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STATE OF CESM

THE 28th ANNUAL CESM WORKSHOP

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CESM Chief Scientist

12 JUNE 2022

NCAR

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Outline

CESM Science and Strategic Plan

High- and ultra-high-resolution efforts

Some highlights

Towards CESM3

The word *community* refers to all entities whose members are engaged in research and / or education in Earth system sciences. They form the collaborative foundations of CESM. These entities include universities, laboratories, private sector, and other organizations, both nationally and internationally.

CESM

Community Earth System Model

CESM Science and Strategic Plan: 2023-2028
March 2023

This Science and Strategic Plan provides scientific and modeling priorities and guidelines for the CESM Project for the next five years.

The Plan is based on the extensive input received from the CESM community via the CESM Working Groups, starting with the 2019 Annual Workshop, and it is consistent with the vision of the NCAR Strategic Plan.

The strategic priories are determined by the Earth system modeling community's present and anticipated / emerging scientific needs.

Guiding principles include advancing science and understanding of the Earth system and providing actionable information for societal use at relevant temporal and spatial scales in strong collaboration with the community.

https://www.cesm.ucar.edu/news/new-cesm-science-and-strategic-plan-2023-2028

The Plan aims to strike a balance between curiosity-driven, use-inspired research, and related technical developments.

The unique aspect and strength of the CESM Project are its community-driven research and developments.

The Plan advances coupled Earth system science and applications through CESM's unique capabilities, bridging weather, climate, chemistry, and geospace communities.

At the same time, it aspires to develop additional capabilities to address emerging science questions, including those associated with (ultra) high-resolution, both globally and regionally, while recognizing related challenges and offering pathways as to how we wish to address those challenges.

The science drivers / goals are articulated within each priority area.

Actionable Science and Climate Justice

Actionable science and climate justice are two related and fundamental objectives for the CESM Project.

To chart an organized path forward on these two topics in strong collaboration with the community, the 2022 Annual CESM Workshop featured two cross-WG sessions on:

Justice and Climate Change and Actionable Science and CESM

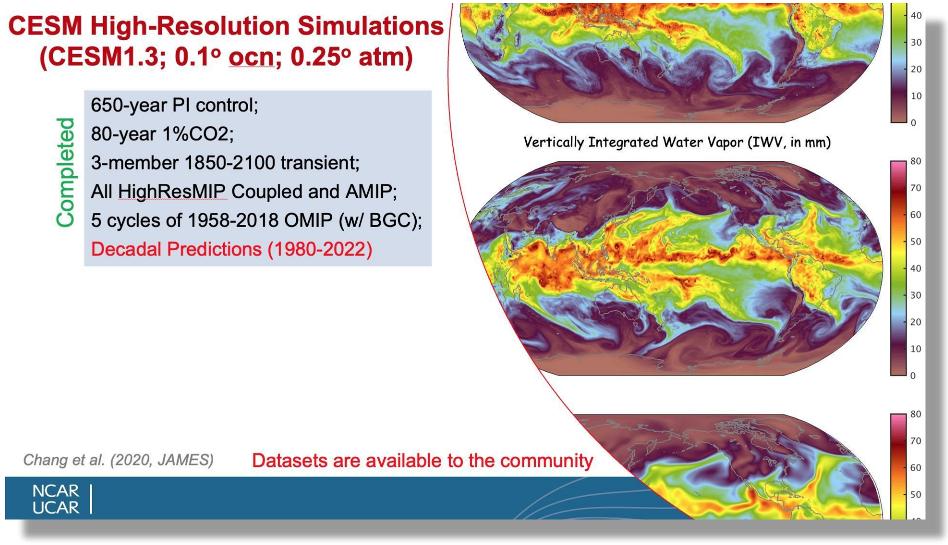
Several recommendations emerged from these sessions which are included in the CESM Strategic Plan.

A Task Team has been initiated, led by Monica Morrison.

Challenge: CESM does not have a critical mass of internal expertise to lead and enhance its societally-relevant science and climate justice efforts. We will reach out and seek strong collaborations with the leaders, universities, and institutions in the community on these topics to lead and guide CESM's efforts.

An initial step is to convene a workshop to entrain and engage the relevant (under-represented, scientifically marginalized, and climate vulnerable) communities and researchers.

High- and Ultra-High Resolution CESM



The datasets will continue to be analyzed to answer a multitude of science questions that include, e.g., changes in ocean heat uptake, ocean upwelling, and modes of climate variability with a changing climate – all in comparison with the corresponding low-resolution simulations and available observations.

This configuration is being used to perform new simulations.

For example….. It provides a platform for the paleo climate community to: study warm and cold climates for process understanding; evaluate extreme weather events, TCs, ARs, and their impacts during past climates; improve climate simulations over ice sheets; and improve model vs. paleodata interpretations near complex topography and ocean upwelling regions.

high: 0.25° atm, 0.1° ocn; ultra-high: 5 km or finer

CESM High-Resolution Simulations
(CESM1.3; 0.1° ocn; 0.25° atm)

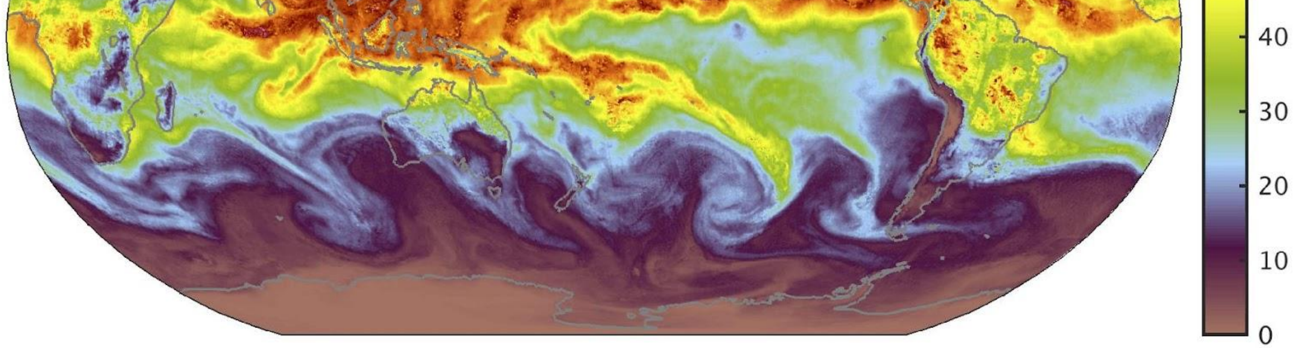
Completed

- 650-year PI control;
- 80-year 1%CO_2;
- 3-member 1850-2100 transient;
- All HighResMIP Coupled and AMIP;
- 5 cycles of 1958-2018 OMIP (w/ BGC);
- Decadal Predictions (1980-2022)

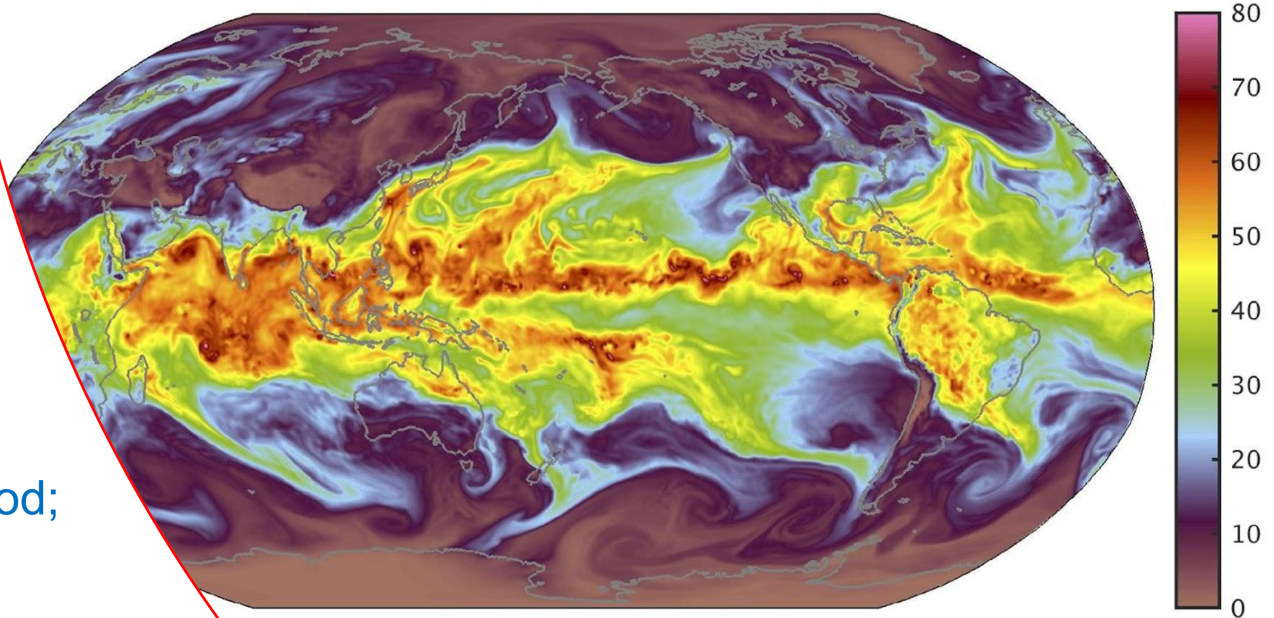
Additional prediction simulations;
Increasing the ensemble size to 10 for the 1850-2100 period;
Performing additional RCP scenario simulations;
Regional CESM for dynamical downscaling, e.g., Gulf of Mexico;
Actionable science applications, e.g., sea level, fisheries, sea turtles, …

