

Project Update from Energy Exascale Earth System Model (E3SM)

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DOE Program Manager

*Earth System Model Development Program Area (ESMD), EESSD, BER
BER SciDAC and ALCC PM*

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E3SM SCREAM Member and Gordon Bell Submission Author

2023 ASCAC Meeting

Sep 28th, 2023



U.S. DEPARTMENT OF
ENERGY

Office of
Science





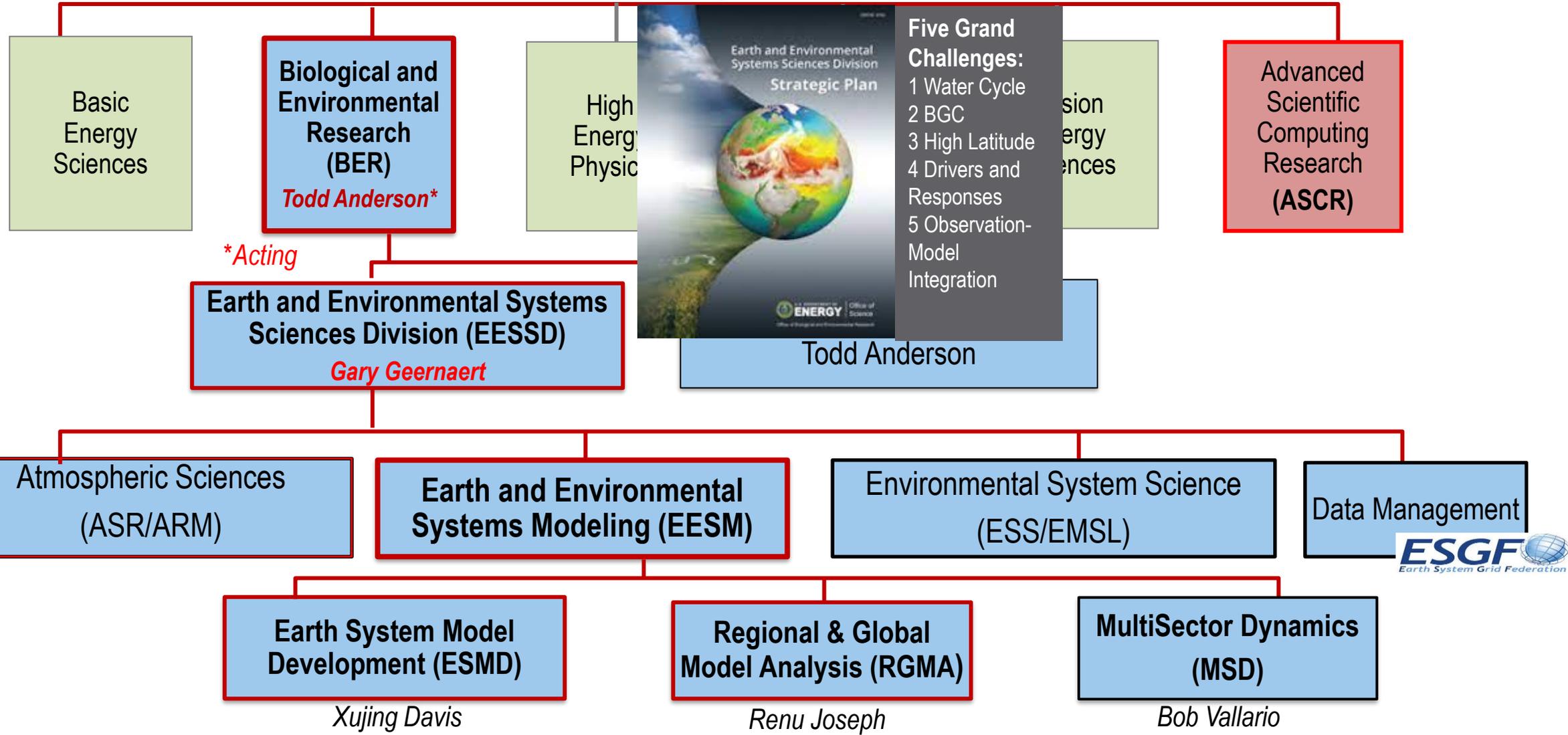
Office of Science
FY23 Budget: \$8.1 Billion



