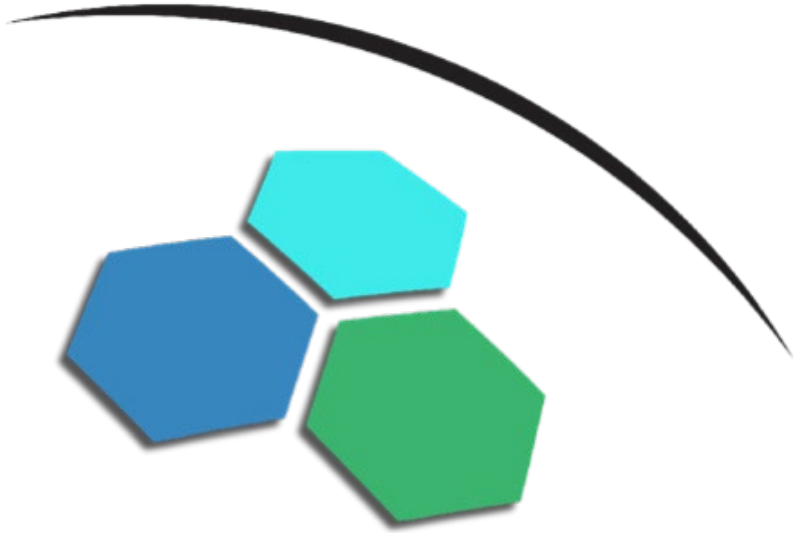
EarthWorks

Progress towards a storm -resolving coupled model



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COLORADO STATE UNIVERSITY

NCAR

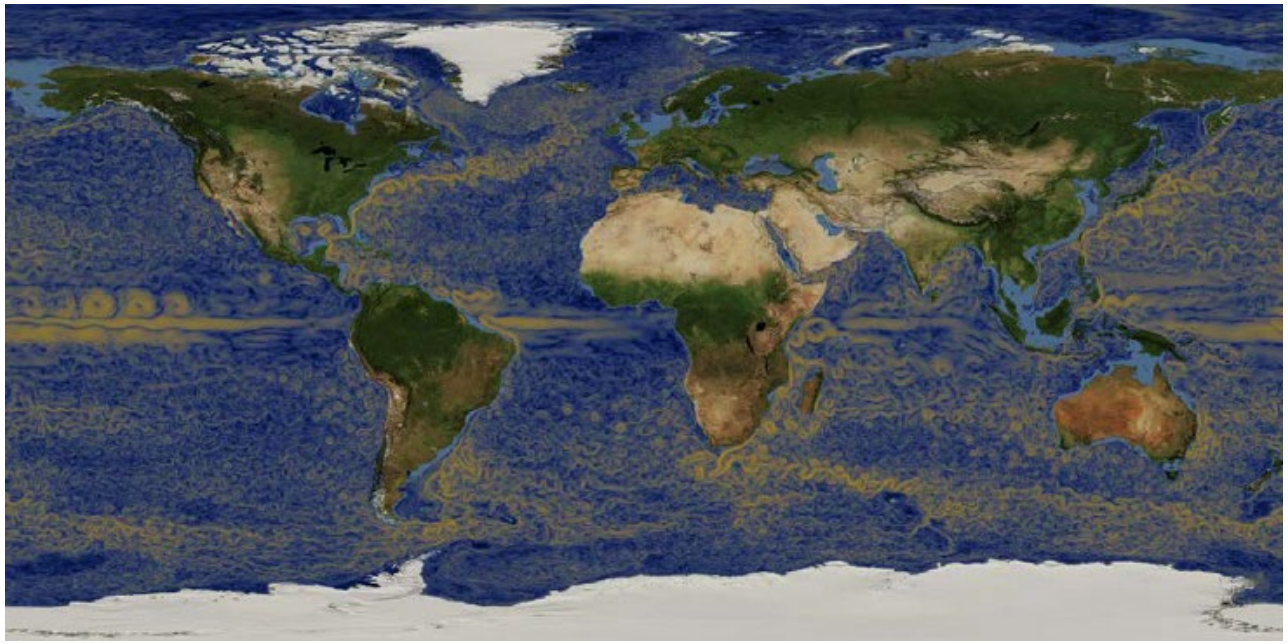
THE ROYAL SOCIETY

Brief Prepared for COP26

November 2021

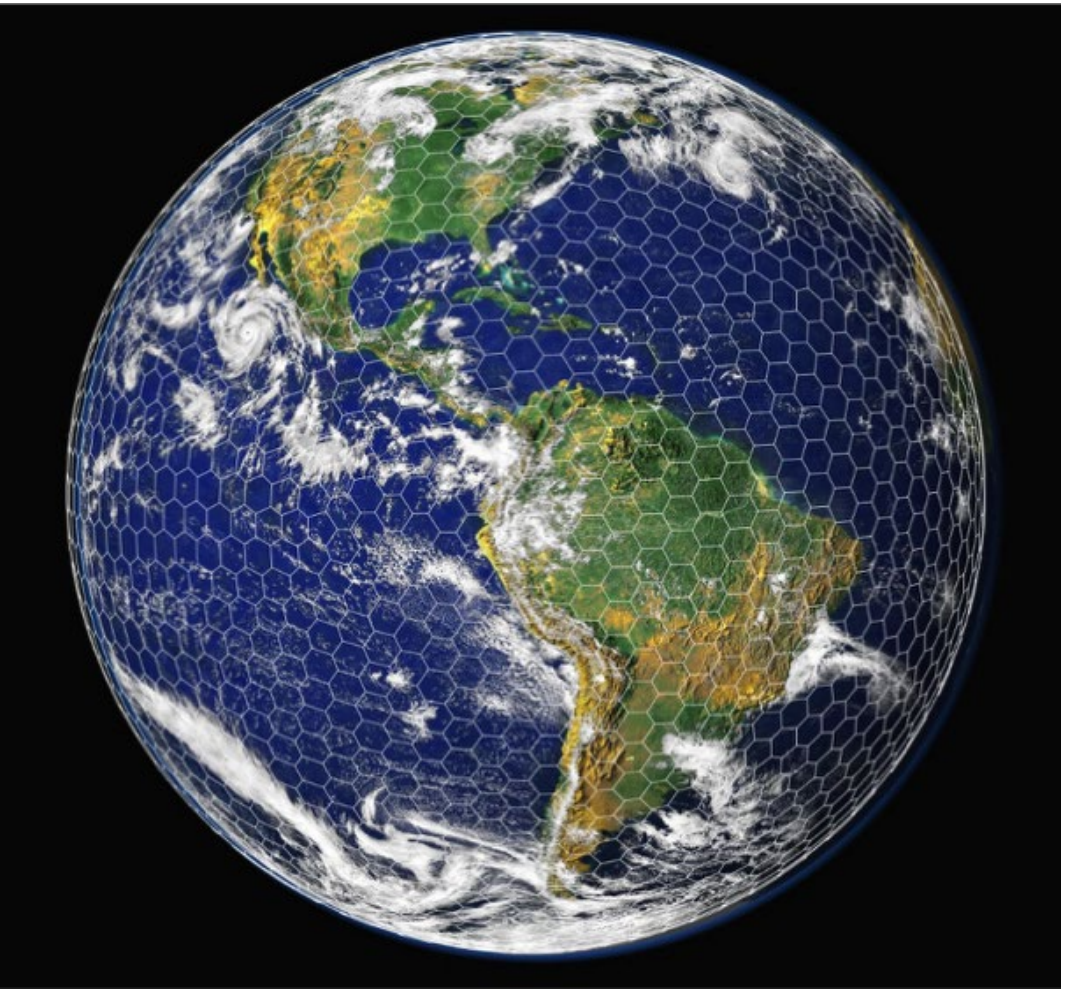
Next generation climate models:

a step change for net zero and climate adaptation



"Next generation global storm and ocean eddy resolving climate models … will deliv
more confident predictions of changes in water availability, damaging weather, how
oceans take up heat and carbon, and in related impacts on natural ecosystem servic

EarthWorks



EarthWorks is a five-year university-based project, supported by NSF CISE, to develop a global storm-resolving coupled model that uses a single uniform global grid for the atmosphere, ocean, sea ice and land surface

Earthworks consists of:

- CAM6 with the MPAS non-hydrostatic dynamical core
- MPAS ocean model developed at LANL
- MPAS sea ice model, based on CICE
- Community Land Model (CLM)
- Community Mediator for Earth Prediction Systems (CMEPS)

Earthworks will retain compatibility with evolving CESM code base and engage with the CESM research community

Goal is to make it possible for the CESM community to do very high-resolution coupled global modeling on U.S. supercomputers

EarthWorks

GOAL:

- Capability to perform 3.75 km fully coupled simulations utilizing GPU-enabled components with end-to-end workflow portability across US leadership computing systems

SOME INITIAL OBJECTIVES:

- Port MPAS Ocean and Sea Ice models into the CESM framework ✓
- Assemble a working CPU version of the EarthWorks configuration ✓
- Complete fully coupled simulations at relatively coarse grid resolutions ✓
- Test MPAS-CAM6 physics at convection-permitting spatial scales (Begun)
- Port critical-path portions of EarthWorks to GPUs (Very Good Progress)