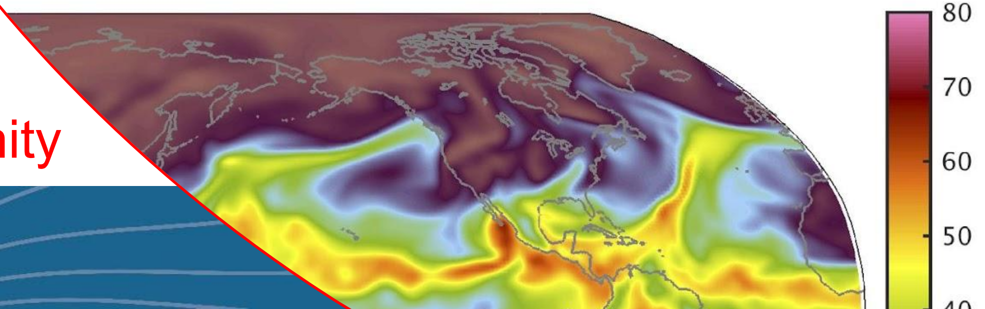
Chang et al. (2020, JAMES)

Datasets are available to the community



Vertically Integrated Water Vapor (IWV, in mm)





High- and Ultra-High Resolution CESM

Enabling Cloud-Permitting Coupled Climate Modeling

(with Exascale Computing Implications)

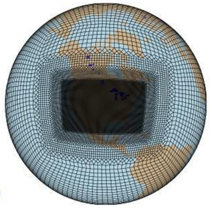
In collaboration with U. Michigan and TAMU

This new project aims to incorporate the DOE E3SM's nonhydrostatic version (NH) of the Spectral Element (SE) atmospheric dynamical core into CAM (within SIMA) to enable cloud-permitting coupled climate simulations and promote CESM's readiness for high-performance computing architectures with accelerators (Fortran, C++).

Initial applications:

Land-Atmosphere Interactions (Mesoscale Convective Systems) in the CONUS domain

Air-Sea Interactions with a foci on Tropical Phenomena, e.g., TCs.



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The Earth system components interact on a wide range of temporal and spatial scales, involving exchanges of momentum, heat, freshwater, carbon, tracers, etc. at their interfaces. These interactions play fundamental roles in shaping the mean state of the climate system, its variability and change, as well as its predictability and prediction at various time scales, with increasing evidence for importance of small-scale interactions (down to the km scale).

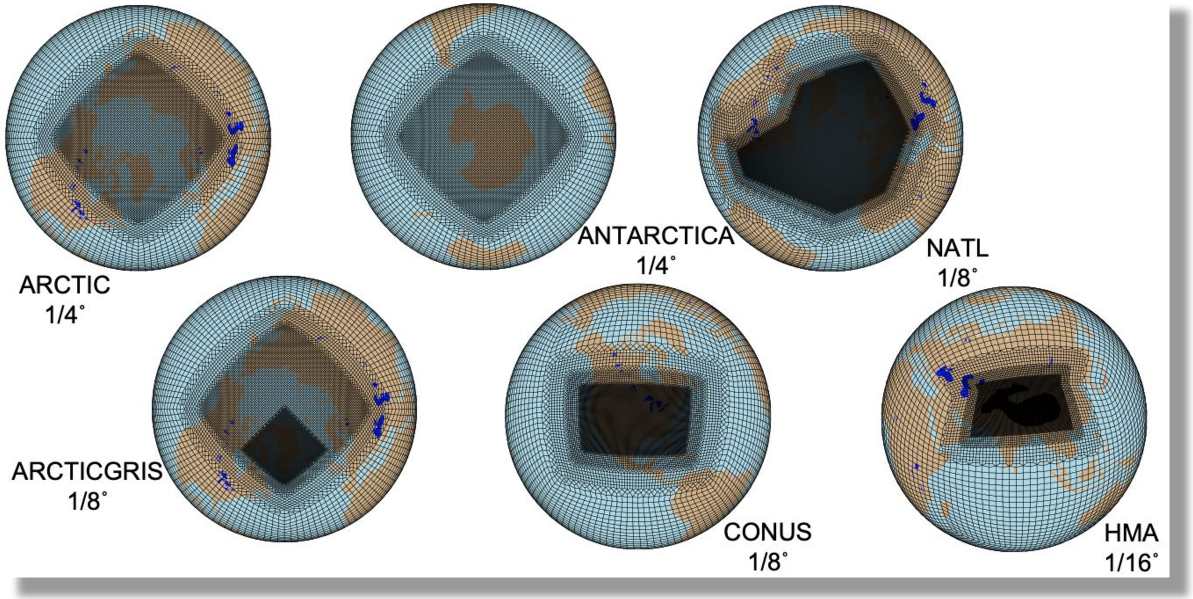
Advancing Earth system science seamlessly by co-production and co-use/analysis of low-, high-, and ultra-high-resolution efforts!

Strategic partnership with the university community, DOE E3SM, EarthWorks, and three NCAR Labs (CGD, CISL, and MMM)

SIMA: System for Integrated Modeling of the Atmosphere

High- and Ultra-High Resolution CESM

Spectral Element Variable-Resolution Grids



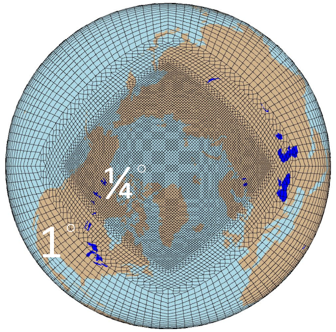
The science areas include simulations with: the North Atlantic configuration to address deficiencies in jet stream variability in relation to North Atlantic SST variability; the South Asia configuration to study air quality and Asian summer monsoons; and the Arctic configuration to study surface mass balance over Greenland with increasing CO_2.

As these configurations target increasingly finer refinements, they push the boundaries of the hydrostatic assumption. Thus, an immediate application area of SE-NH capability will be in these regionally-refined configurations.

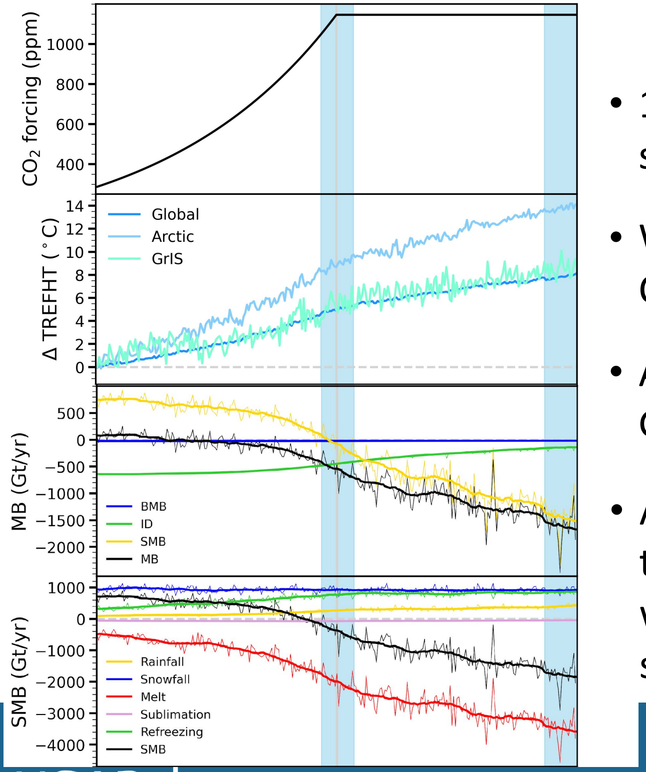
Fully coupled CESM2.2-CISM2.1 using variable-resolution grid