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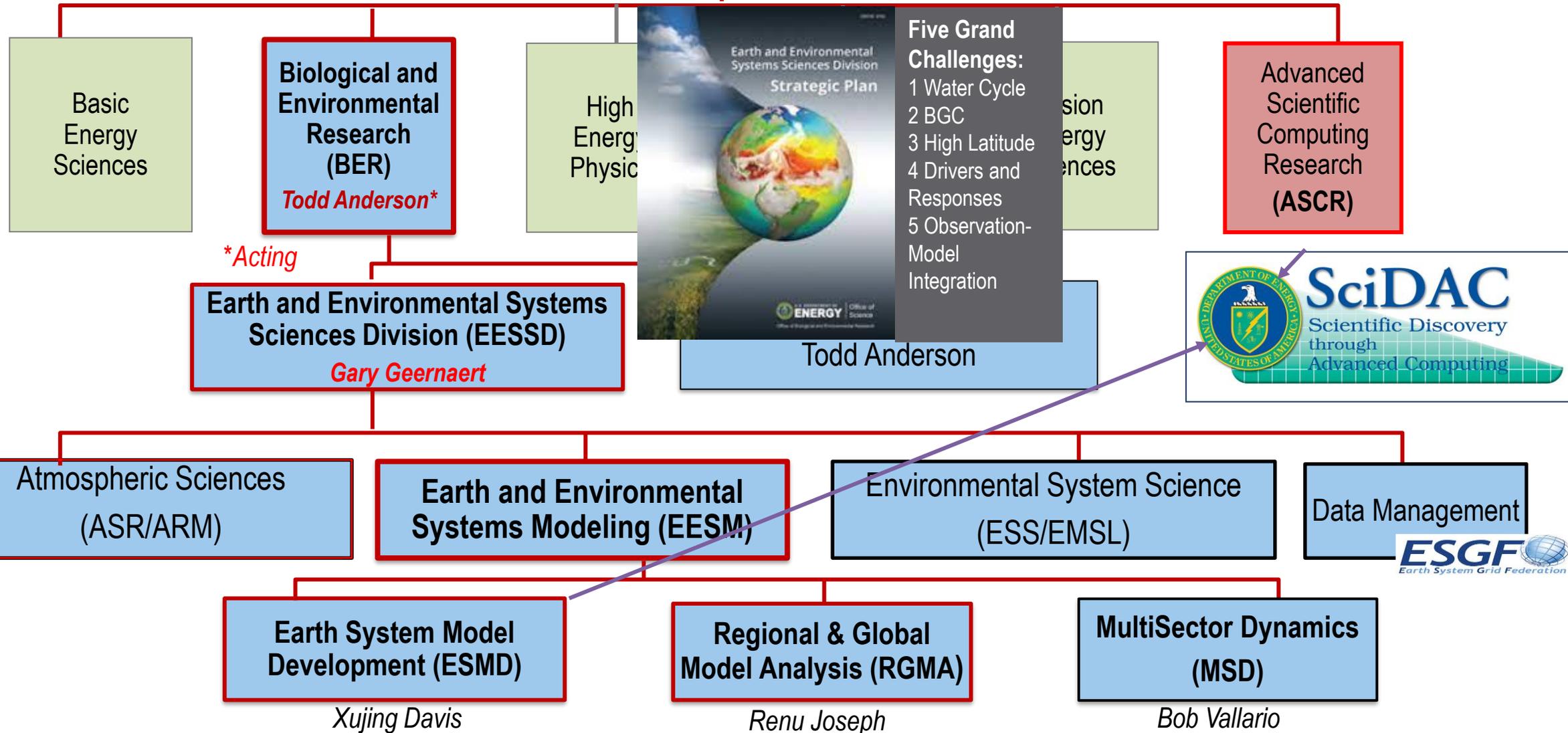
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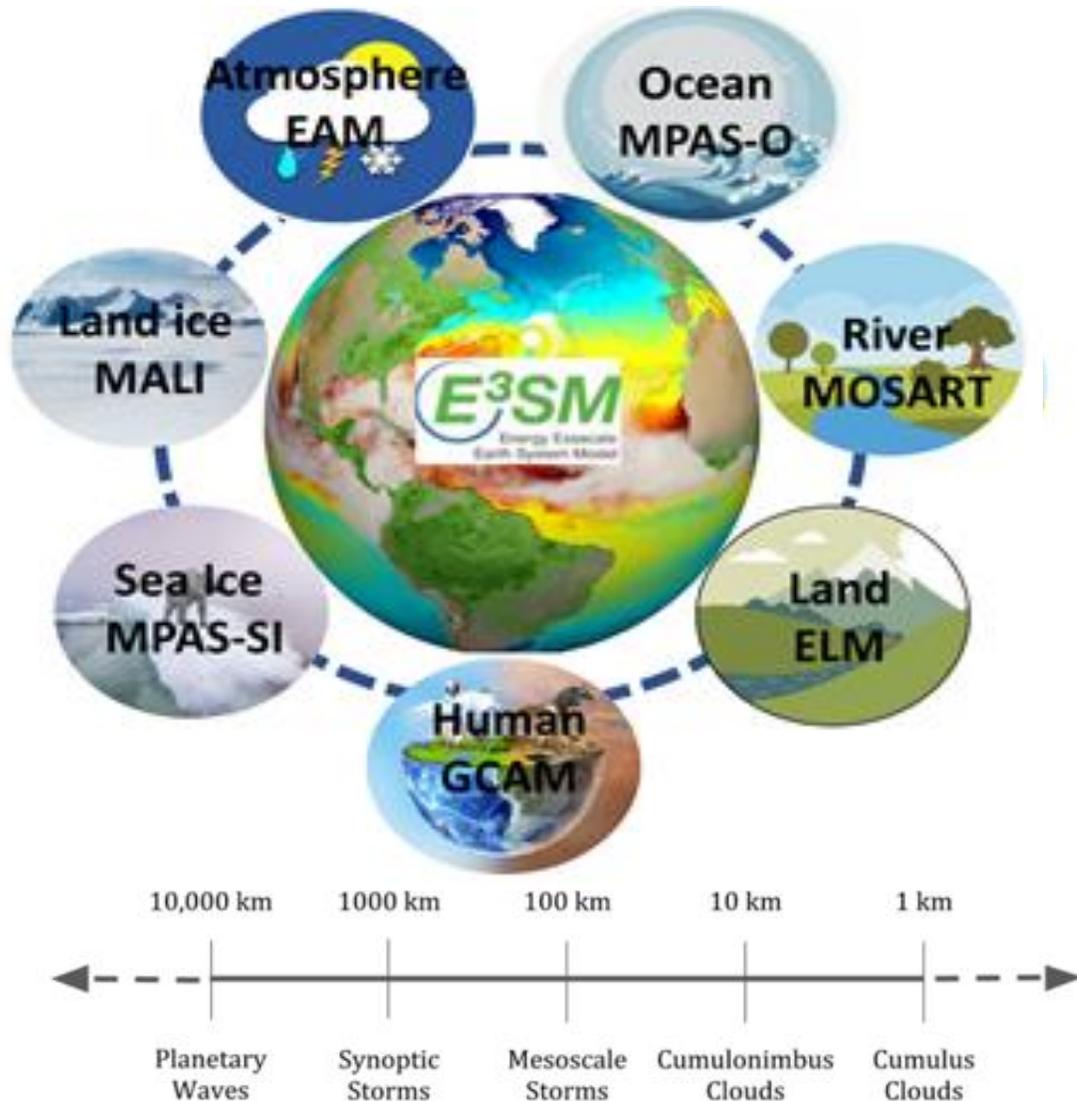


