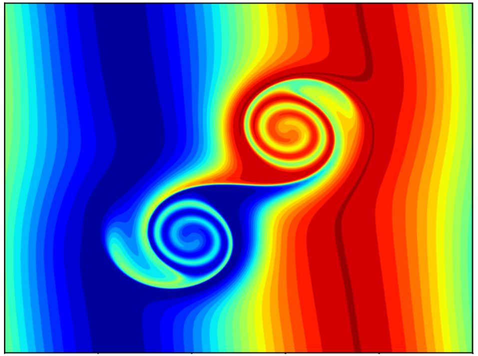


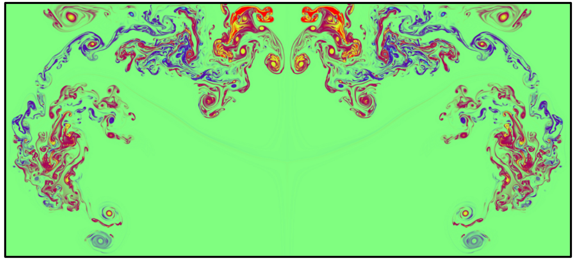
Future Plans - SAM, meet PAM

The current CRM code has diverged from SAM (now with more C++!), but we are also building a new CRM from scratch!

The **Portable Atmospheric Model (PAM)** will be written in C++

- Optimized for MMF performance
- New physics from SCREAM (P3/SHOC)
- New dynamics
  - High-order finite volume using WENO methods
  - ADER time stepping for long time steps
  - Anelastic (potentially with Compressible option)
- Standalone capability for testing, development, and science





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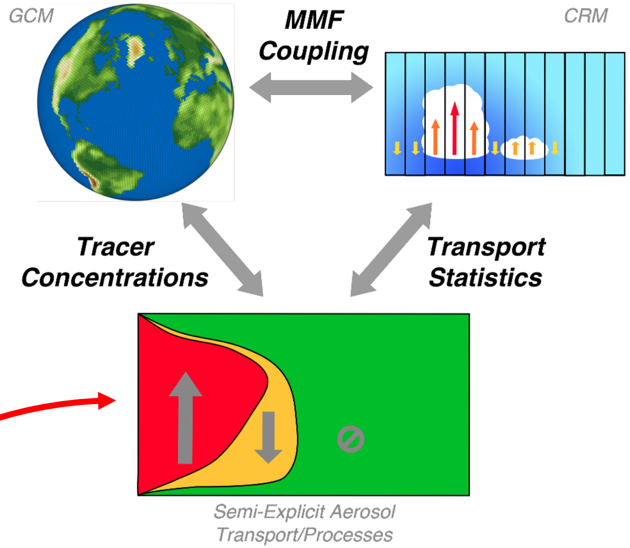

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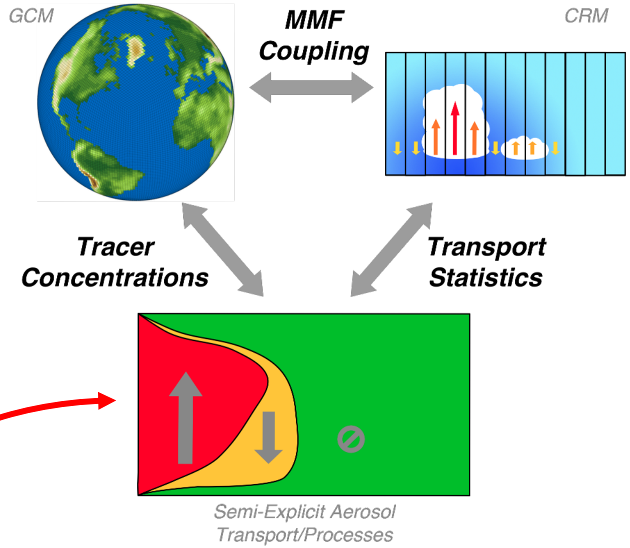