A. Herrington (NCAR), Z. Yin (CU) + AMWG, LIWG, and PCWG

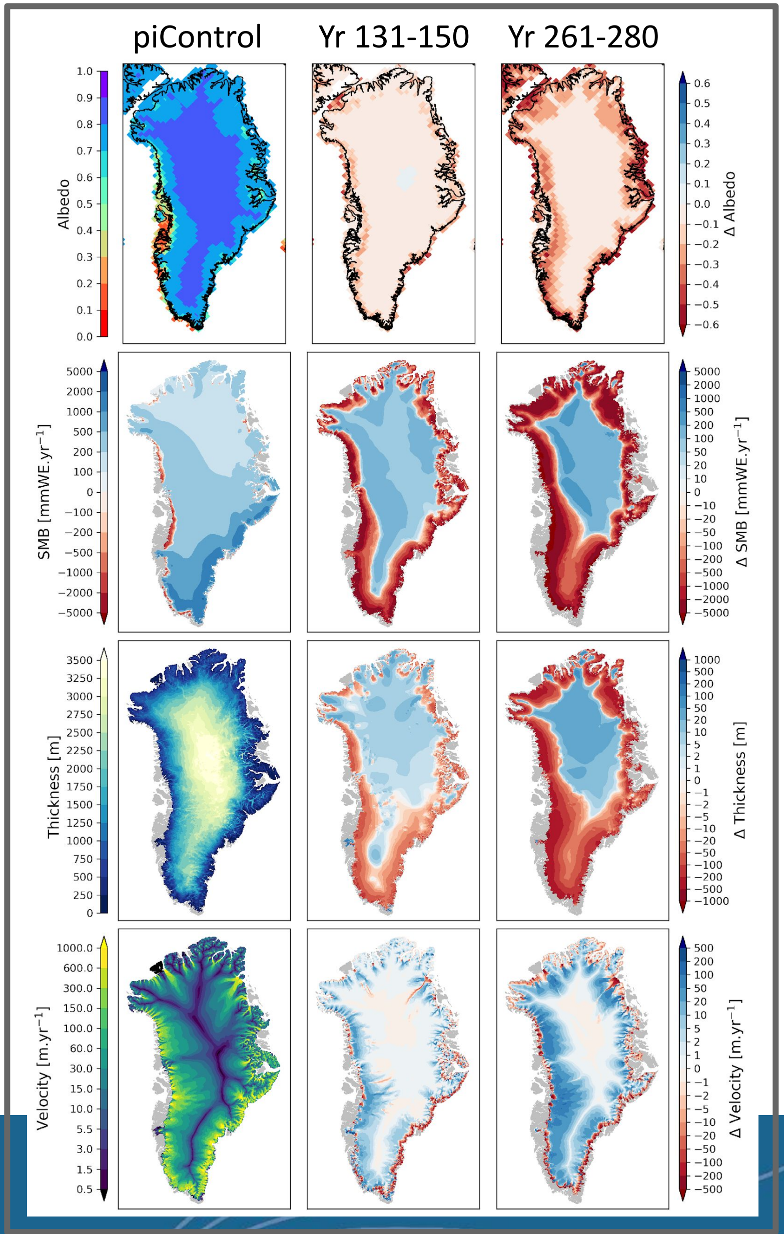
ARCTIC grid



- CAM6-SE/CLM5: ARCTIC grid
- CISM2: 4km
- POP2: 1°
- 32 hybrid σ-p vertical atmospheric levels
- 180 years piControl simulation



- 1%CO_2/yr until 4xCO_2 stabilization
- Weaker warming trend after CO_2 stabilization
- Arctic amplification ~1.8, Greenland amplification ~1.1
- Accelerated mass loss from the Greenland Ice Sheet, which is due to accelerated surface melting

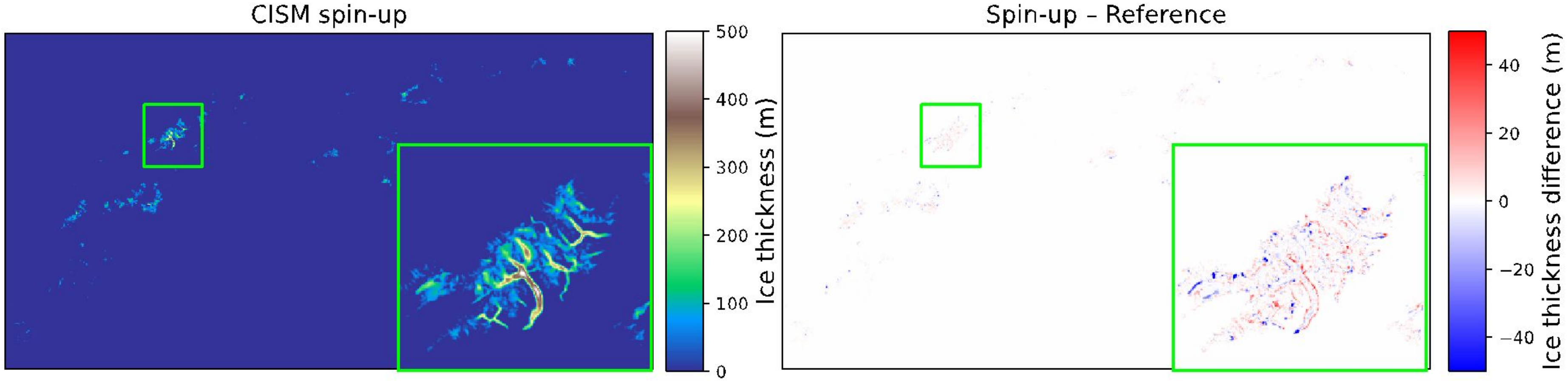


- Ice-albedo feedback is triggered and accelerates melting as the ablation area expands, exposing more (dark) bare ice
- Extensive ice sheet thinning with interior thickening
- Accelerated ice flow from the interior towards the margins due to steeper slopes, increasing the gravitational driving stress

Herrington et al. (2022, JAMES)

Using CISM for Mountain Glacier Simulations

Bernese Alps glaciers
(NASA Earth Observatory)



Left: CISM ice thickness simulation for the full Alps and the Bernese region (inset).
Right: Ice thickness difference between CISM spin-up and reference thickness (Farinotti et al. 2019).

Using CISM for mountain glacier simulations

> First 3d-order ice sheet model used to simulate mountain glaciers
> Simulations performed at a resolution of 200 m or finer
> Good agreement with observations

Ongoing work

> Submission to the GlacierMIP3 project
> High Mountain Asia simulation is underway

Future work

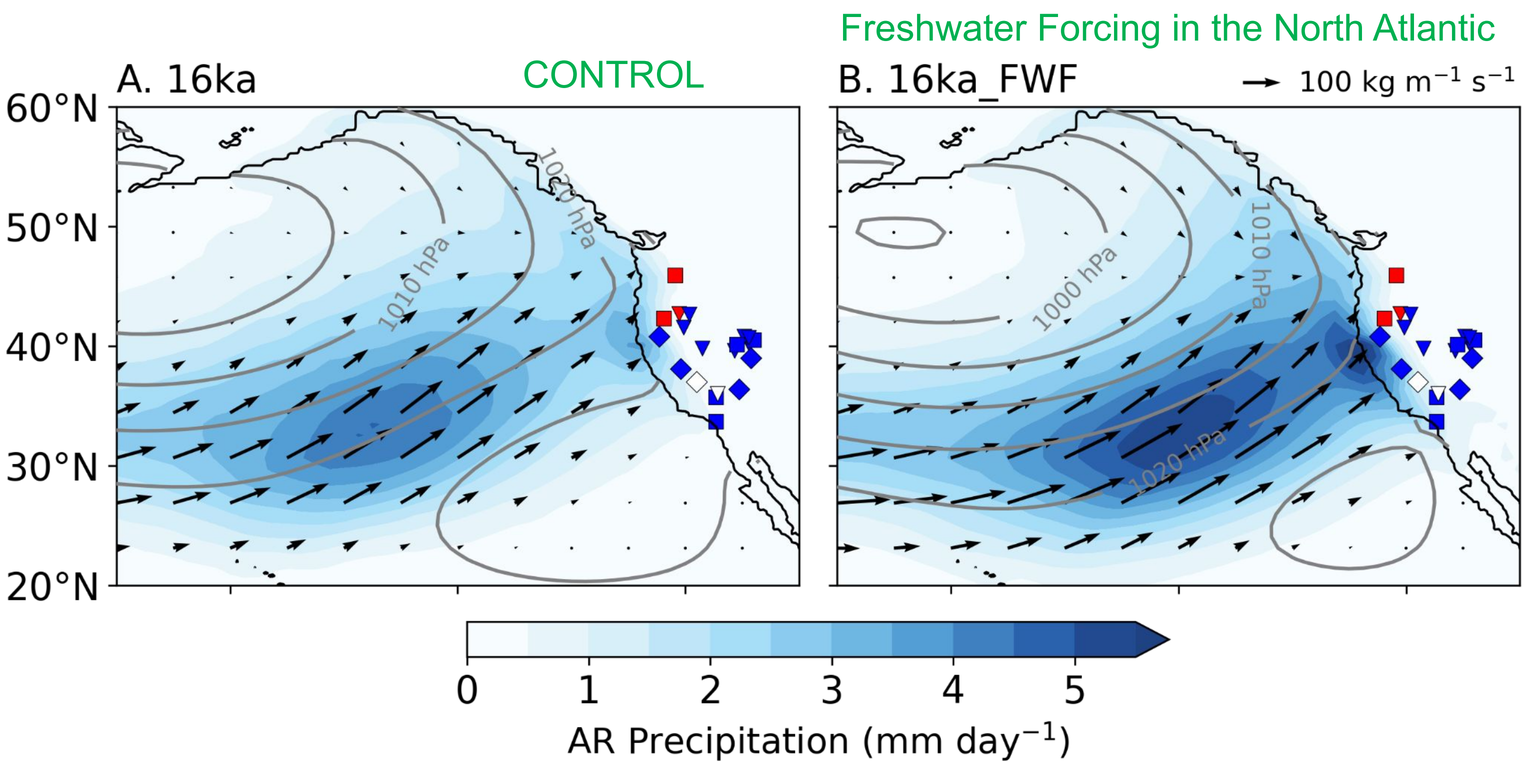
> Simulate all Randolph Glacier Inventory (RGI) regions
> Study freshwater availability and security at decadal time scales
> Couple to CLM within the CESM framework