Earth System Model Development (ESMD)



Innovative and computationally advanced ESM capabilities, in support of Energy science and mission

Earth System Across Scales



Goal:

Develop Energy Exascale Earth System Model (E3SM) and its subcomponents, to address the grand challenge of actionable predictions of the changing Earth system, emphasizing on the most critical scientific questions facing the nation and DOE

Strategies:

- Science driver for model development
- Earth system across scales (high-resolution frontier, bridge gaps, quantify uncertainty via LE)
- Prepare for and overcome the disruptive transition to next era of computing, leverage ASCR HPC capabilities
- Innovative mathematical, computational methods, tools, algorithms (e.g., SciDAC)

EAM: E3SM Atmosphere Model; **ELM:** E3SM Land Model ; **GCAM:** Global Change Assessment Model; **MOSART:** Model for Scale Adaptive River Transport; **MPAS-SI:** Model for Prediction Across Scales (MPAS) – Sea Ice; **MPAS-O:** MPAS – Ocean; **MALI:** MPAS-Albany Land Ice Model.

E3SM Acronyms: <https://e3sm.org/resources/help/acronyms/>



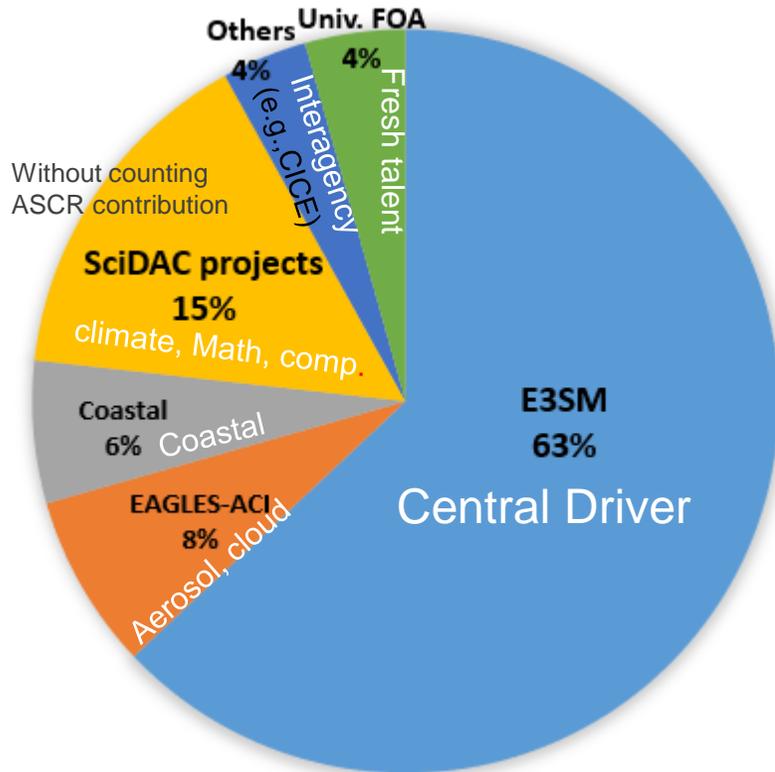


ESMD Portfolio in Support of E3SM



E3SM: An integrator of DOE earth, environmental, mathematical and computational sciences, in advancing ESM capability for DOE science mission.

FY 22 Budget Distribution



ESMD supported Projects:

- Funding instruments:
 - 1. Lab-led projects including Scientific Focus Area (SFAs, e.g., E3SM); 2. Scientific Discovery through Advanced Computing (SciDAC) Awards; 3. Univ. Awards and 4. Other projects: e.g., Early Career awards, Interagency activities (e.g, USGCRP, CICE Consortium...)
- E3SM SFA is the central driver of the E3SM development with focused scientific questions, well defined time frames, goals and strategies
- Other projects contribute to E3SM development in various ways on different time frames: e.g., SciDAC supports deep, necessary collaboration between BER and ASCR

Other close relevant EESSD and ASCR supported projects

- RGMA: PCMDI, RUBISCO, HYPERFACETS, WACCEM, HiLAT-RASM, CATALYST, CASCADE...
- MSD: GCIMS (GCAM), HYPERFACETS, IM3 ...
- ARM/ASR: Field Campaigns, THREADS, LASSO, ...
- ESS: NGEA-Arctic, NGEA-Tropic, SPRUCE, COMPASS-FME ...
- ASCR's Exascale Computing Project (ECP)

Note: Univ. scientists across ESMD projects

See detail about [ESMD Projects](#)

