

Energy Exascale Earth System Model (E3SM) & ARM/ASR Synergies

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U.S. DEPARTMENT OF
ENERGY

Office of
Science





Earth System Model Development Program Area (ESMD)



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

Earth System Across Scales

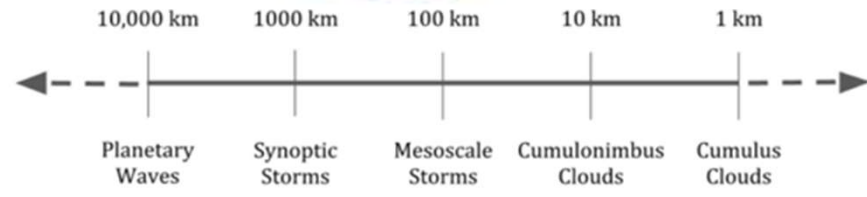


Goal: Develop Energy Exascale Earth System Model (E3SM) and its subcomponents, to address the grand challenges of actionable predictions of the changing Earth system, emphasizing on the most critical scientific questions facing the nation and DOE

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
- Integrate computational, mathematical innovation

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.



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

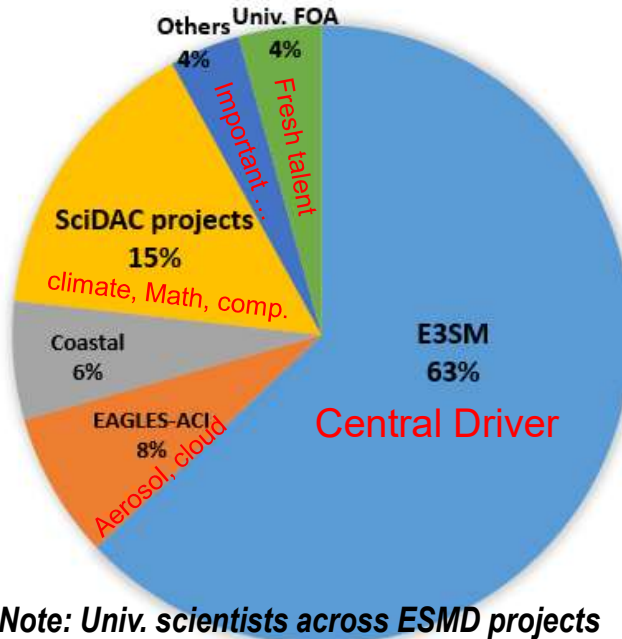




ESMD in Support of E3SM



FY 22 Budget Distribution



Note: Univ. scientists across ESMD projects

FY 23 Budget: \$49 M

See detail about [ESMD Projects](#)

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

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, CEDS, Interagency activities (e.g., IGIM/USCMS, CPTs ...)
- E3SM SFA is the central driver of the E3SM development with focused scientific questions, well defined time frames, goals and strategies (>100 scientists from 8 DOE labs and multiple universities)
- Advancement from other projects contribute to E3SM development in various ways on different time frames

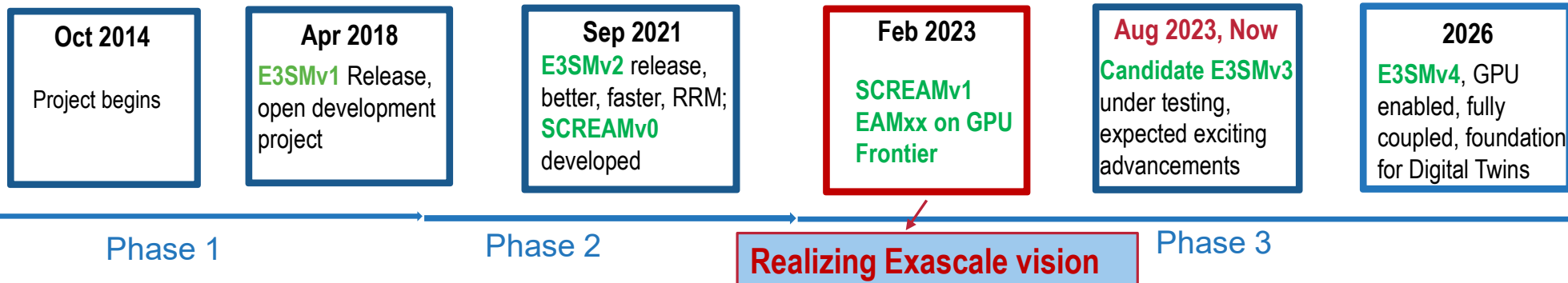
Other close relevant EESSD and ASCR supported projects