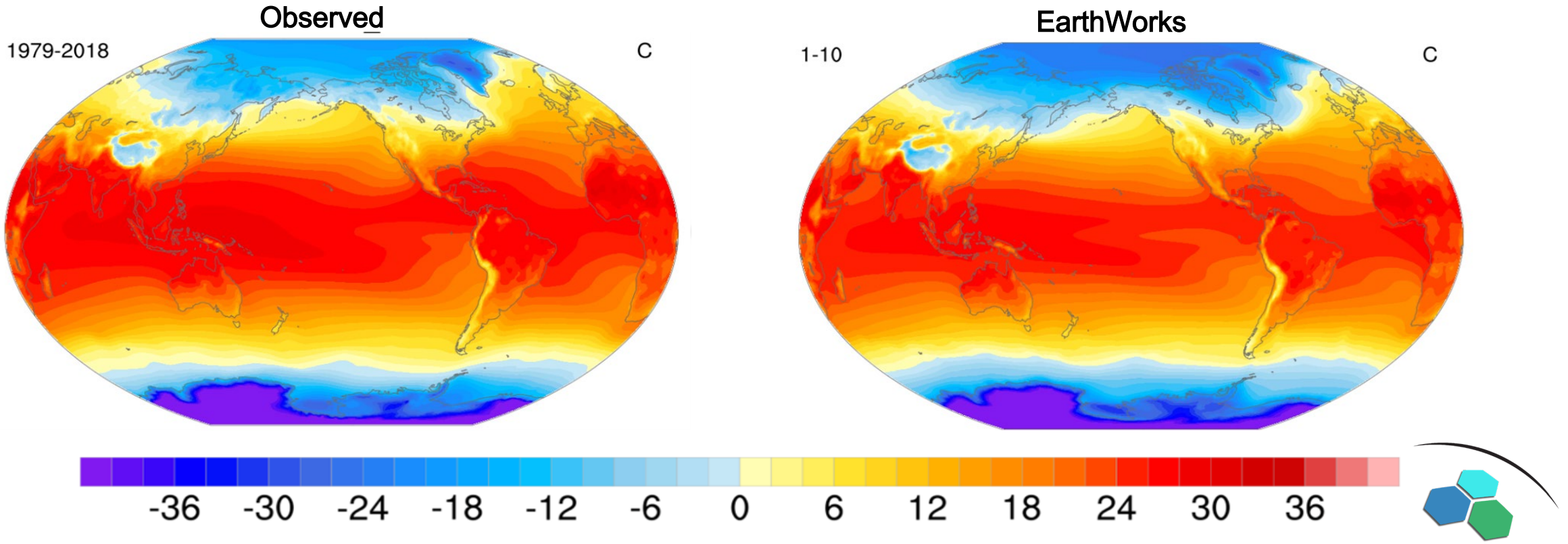
EarthWorks

CPU version of the EarthWorks configuration

run at relatively coarse resolutions (e.g., 60 km)

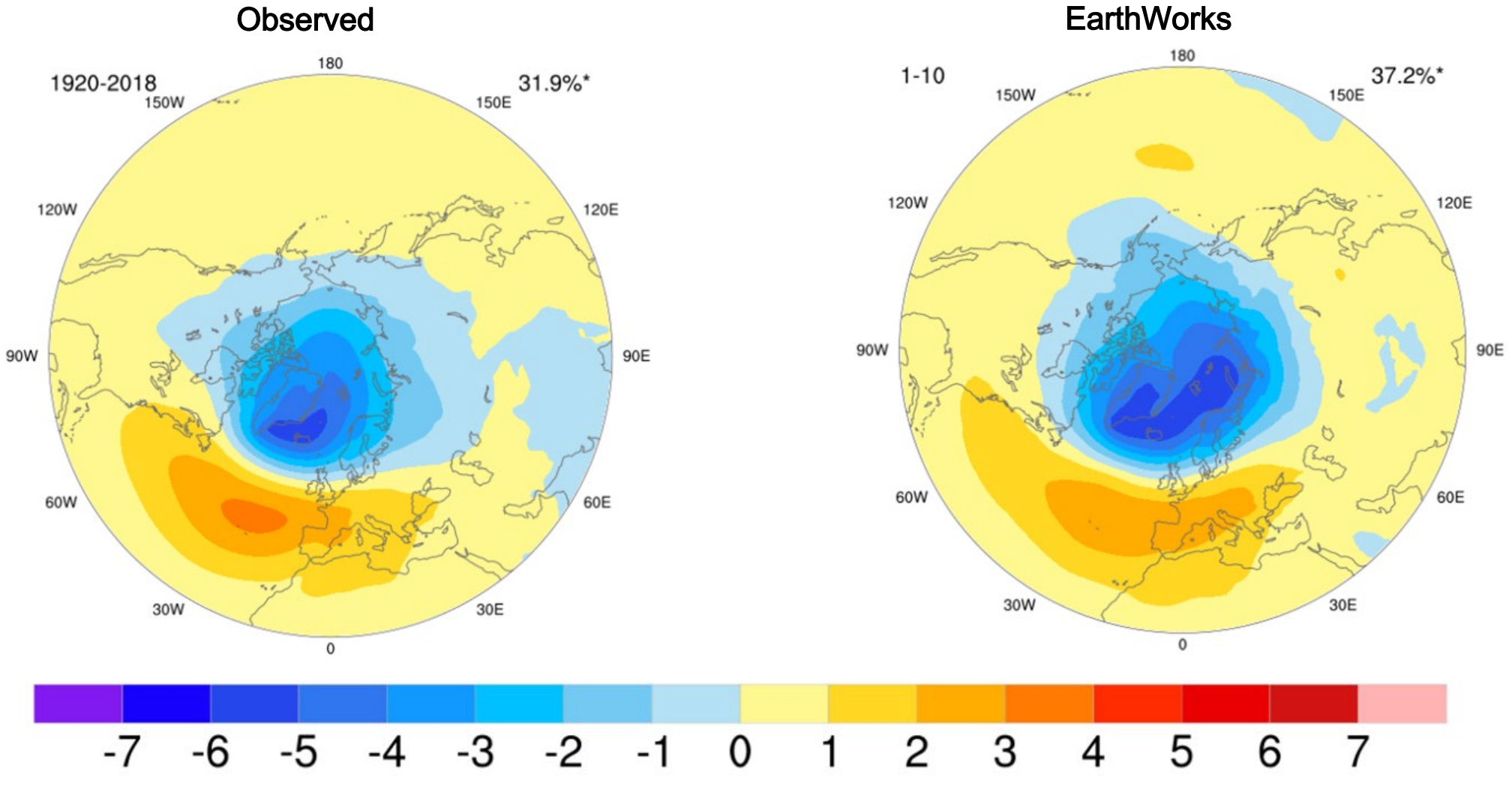
(diagnostics available at http://gback.atmos.colostate.edu/earthworks/)