Year	FY17	FY18	FY19	FY20	FY21	FY22	FY23
ESMD (\$M)	35M	40M	44M	44M	44M	46M	49M

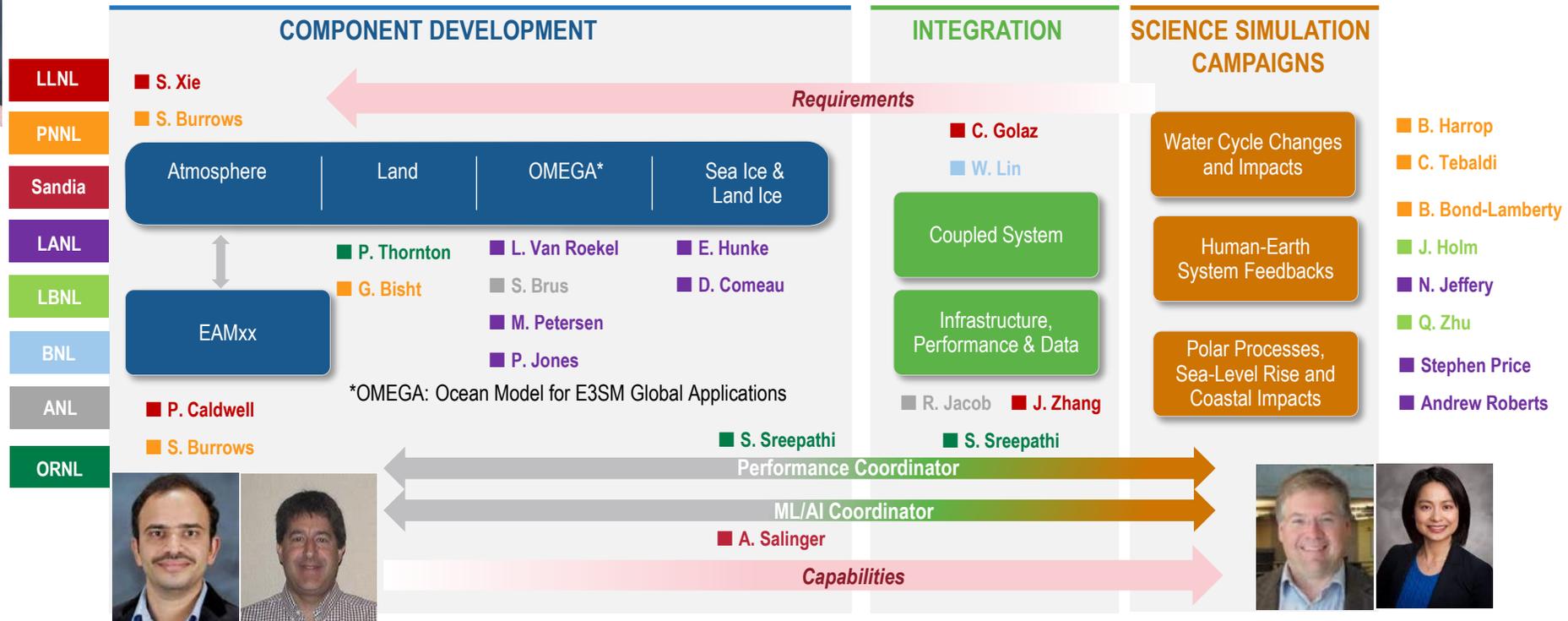
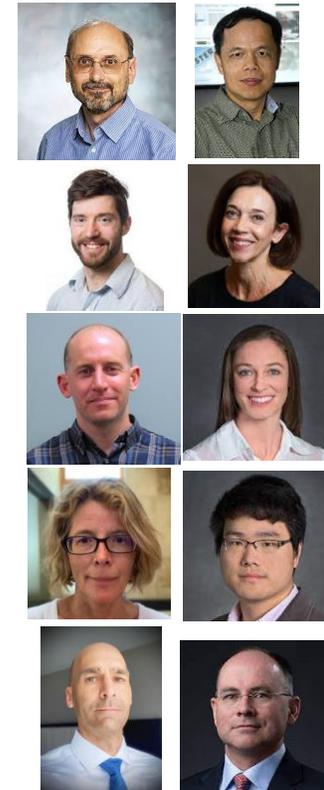
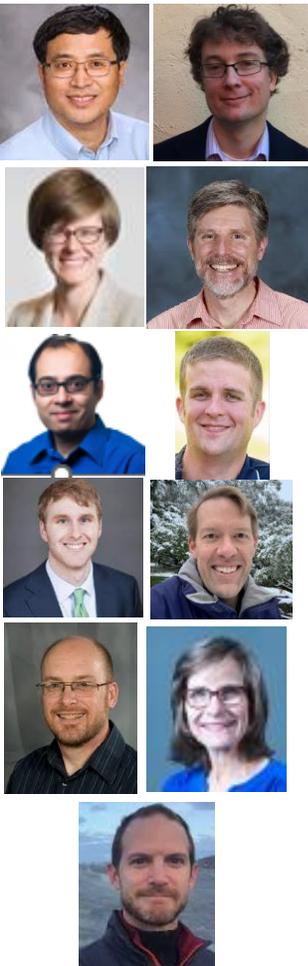