Lipscomb, Minallah, & Leguy

Last Deglaciation in Western US: Implications for Hydroclimate Change

- Proxy records suggest ***wetter western US*** during Heinrich Stadial 1
- CESM1 suggests that AMOC slowdown was a key driver of increased ARs in western US
- Similar teleconnections may influence future precipitation in western US under potential AMOC weakening

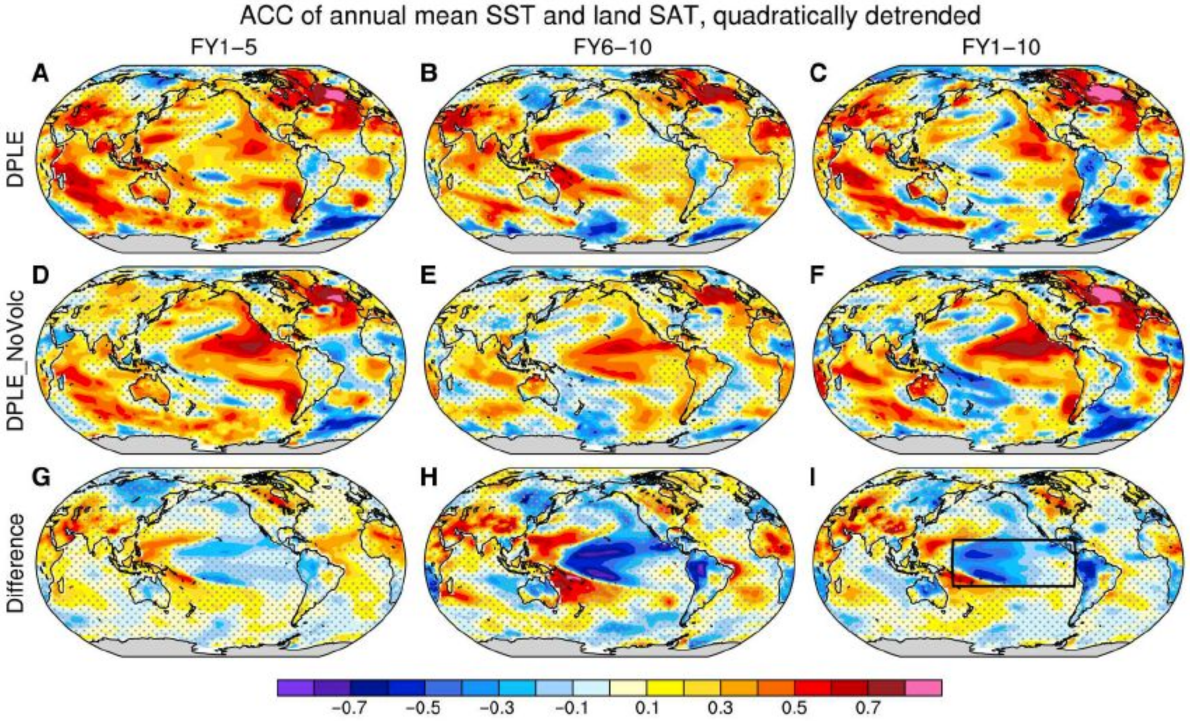
DJF-mean Atmospheric Rivers



Vectors = integrated vapor transport
Gray contours = sea level pressure
Colored contours = precipitation

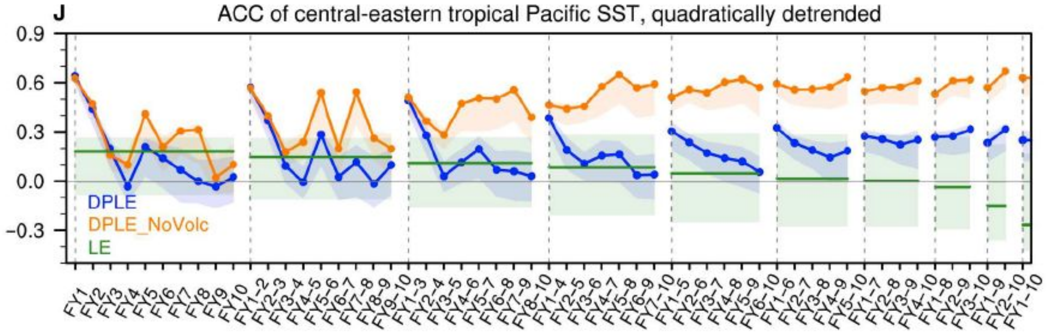
Oster, Macarewich, Lofverstrom, de Wet, Montañez, Lora, Skinner, & Tabor (sub., Nature Comm.)

Impacts of Volcanic Eruptions on Multiyear-to-Decadal Prediction Skill



Wu, Yeager, Deser, Rosenbloom, & Meehl (2023, Sci. Adv.)

Surface Temperature Skill Comparison



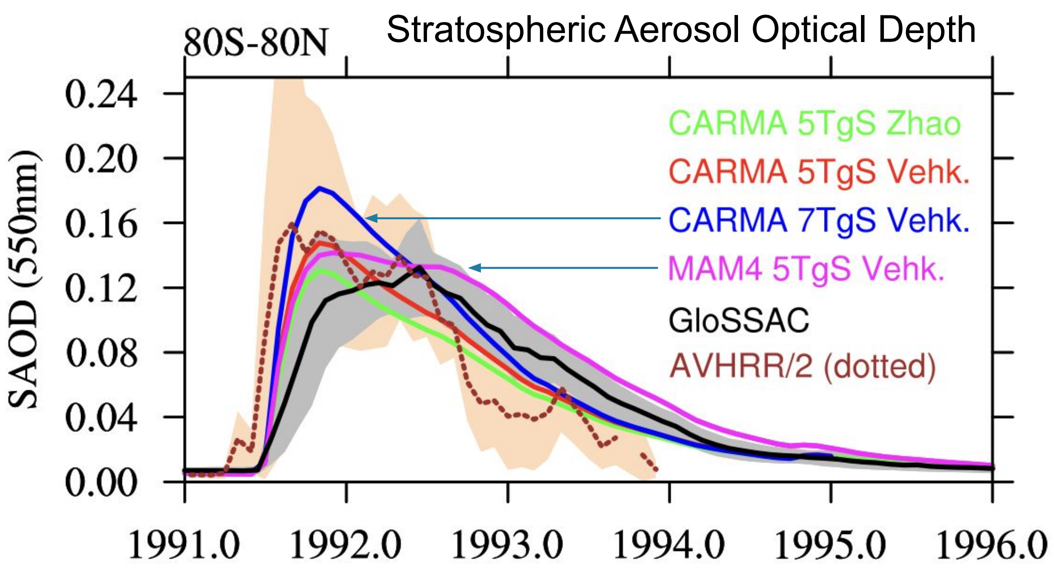
An incorrect response to volcanic forcing in CESM1

Potential to improve realism of initialized and uninitialized simulations of historical change by correcting model response to volcanoes