Surface Air Temperature



EarthWorks

North Atlantic Oscillation (Monthly)



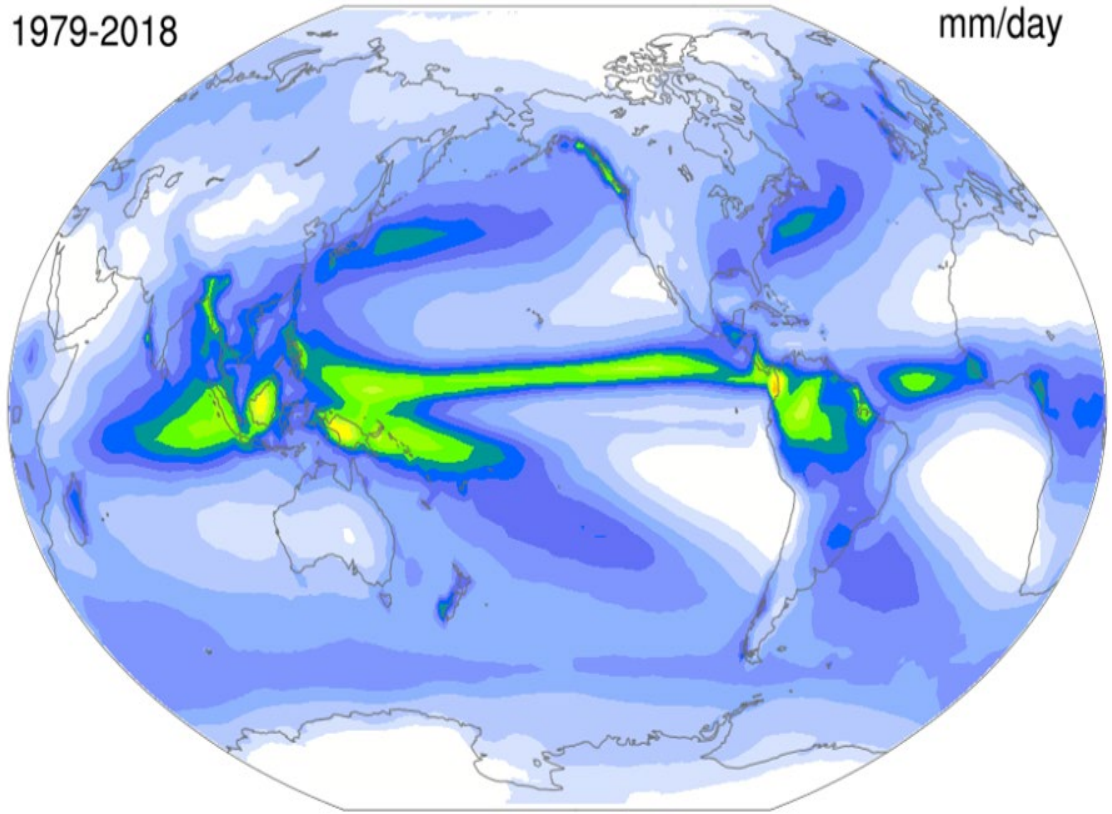
EarthWorks

Total Precipitation

Observed

1979-2018