E3SM: a collaborative and integrative effort across 8 DOE labs and universities



E3SM Executive Committee

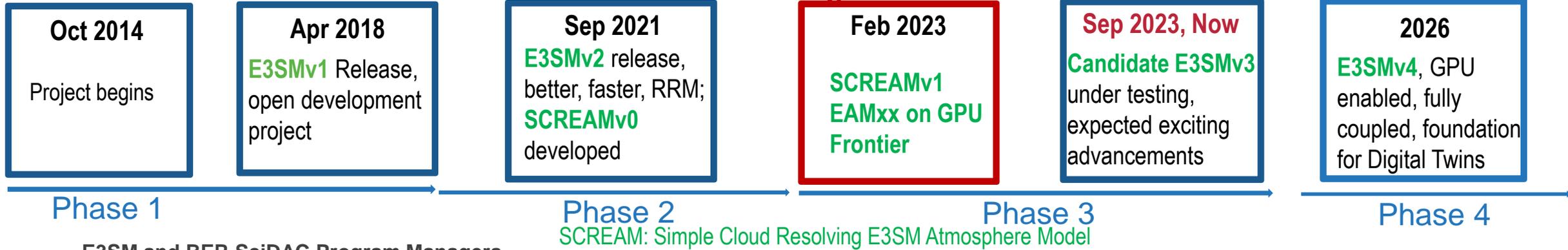
■ **David Bader**, Chair ■ **Ruby Leung**, Chief Scientist ■ **Mark Taylor**, Chief Computational Scientist ■ **Renata McCoy**, Project Engineer



E3SM Timeline and Major Achievements

Approaching its 10th year

Thanks to ECP for enabling early access to Frontier!
Realizing Exascale vision



E3SM and BER SciDAC Program Managers



Dorothy Koch
2014-2019



Sally McFarlane
2019-2020



Xujing Davis
2020-Present

ASCR SciDAC Program Managers



Randall Lavolette
2014-2022



Lali Chatterjee
2022-present

E3SM Unique Capabilities for Actionable Science:

- **Exascale Readiness:** developed the 1st benchmark of its kind by running ~3km global simulation SCREAM on Frontier with record setting performance, i.e., the 1st global cloud-resolving model (~3km) to simulate a world's year of climate in a day
- **RRM** – 1st ESM running fully coupled global simulations with RRM in all components (except river), completed climate production simulations
- **Coupled Earth-Human Feedback:** coupling with GCAM

E3SM is one of three finalists for 2023 Gordon Bell Prize Competition!

Phase 3: 2023-2025

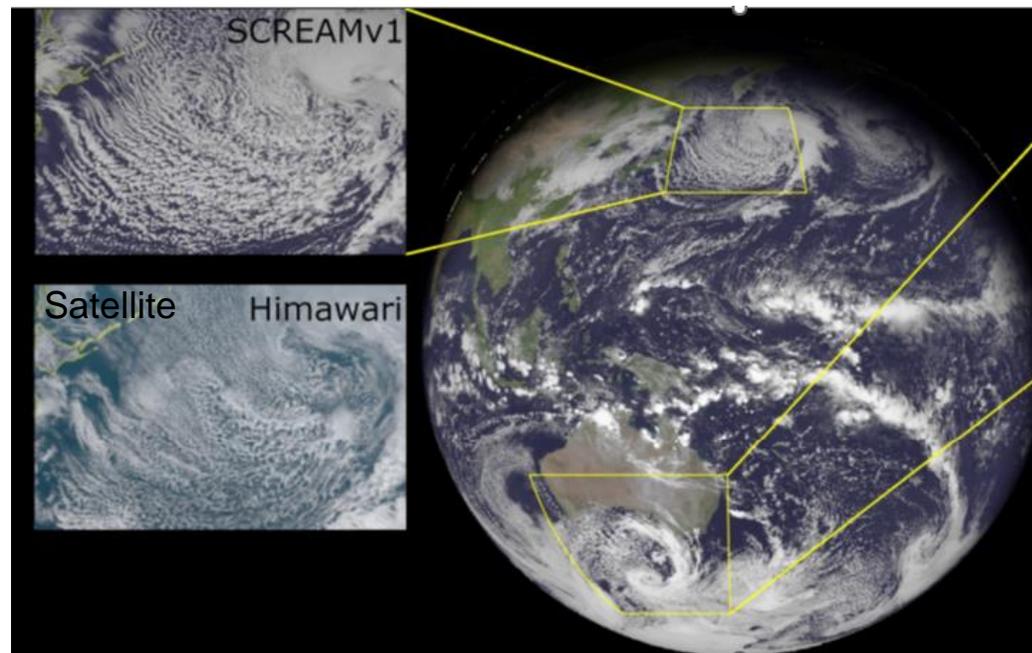
Many of our major simulation campaigns still using the Fortran code running on CPUs, but we have several new

GPU capabilities:

- ✓ **SCREAM v1** Cloud resolving simulations
- ✓ **Multiscale Modeling Framework (MMF)** (“super-parameterization”) coupled climate simulations
- ✓ **High-res Land** simulations
- ✓ **MALI** simulations of the entire Antarctic Ice Sheet using an RRM

Phase 4: 2026-2028

- ✓ **GPU: Full Earth System Model running efficiently on GPU**



SCREAMv1 exascale simulation of extreme events



Successes and Challenges for the Simple Cloud-Resolving E3SM Atmosphere Model

Speaker: Dr. Peter Caldwell
Laurence Livermore National Laboratory, US

Tuesday 12 September 2023
15:00-16:00 UTC



WCRP Digital Earths
Lighthouse Activity
Webinar Series



Impact:

1. Demonstrated that DOE is an international leader in km-scale climate modeling
2. Reached a group who may not have expected DOE in this role
3. Provides a foundation for future collaborations

Key Points Made:

1. SCREAM is the first climate model to beat 1 simulated year per wallday at <5 km resolution
2. This speed enables many novel upcoming simulations
3. SCREAM is excellent at capturing extreme weather events

SCREAM resonates in the race for the Gordon Bell Climate Prize

A look at America's next top model ... in fine resolution

 [Nicole Hemsoth Prickett](#)

Tue 19 Sep 2023 // 18:00 UTC

The Bell will toll for some of the more intense world's most powerful supercomputers s

The new Gordon Bell Prize for Climate M 10 years, starting in 2023, to acknowledge engineers in this domain.