CESM2 CARMA Sectional Aerosol Model Implementation

WACCM-MA and CAMchem CARMA vs MAM4

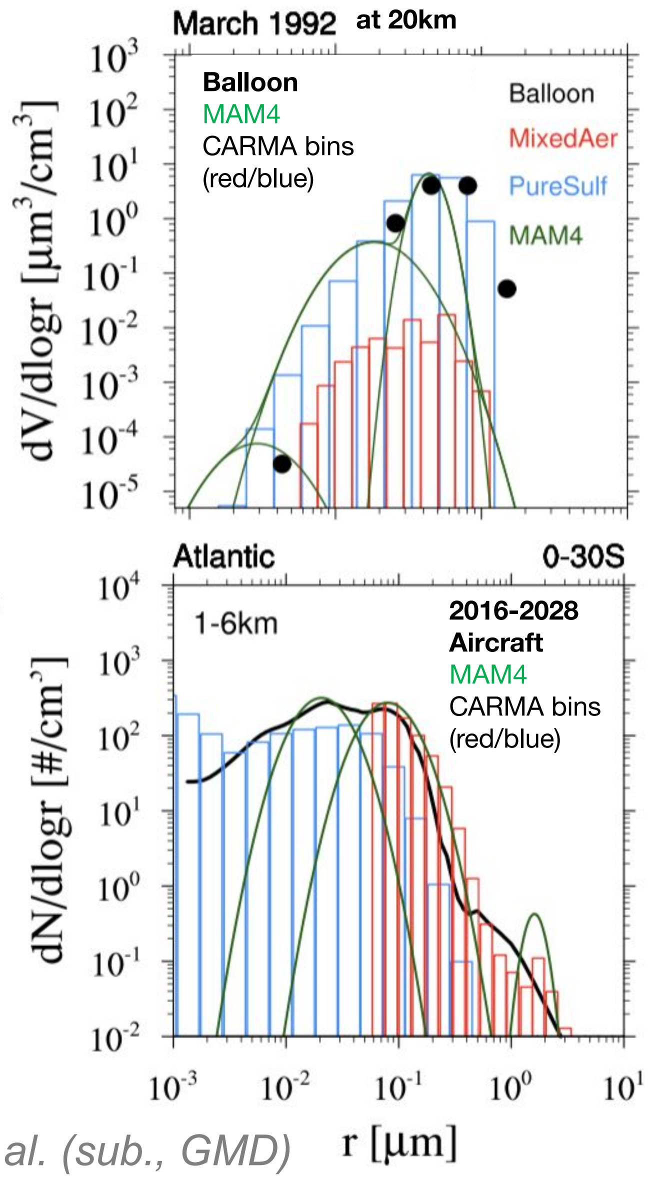
- Both CARMA and MAM4 reproduce stratospheric aerosol properties quite well during the Pinatubo eruption period



- CARMA shows an improved representation of the aerosol volume size distribution compared to observations (March 1992, at 20 km)

  can make an important difference for geoengineering studies

- CARMA better captures size distribution in the troposphere, e.g., Atlantic 1-6 km 2016-2018 in comparison to aircraft observations



CARMA: Community Aerosol and Radiation Model for Atmospheres

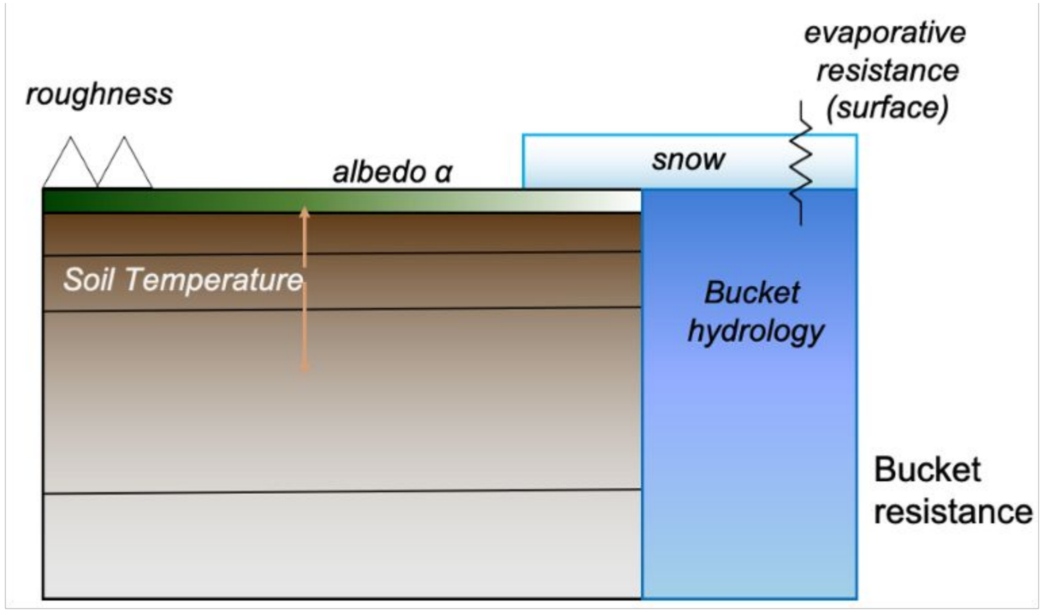
Tilmes et al. (sub., GMD)

Towards CESM3

Simpler Models: Two New Capabilities

SLIM (Simple Land Interface Model)

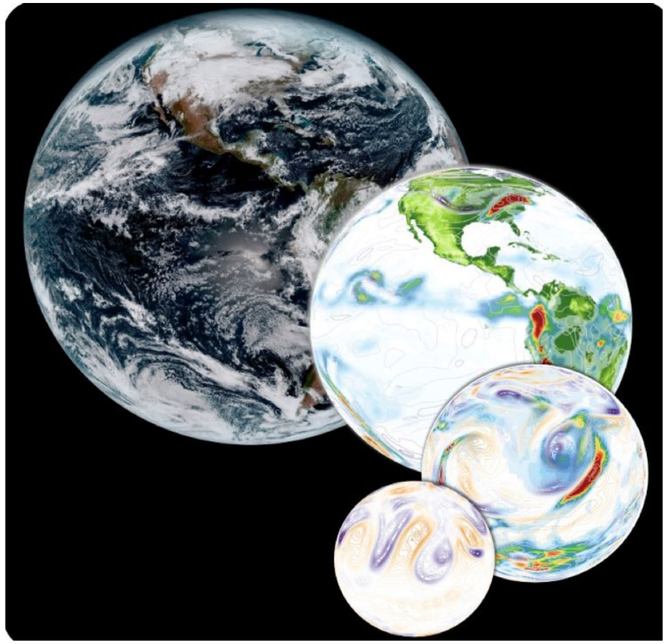
Implemented as its own component within CESM. (will be released soon)



(Laguë, Kluzek, Levis, Swann, & Bonan)

Gray Radiation Aquaplanet

Implemented following Frierson et al (2006). (about to be released)



(Callaghan, Craig, & Simpson)

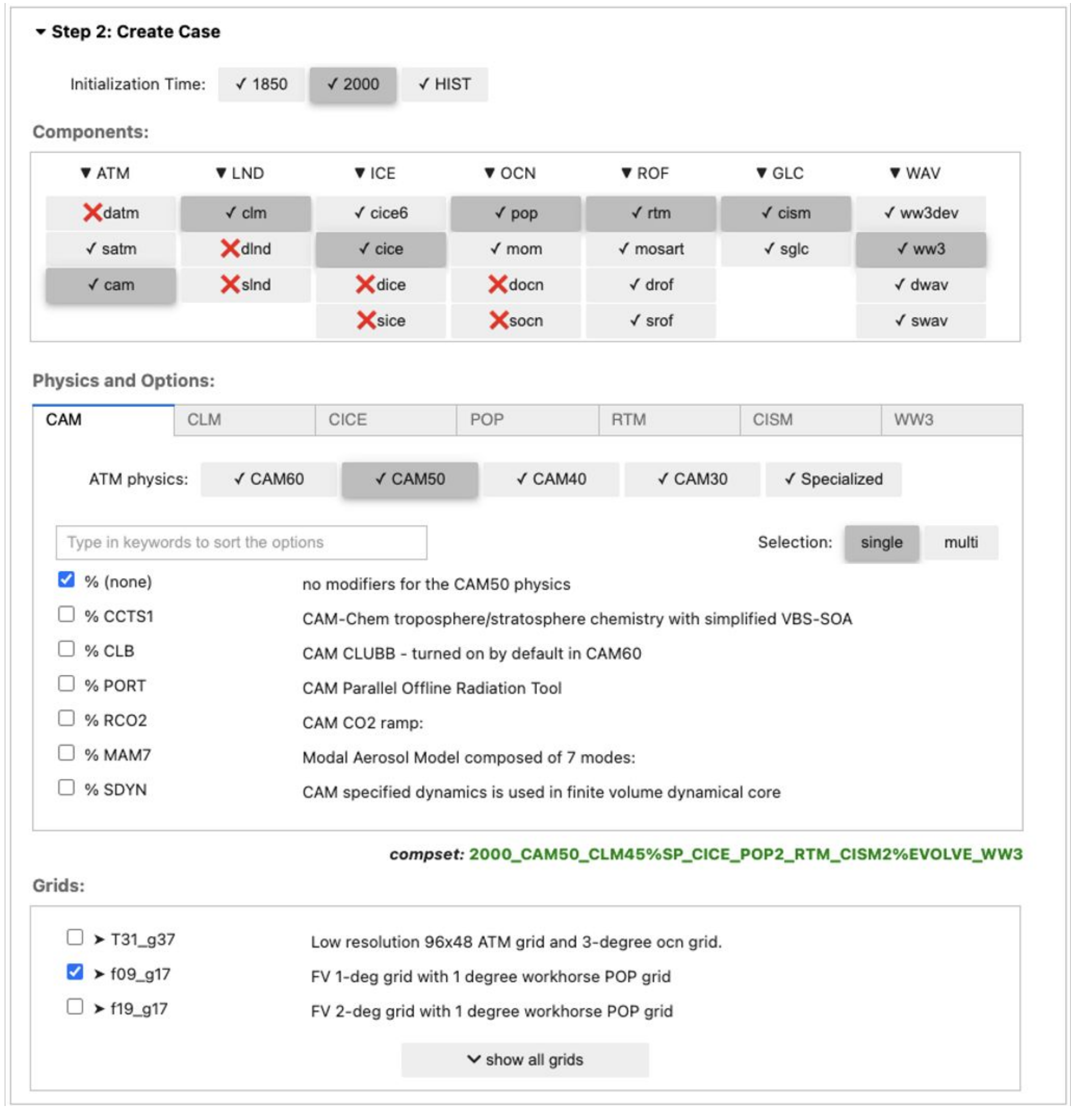
GUI & Tools to Support CESM Specialized and Flexible Models Configurations