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



E3SM Timeline and Major Achievements

Approaching its 10th year



E3SM Unique Capabilities:

- Exascale Readiness: developed the 1st benchmark of this kind by running ~3km global simulation 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
- Coupled earth-human feedback: coupling with GCAM

P.S.: the 1st major ESM pursuing [open development](#)

E3SM configurations- Atmosphere Component:

- Standard, low res.: 100 km (E3SMv1, E3SMv2)
- High res., Regional refined (RRM): 25 km (E3SMv1, E3SMv2 NARRM)
 - Ultra high res. Atm. component: up to 500m (SCREAM, DP-SCREAM, SCREAM-RRM) ... and SCM
- for ASR scientists to study atmospheric processes and develop parameterizations.

ARM-E3SM Synergies

Theme 4: Accelerate and amplify the impact of ARM measurements on Earth system models by exploiting ARM and ESM frameworks to facilitate the application of ARM data to ESM development

ARM User Executive Committee

Enhancing Communication - Modeling/E3SM Subgroup



Susannah Burrows - Chair
Pacific Northwest
National Laboratory



Daniel Feldman
Lawrence Berkeley
National Laboratory



Scott Giangrande
Brookhaven
National Laboratory



Xiaohong Liu
Texas A&M
University



Christina McCluskey
National Center for
Atmospheric Research



Yunyan Zhang
Lawrence Livermore
National Laboratory

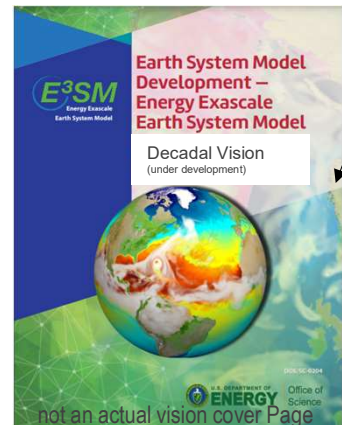
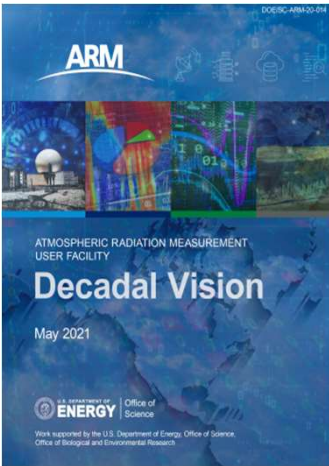
Subgroup discussion, 2022: opportunities for synergies between ARM and E3SM (e.g., use of ARM data in E3SM-diags, and use of E3SM's RRM and DP-SCREAM).

E3SM Decadal Vision is under development, with ARM vision as an important reference

ARM Modeling Outreach and Communication Plan focus on E3SM, 2023: ARM data for both high-res and low-res E3SM evaluations, ARM case library for E3SM-SCM and DP-SCREAM



Such efforts are very much appreciated and encouraged! ARM's new translator vision plan eight authors: Scott Giangrande, Jennifer Comstock, Scott Collis, John Shilling; (bottom row, from left) Krista Gaustad, Ken Kehoe, Shaocheng Xie, and Damao Zhang.



ARM

Data



ASR

Atmospheric
System Research

Process Knowledge
& Parameterization

Model

- **Model Validation & Testing:** e.g., Diagnostic packages - E3SM diagnostics is integrating ARM diagnostics, ARM case library with forcing and evaluation data for E3SM-SCM and DP-SCREAM, EAGLES designed 4 testbeds around ARM sites to cover a wide range of conditions of aerosol, cloud and meteorological factors; E3SM feedbacks on critical data and analysis tools needed could inform ARM campaigns
- **ASR Process Knowledge & Parameterization Improvement:** e.g., clouds, aerosols, convection, and precipitation, E3SM SCM/DP-SCREAM for ASR scientists to study atmospheric processes and develop parameterizations ... Several ASR scientists (e.g., Xiaohong Liu and Guang Zhang) are also major E3SM developers for atmospheric physics;
- **Bridging Scales:** THREAD bridges scales via DP-SCREAM; EAGLES leverages LASSO capabilities to generate new LES data containing detailed information about aerosol-cloud interactions
- **Model-Data Integration:** e.g., 1 of 5 grand challenges in EESSD, essential for AI4ESP, Digital Twins, ASR THREAD (E3SM and ARM),

Delving into Earth's Systems Today to Support the Solutions of Tomorrow

The following column by Asmeret Asefaw Berhe, Director of the Office of Science at the U.S. Department of Energy was published on the [Office of Science website](#) on April 21, 2023.