Prize-winning submissions are expected science and its allied fields, the effects of supercomputers and parallel computing i

A team at the Lawrence Livermore National Department of Energy (DOE) national lab for the inaugural Association for Computi



HPC wire

See

Go

SC23 Spotlight: ACM Introduces First-Ever Gordon Bell Prize for Climate Modeling

September 20, 2023

Sept. 20, 2023 — In 2023, the Association for Computing Machinery will present its first-ever [ACM Gordon Bell Prize for Climate Modelling](#) during a [special ceremony](#) at SC23 this November in Denver. The award, which will be given annually for the next 10 years, aims to



- **Each component, each version of E3SM have benefited from SciDAC:** e.g., Dycores and tracer transport schemes in all components, biogeochemical capabilities in atm, ocean and land, coupling infrastructure
- **SciDAC has contributed to Earth System Modeling** since its start (CCSM/CESM, ACME to E3SM)

Examples:

- ✓ **Ice sheet modeling** (ISICLES, 2009-2011; PISCEES, 2012-2017; and ProSPect, 2017-2022; FAnSSIE, 2022-2027): a world-class ice sheet modeling capability from scratch; three new icesheet models being coupled to world-class Earth system models (CESM, E3SM, HadCM3)
- ✓ **Performance and algorithm:** coupling infrastructure, nonhydrostatic Dycore, HOMME, RRM and multi-scale approaches for the atmosphere, MPAS variable-resolution approaches for ocean; Semi Lagrangian transport, PhysGrid (with ECP),
- ✓ **Improved physics and accuracy:** error source identification, understanding and reduction; diagnostics tools, error analysis method

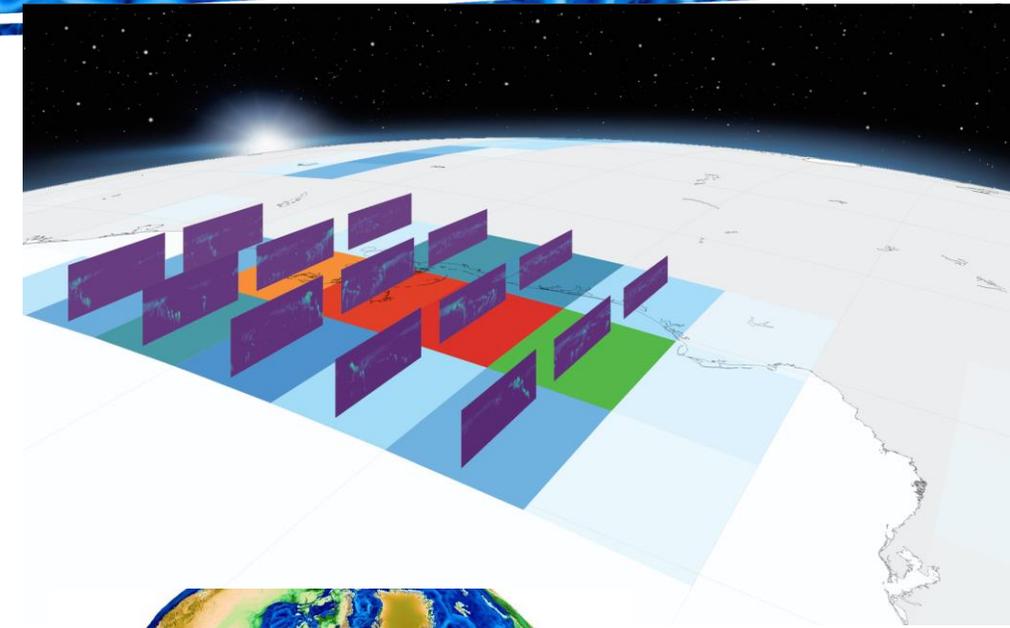
Thanks to input from PIs of previous phase SciDAC projects:

Phil Jones, Steve Price, Pete Bosler, Hui Wan, Gautam Bisht, Adrian Turner, Tak Yamaguchi, Lili Ju

ECP Contribution to E3SM

E3SM-MMF: Multiscale Modeling Framework

- **E3SM-MMF: New GPU enabled configuration of E3SM**
 - Multiscale approach incorporates cloud resolving “super” parameterizations. GPU performance achieves throughput necessary for long climate simulations
 - Completed long (100+ years) radiative balanced control simulations at standard resolution (100 km atmosphere)
 - **Exascale ready**: High resolution (25 km atmosphere coupled to eddy resolving ocean) running at > 5 SYPD on OLCF Frontier
- **Contributions to E3SM’s traditional configurations:**
 - C++ GPU port of RRTMGP
 - Performance improvements for new GPUs for SCREAM physics
 - OpenACC port of MPAS-Ocean
 - I/O improvements including new ADIOS I/O option
 - YAKL performance portability library (adopted by E3SM next-gen ocean/ice components)





E3SM, 1st major ESM pursuing Open Development, contributes to national and global endeavor in advancing Earth System Predictability.