Graphical user interface guides users through the process of creating CESM cases

New metadata and logic module to check compatibility of compsets and grids

Custom MOM6 grid and bathymetry generator

Land model tools to facilitate creating surface datasets for custom grids and configurations



Altuntas, Bachman, Simpson, Danabasoglu, Vertenstein, & Dobbins

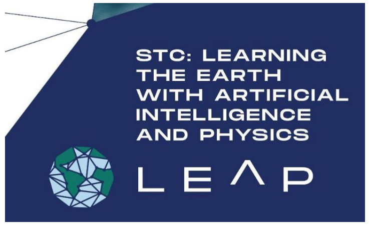
Pursuing New Technologies to Advance Science

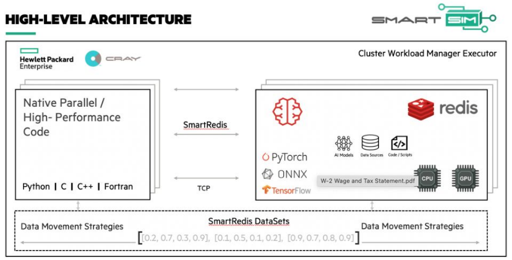
Machine Learning (ML) with CESM

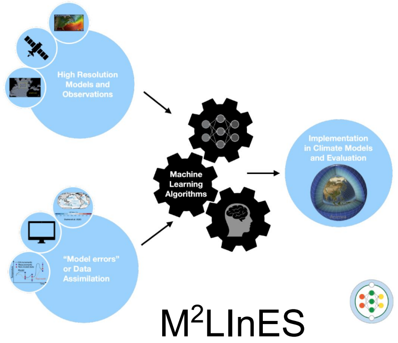
CESM intends to use / explore ML methods primarily for process-understanding, parameterization development, parameter estimation, and improving prediction skill studies in strong collaboration with several university- / industry-led projects.

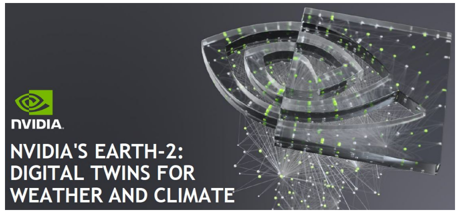
CESM would like to be able to run models at finer resolutions with more processes represented and coupled together to improve the realism of the simulations, but these scientific ambitions are challenged by the expected trajectory of our computing resources.

ML approaches promise a computationally efficient and scalable means to model the physical, biological, or chemical relationships that can be seen in large observational or high-resolution model datasets.









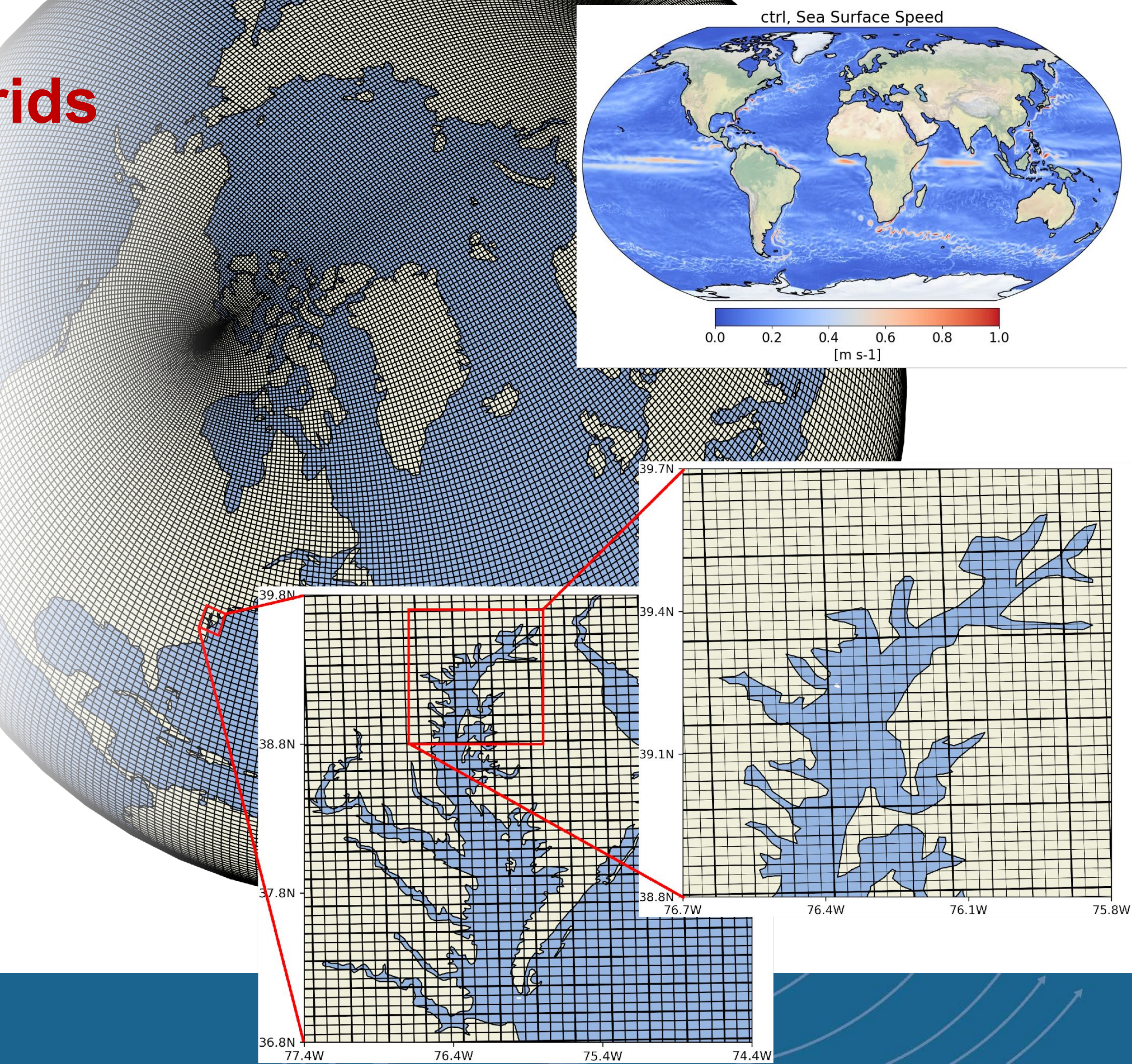
MOM6 Global Tripolar Grids

A hierarchy of global colocalized grids

- from coarse (2/3°)
- to eddy permitting (1/4°)
- to eddy resolving (1/12°)
- to submesoscale permitting (1/36°)

The hierarchy will also allow for easy implementation of regional and out-of-the-box configurations