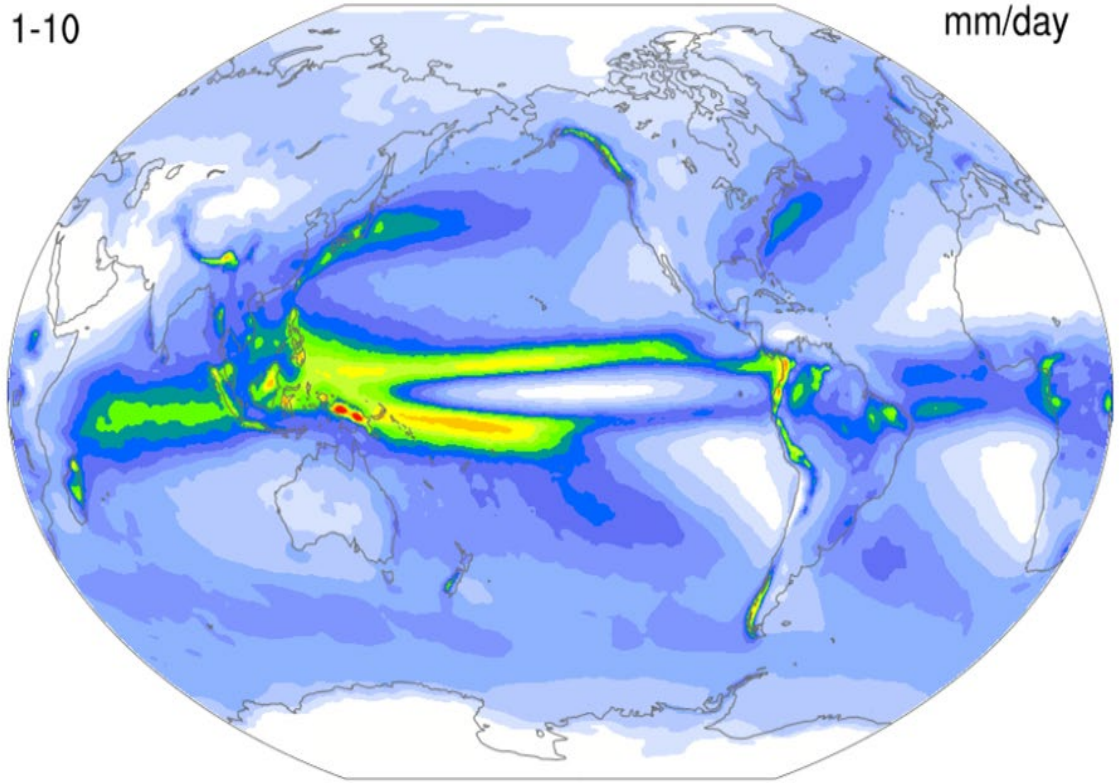
mm/day



EarthWorks

1-10

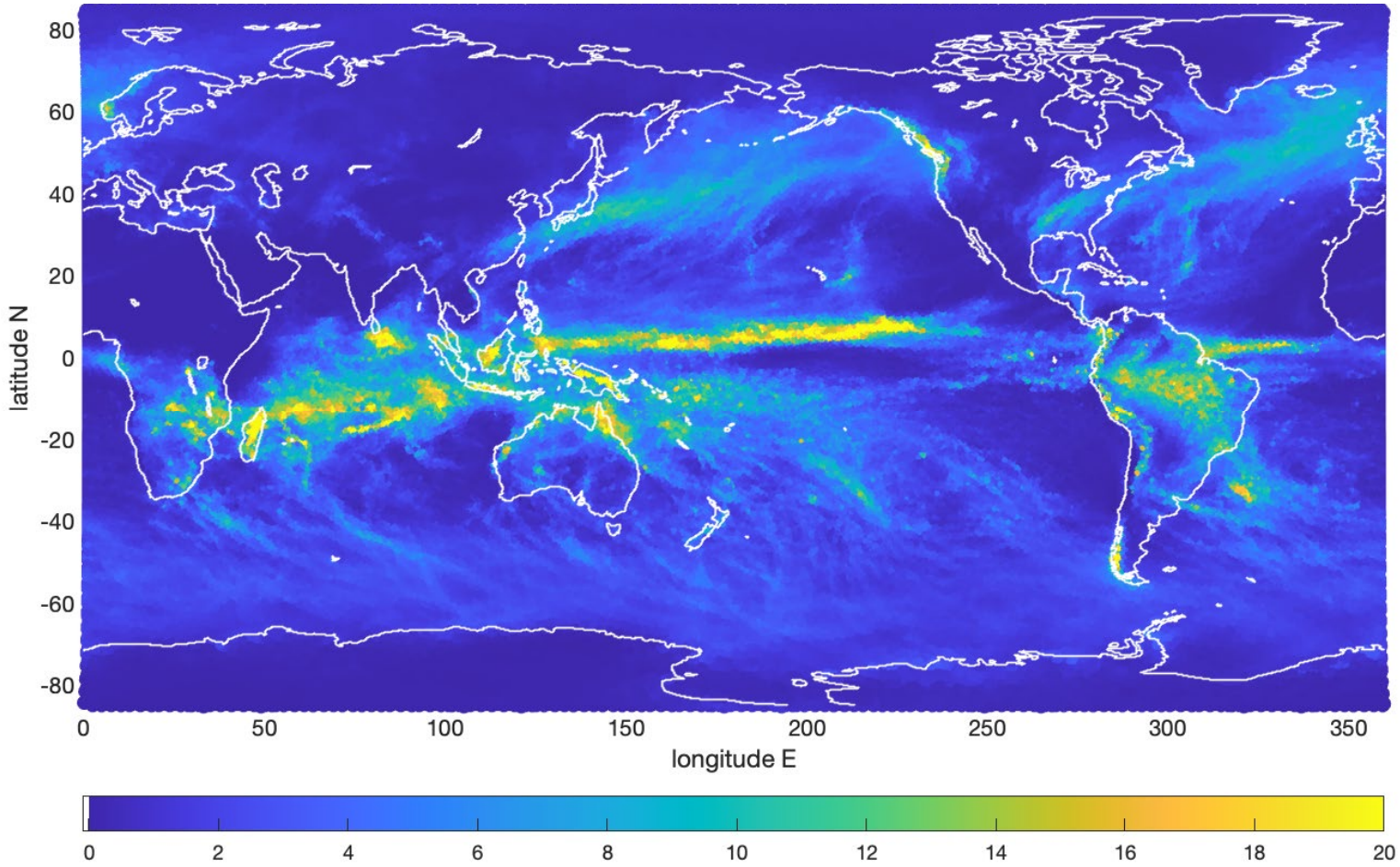
mm/day



EarthWorks

Total Precipitation Rate (30 km)