E3SM Longer term goal:

Assert and maintain an international scientific leadership position in the development of Earth system models while addressing DOE mission

Opportunities and Challenges

- **E3SM:** major biases, new capabilities, transition to C++ (CPU to GPU), team retention & thriving
- **DOE:**
 - ✓ Strengthen the core (BER programs including **SciDAC partnership**)
 - ✓ Enhance the integration with other DOE programs (**ASCR, Earthshots ...**)
- **Coordination & Collaboration** OSTP/USGCRP, CLIVAR, WCRP, CMIP, IPCC
- **Science Community New initiatives:** ML/AI, Destination Earth (DestinE), Digital Twin, Earth Virtualization Engines (EVE), WCRP **ESMO**

What's E3SM like in 2033?

ASCR is essential in shaping future E3SM!

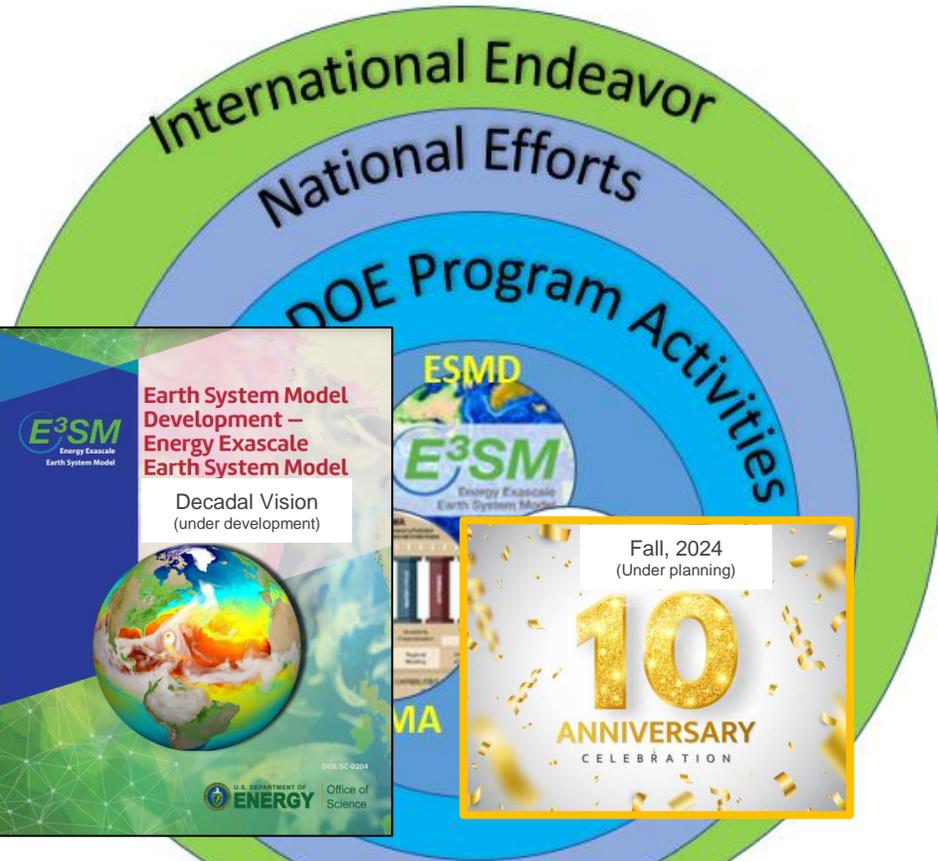
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Town Hall: E3SM: A decade of Earth System Modeling Effort at the Department of Energy

ASCR

- SciDAC Partnership, FASTMATH, RAPIDS
- Exascale Computing Project
- HPC user facilities: NERSC, ORNL and ANL Leadership Computing Facilities
- ALCC



BER:

- Leadership and EESSD PMs

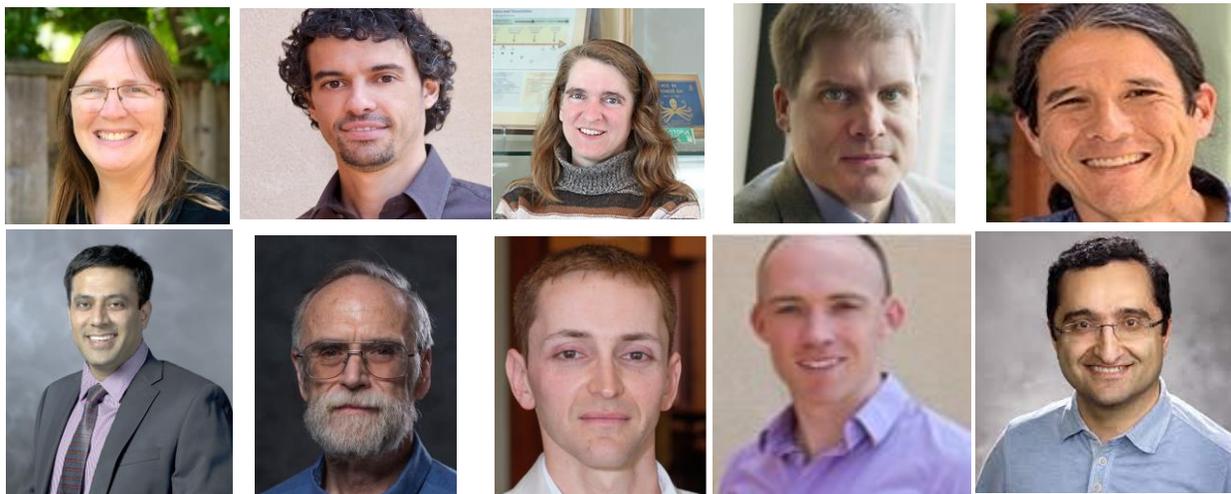


Thank you!