Marques, Bryan, Castruccio, & many others



Workhorse CESM3 Configuration

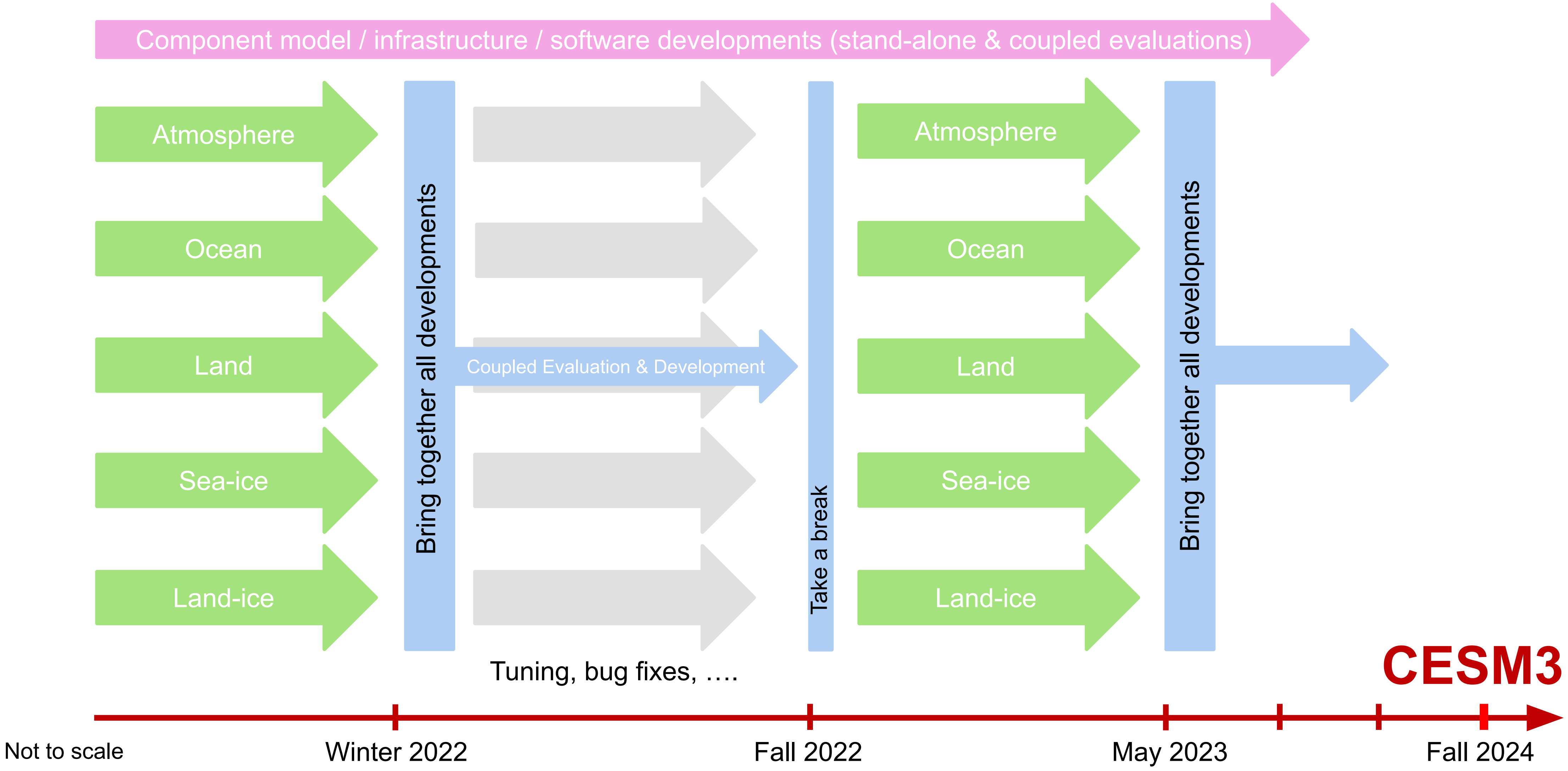
Following the CESM SSC decision in December 2021, an initial goal was to perform preliminary evaluations of the coupled simulations with a new CESM configuration that uses preliminary versions of CAM6/SE/L58 + MOM6 + CICE6 at nominal 1° horizontal resolution.

There are numerous new developments and features in each component model.

To date, > 50 multi-decadal / centennial time scales simulations have been performed.

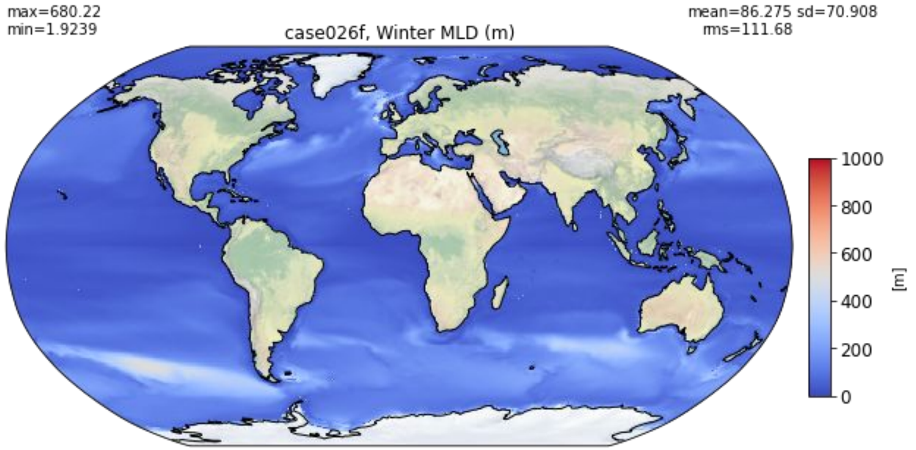
These runs have been useful to identify and resolve various scientific and technical issues, such as, enthalpy non-conservation and its ad-hoc fix, salt non-conservation, initialization errors, incorrect areas being used in sea-ice and the ocean, and incorrect subgridscale topography in the atmosphere.

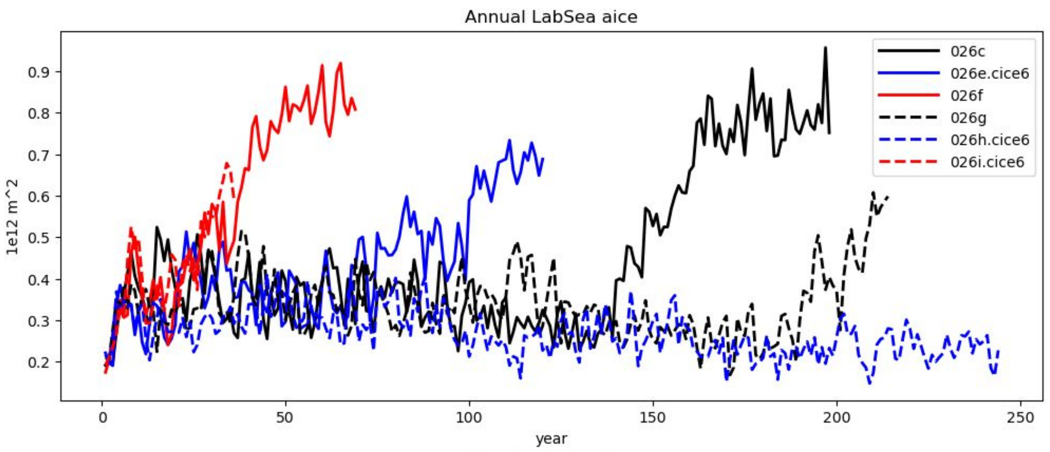
Development Timeline

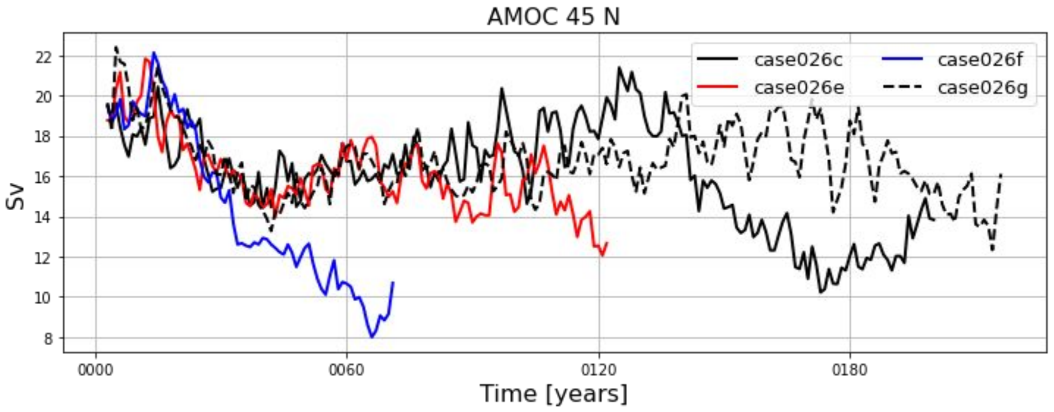


Early Results

	ATM	ICE	Purpose	Nyrs
Control	cam6/L32/FV	CICE5	control: MOM6+CAM6+CICE5	100
016	cam6/L32/FV	CICE5	Repeat control with recent sandbox	58
26c	cam_dev/L58/SE	CICE5	Same as 26a with spun up ice and land	199
26e	cam_dev/L58/SE	CICE6	Same as 26c + cice6	121
26f	cam_dev/L58/SE	CICE5	Same as 26c + perlim = 1e-14	70
26g	cam_dev/L58/SE	CICE5	Same as 26c + perlim = 2e-14	205
26h	cam_dev/L58/SE	CICE6	CICE6 + Advanced Snow Physics	240
26i	cam_dev/L58/SE	CICE6	CICE6 + Advanced Snow Physics (turned off the snow loss to leads)	27*
009	cam_dev/L58/SE	CICE6	Target simulation MOM6+CAM-dev+CICE6	63