January (Year 1, mm day $^{-1}$)



Data Analysis Project Raijin

Community Geoscience Analysis Tools for Unstructured Mesh Data

For more information, see Clyne et al. poster at 2022 EarthCube Annual Meeting

Scalable Python tools for analyzing and plotting geoscience data on unstructured grids

- ★ Climate and global weather modeling communities focus (also works with regional data)
- ★ Generalizes NCAR's GeoCAT analysis package to support unstructured mesh data
- ★ Builds on the ubiquitous Xarray package

This work supported through the National Science Foundation Award 2126458.

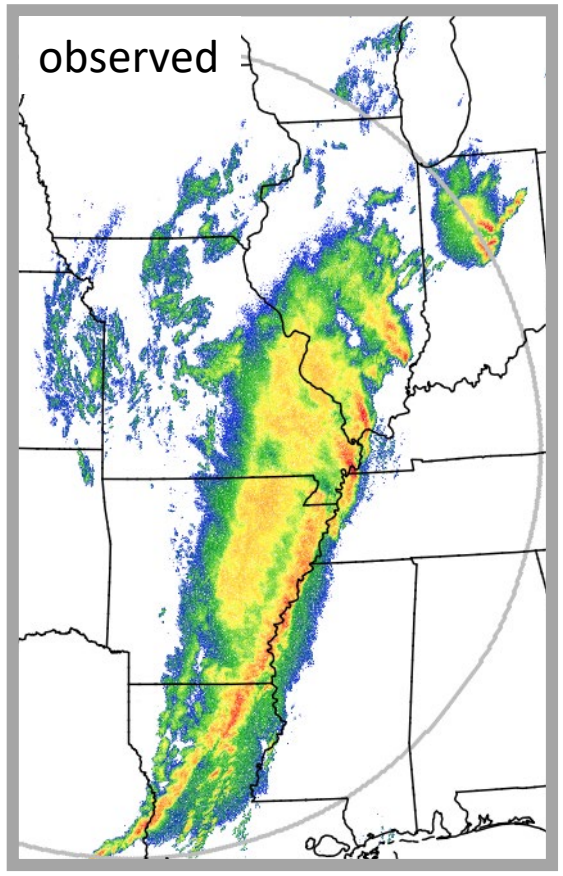
0 UTC 26 April 2017
60-3 km variable-resolution mesh

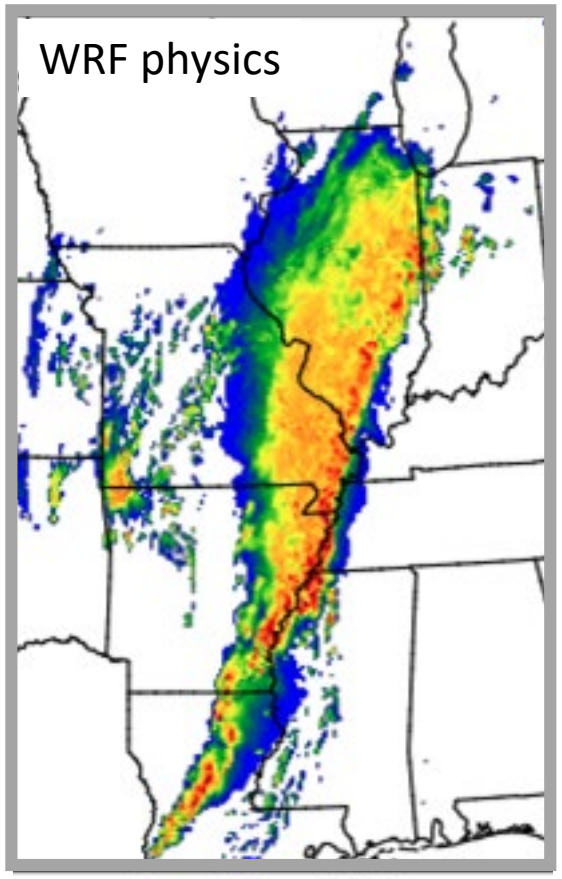
3 global simulations:
(1) Stand-alone MPAS (WRF physics)
(2) MPAS-CAM, CAM6 physics
(3) CAM6 physics, MG3 microphysics