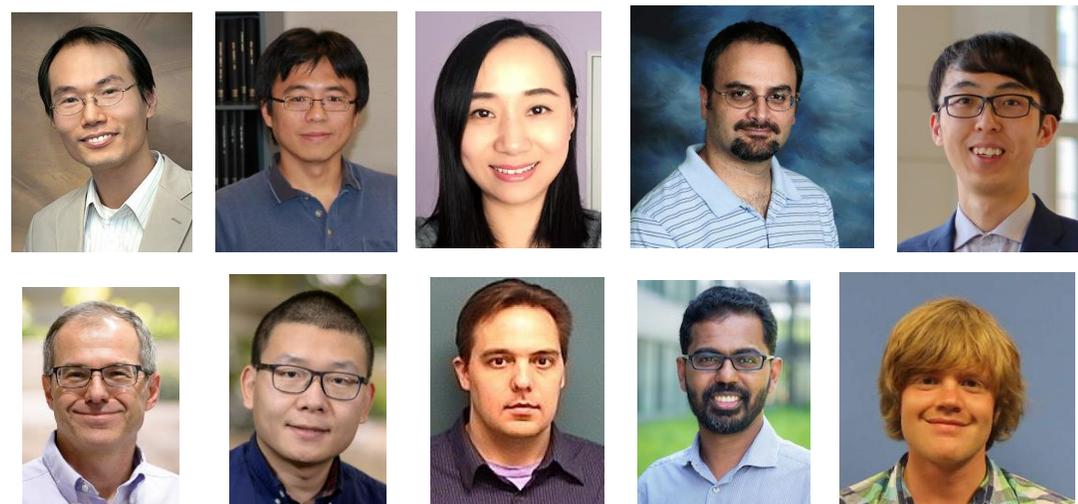
ASCR Scientists on BER SciDAC-5 projects



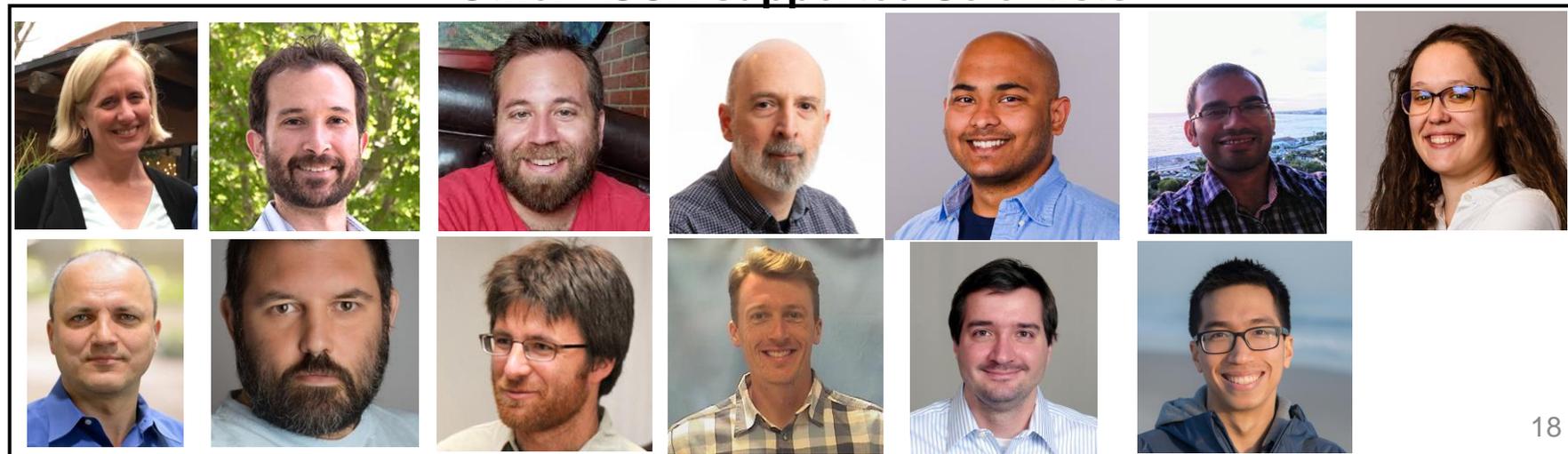
FASTMath Institute



RAPIDS2 Institute



Other ASCR supported Scientists





E3SM Resources



More about ESMD, E3SM: <https://climatemodeling.science.energy.gov/program-area/earth-system-model-development>; [ESMD-E3SM 2020 PI Meeting Report](#)

Earth and Environmental System Modeling (EESM) - <https://climatemodeling.science.energy.gov/>

E3SM code is open development (<https://github.com/E3SM-Project/>)

- One-stop shop: <https://e3sm.org>
- The model: <https://e3sm.org/model/running-e3sm/e3sm-quick-start/>
- The data: <https://e3sm.org/data/>
- Resources: <https://e3sm.org/resources/>
- Collaboration: <https://e3sm.org/about/collaboration/>

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