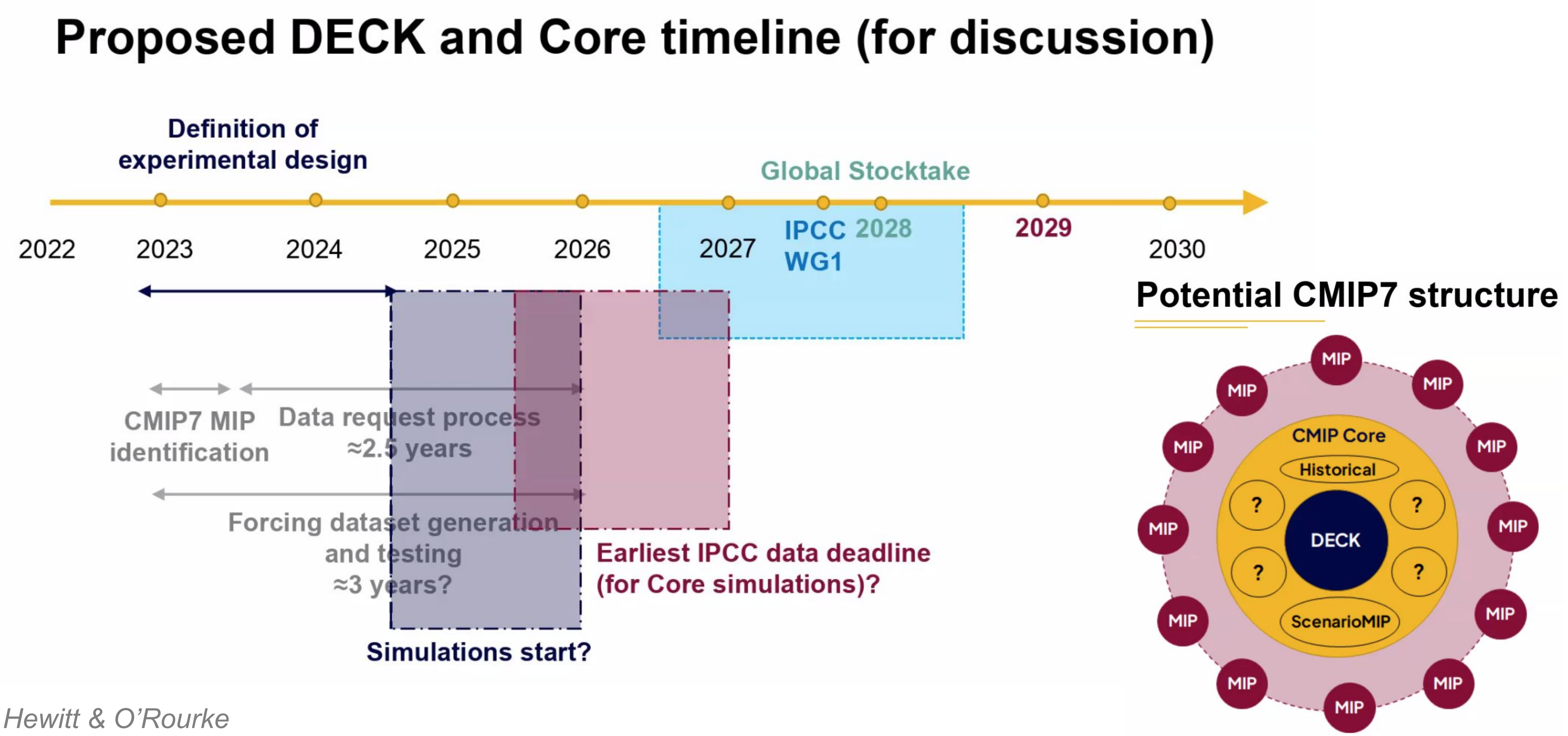






Marques, Hannay, & many many others

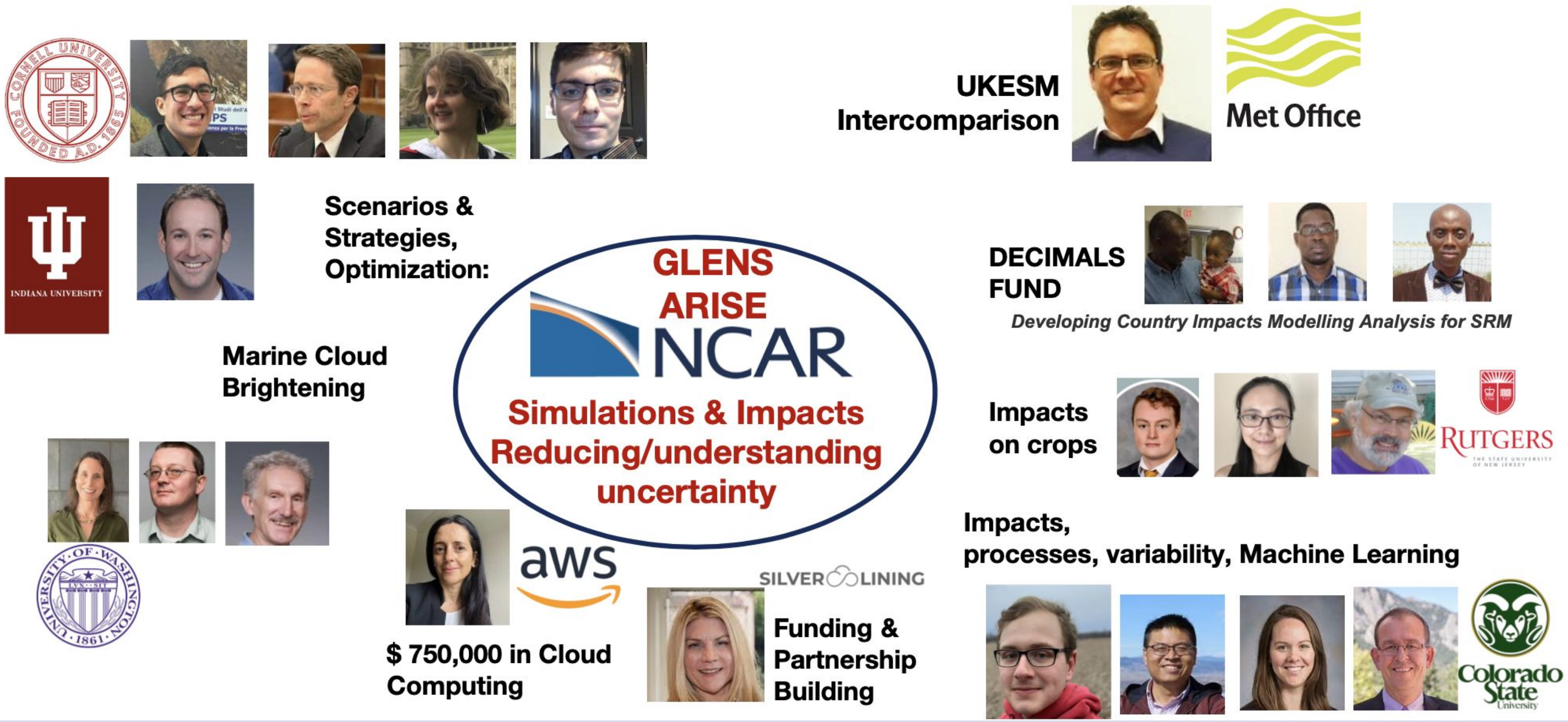
Draft CMIP7 Timelines



Hewitt & O'Rourke

ARISE: A Celebration of Partnership

ARISE: Assessing Responses and Impacts of Solar climate intervention on the Earth system



Partnership between: SilverLining NGO, NCAR, AWS, and University Community

- Shared goal
- Co-designed experiments
- Simulations on Cheyenne HPC & AWS Cloud Computing
- Community Analysis

Tuesday 5:30 - 7:30 pm (including Reception)

The Use of CESM in Climate Services and Climate Technology

While the CESM has traditionally been oriented toward the academic and Earth system-research, and related assessment communities, it is clear that it is a powerful tool for addressing societal needs that are being identified and served by the emerging climate services and climate technology industries. This session brings together industry leaders to speak about current / prospective use cases for the CESM model and CESM data in the private sector. Join us to hear four perspectives on how the need for information on climate-risk / climate-solutions is driving a new user-base for CESM models and datasets.

JUPITER™

EARTHSHOT LABS

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Tuesday 5:30 - 6:30 pm

Thank You!

2023 CESM Distinguished Achievement Award

Julio Bacmeister & Peter Lauritzen (NCAR)

2023 CESM Graduate Student Award

Claire Zarakas

University of Washington