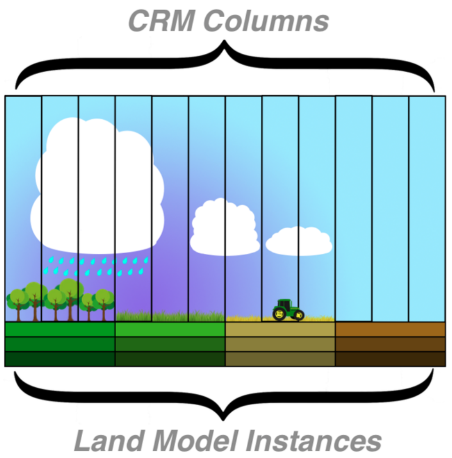

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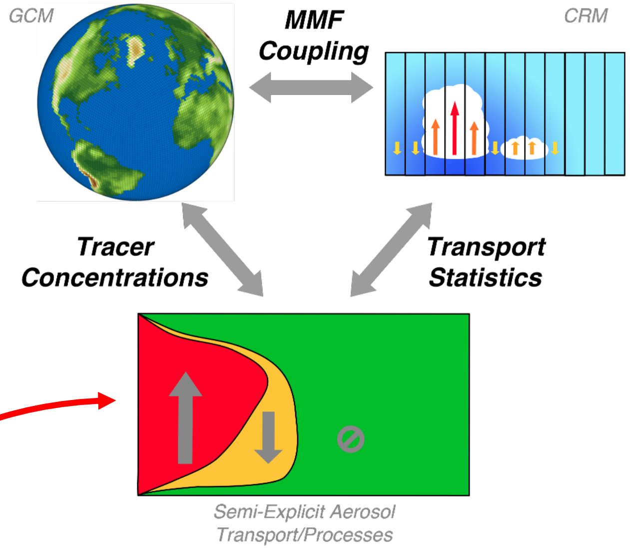

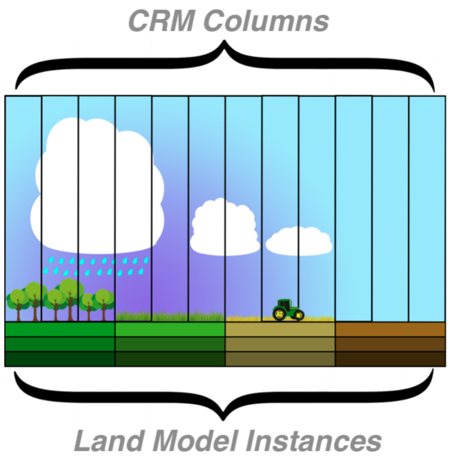

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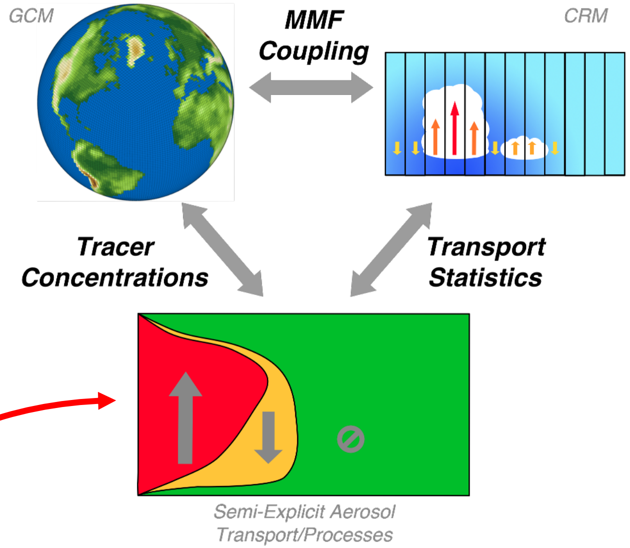
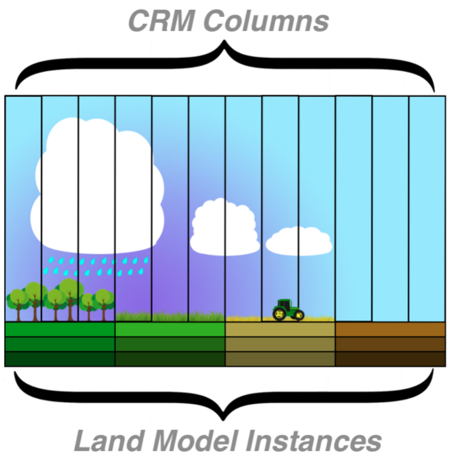
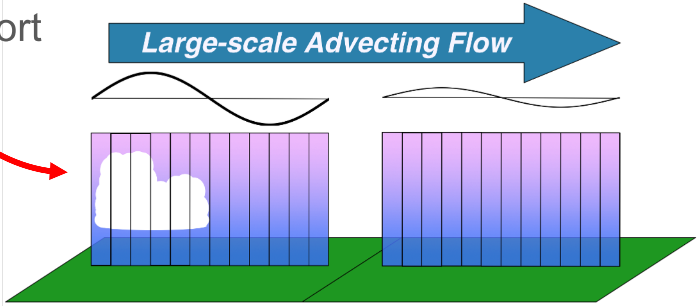
- CRM variance transport







In Summary...

E3SM-MMF will be viable for climate experiments in v4

- The MMF approach is well suited for utilizing GPUs
- Performance will be portable across current and upcoming DOE machines
- Throughput is on par with traditionally parameterized models,
which allows for multi-decadal experiments
- Explicit convection can overcome long-standing parameterization issues