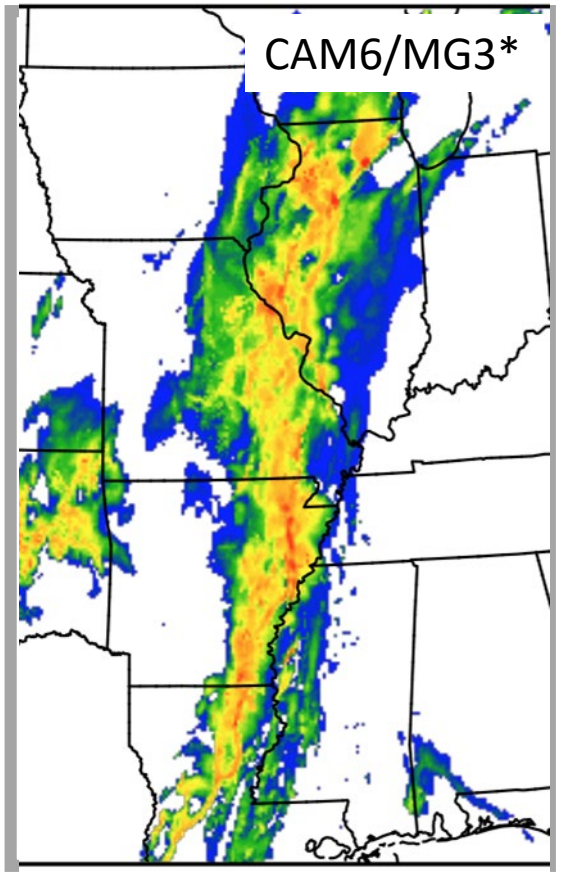
See Skamarock talk at WRF-MPAS Workshop

Testing MPAS - CAM6 physics at convection-permitting scales

Central US spring test case
24 hour forecast



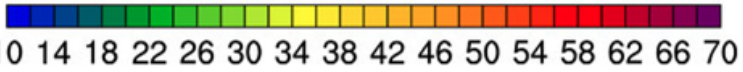




Takeaways:

- CAM6 physics is stable at 3 km *for this case*
- MG3 is an improvement over MG2 (not shown)
- There are other issues with the initialization or the physics that need to be sorted.

Reflectivity (dBZ)



(* Computed using single-moment reflectivity diagnostic)

Earthworks Computational Objectives

EarthWorks is focused on end-to-end workflow portability across leadership-computing systems to enable high-resolution weather and climate researchers to write successful large-scale computational research proposals.

Keys to enabling successful large-scale computational research proposals:

- **Demonstrate application portability**
  - **Containers for portability of the environment:**
  - **Paradigms for application performance portability:** OpenACC OpenMP MPI
- **Demonstrate scalable end-to-end workflows**
  - **Scalable I/O: Eliminate bottlenecks in model initialization and restart/history file output**
  - **Analysis: Leverage the Atmospheric Diagnostic Framework and Raijin**
  - **Data transfer: Globus for inter-facility transfer**
  - **Science gateways: e.g. containerized gateway for community data access, e.g.**

Earthworks Initial Target Platforms

EarthWorks is currently pursuing workflow portability across these leadership-computing systems.

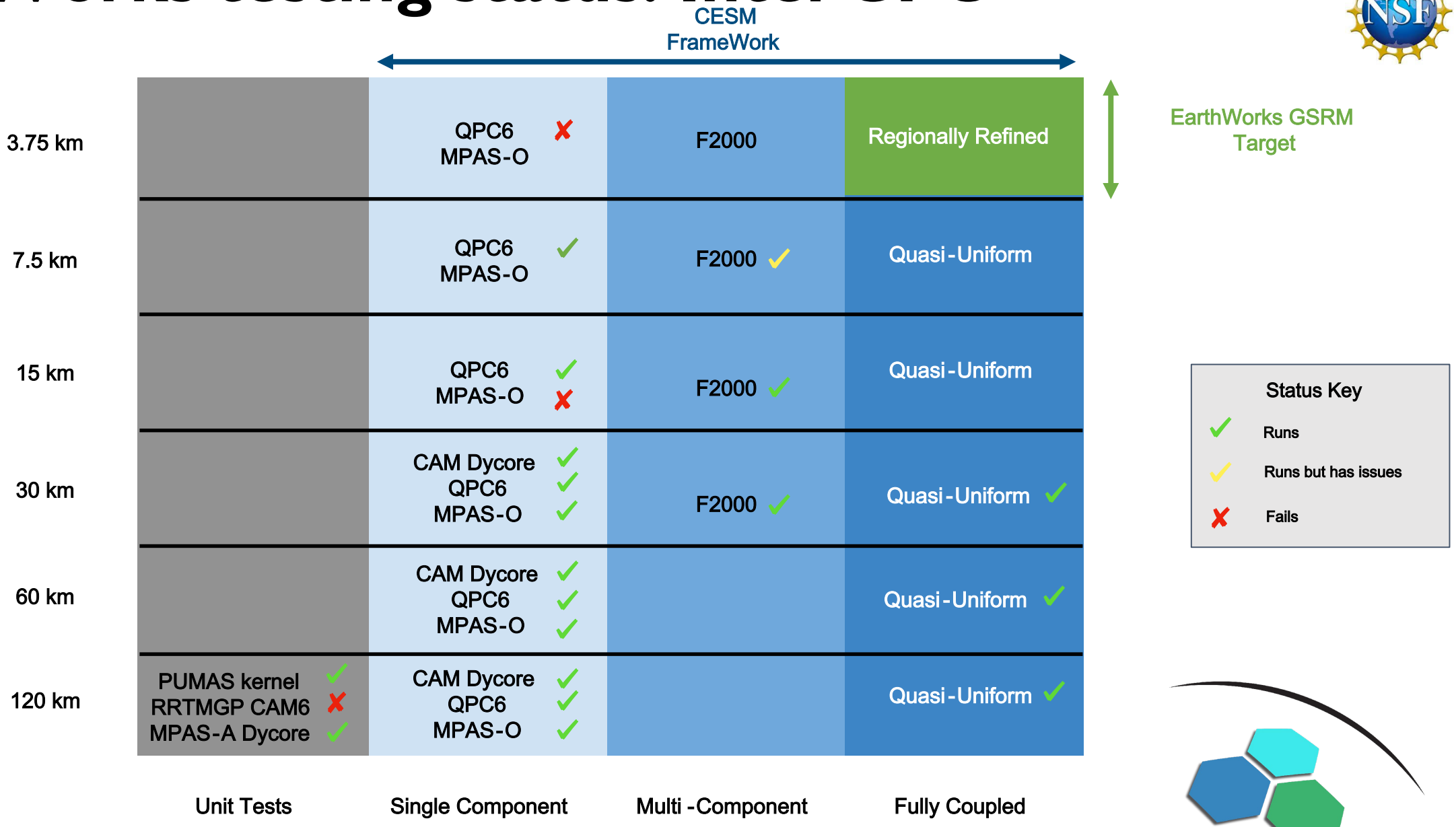
- **NSF Systems:**
  - *NCAR:* Cheyenne[1] ⟶ Derecho*
  - *Texas Advanced Computing Center:* Frontera[1] ⟶ Horizon[2]
- **DoE Systems:**
  - *Argonne National Lab:* ThetaGPU* ⟶ Polaris*
  - *NERSC:* Perlmutter*

*AMD + NVIDIA GPU

[1]Intel CPU architecture

[2]Unknown architecture

EarthWorks testing status: Intel CPU



EarthWorks testing status: GPU

Component	Subcomponent	Package	GPU Porting Status	Offload Paradigm	Version Skew?	Optimized	Comments
Atmosphere			in progress				
	Dycore	MPAS-7.x	completed	OpenACC & OpenMP	merge with CAM	yes	Awaiting results of high-res scaling tests. AMD has ported MPAS from OpenACC to OpenMP
	Physics	CAM-6	in progress				
		PUMAS	completed	OpenACC & OpenMP	MG2->MG3	yes	Add new μprocesses: e.g. graupel.
		RRTMGP	completed	OpenACC	no	deferred	Need correct CPU version before benchmarking and optimizing on GPUs.
		CLUBB	in progress	OpenMP		no	Loop order refactoring for better vectorization, GPU parallelism underway. Merging physics to better represent tropical cyclones may be required.
Ocean	MPAS-O		completed	OpenACC	yes	yes	Need to test E3SW GPU versions at 60 km and merge with CPU version.
Sea-Ice	MPAS-SI		deferred				Low priority but looks doable.

Shout out to other EarthWorks-related talks

27th Annual CESM Workshop
ATMOSPHERIC MODEL WORKING GROUP MEETING

Tuesday, June 14
** All times are Mountain Time*

11:15	EarthWorks: Progress towards a storm-resolving coupled model	Jim Hurell
11:30	Linking the large-scale processes and the landfalling features of atmospheric rivers in non-hydrostatic CESM simulations	Xingying Huang (NCAR)
11:45	Discussion	
12:00	*Optional* Informal Discussion	

27th Annual CESM Workshop
SOFTWARE ENGINEERING WORKING GROUP MEETING

Wednesday, June 15
** All times are Mountain Time*

Time	Topic / Title	Speaker
8:30	Welcome and logistics	Bill Sacks & Ligia Bernardet
8:35	Update on ESMF/NUOPC coupling infrastructure in CESM	Mariana Vertenstein
9:05	Common Community Physics Package (CCPP) update	Dom Heinzeller
9:25	CESM & new technologies: clouds, containers and accelerators (GPUs)	Brian Dobbins
9:45	Enabling the execution of PUMAS on GPUs	Jian Sun
10:05	***BREAK***	
10:25	Development and current status of the Atmosphere Diagnostics Framework (ADF)	Jesse Nusbaumer
10:45	Fine-tuning evaluation metrics for lossy compression of CESM data	Allison Baker
11:05	Predicting optimal lossy compression settings for CESM-LENS data	Alex Pinard
11:25	**Open discussion**	
12:00	**Adjourn; we welcome you to stay on for informal networking over lunch**	

Summary

- MPAS ocean and sea ice have been successfully ported into the CESM framework
- Fully coupled 60 km 10-year simulation completed; 30 km simulation underway
- MPAS atmosphere and ocean can now be run on GPUs
- Once CLUBB has been ported to GPUs, CAM6 physics will run on GPUs as well
- CAM6 physics is being tested at convection-permitting scales
- Our goal is that EarthWorks will produce at least one simulated year per day on a 3.75 km grid by the completion of the project