Office of Science's leadership in Earth system science observations and modeling

An important part of dealing with the climate crisis is measuring and documenting the past and potential effects of climate change. The Office of Science has a long-standing role as a leader in [atmospheric systems research](#) and Earth systems modeling.

Our Biological and Environmental Research program manages the [ARM user facility](#), which has been collecting long-term climate data for more than 30 years. Scientists using ARM instruments have helped fill in major gaps in our knowledge, from the [Green Ocean \(GO\)-Amazon experiment](#) to the [MOSAiC expedition](#) in the Arctic. Our researchers have also played an essential role in examining how ecosystems will respond to climate change. In our [SPRUCE experiment](#), researchers have been collecting data since 2015 on how heating and increases in carbon dioxide affect a northern Minnesota bog.

This data has led to huge improvements in climate models, including the development of the Energy Exascale Earth System Model (E3SM). This advanced simulation of the Earth can help us project how ecosystems will react to climate change and how that can affect energy production and use. Last year, scientists launched a [new global atmosphere model](#) for E3SM that has a 30 times finer resolution than the previous one. It allows scientists to study the atmosphere with far more detail than before. Previous studies have shown that higher resolution allows researchers to [better predict tropical cyclones](#).

Our computing facilities have also enabled these modeling capabilities. E3SM is designed to run on exascale computers, like Frontier at the Oak Ridge Leadership Computing Facility DOE Office of Science user facility. These supercomputers also make it possible to incorporate new types of data into Earth systems models.



Opportunities and Challenges



E3SM contributes to national and global endeavor in advancing Earth System Predictability while addressing the DOE mission

E3SM Longer term goal:

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

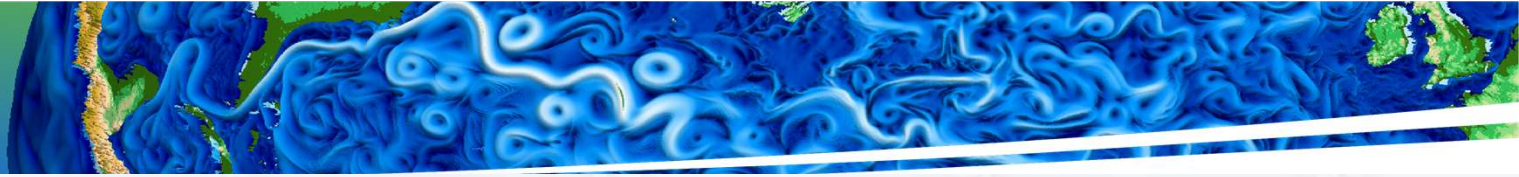
Opportunities and Challenges

- **E3SM:** major biases, new capabilities, transition to C++, team retention & thriving
- **DOE:**
 - ✓ Strengthen the core (ESMD and with RGMA, MSD, DM)
 - ✓ Enhance the integration with DOE programs (EESSD programs, SciDAC, ECP, Earthshots ...)
- **Coordination & Collaboration** USGCRP (e.g., IGIM), IARPC, USCLIVAR (e.g., CPTs), 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?





Teşekkür ederim Aitäh Je vous remercie Дзякуй Dziękuję Ci Dėkuji
Dank je Ευχαριστώ Ацiу КТХДР Tak ارڪشش
Дякую Danke Tack Gracias Gratias tibi
Хвала вам Hvala Kiitos Paldies Спасибо Takk skal du ha
Multumesc Obrigado Grazie 고맙습니다
ありがとうございました 謝謝

Thank You!



ESMD, E3SM and Resources



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

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/>

Latest News, Research Highlights

- E3SM Quarterly Newsletter Archives: <https://e3sm.org/about/news/newsletter-archive/>
- Subscribe to quarterly E3SM Newsletter by emailing to LISTSERV@LISTSERV.LLNL.GOV with body: 'subscribe E3SM-news' (subject line is ignored)

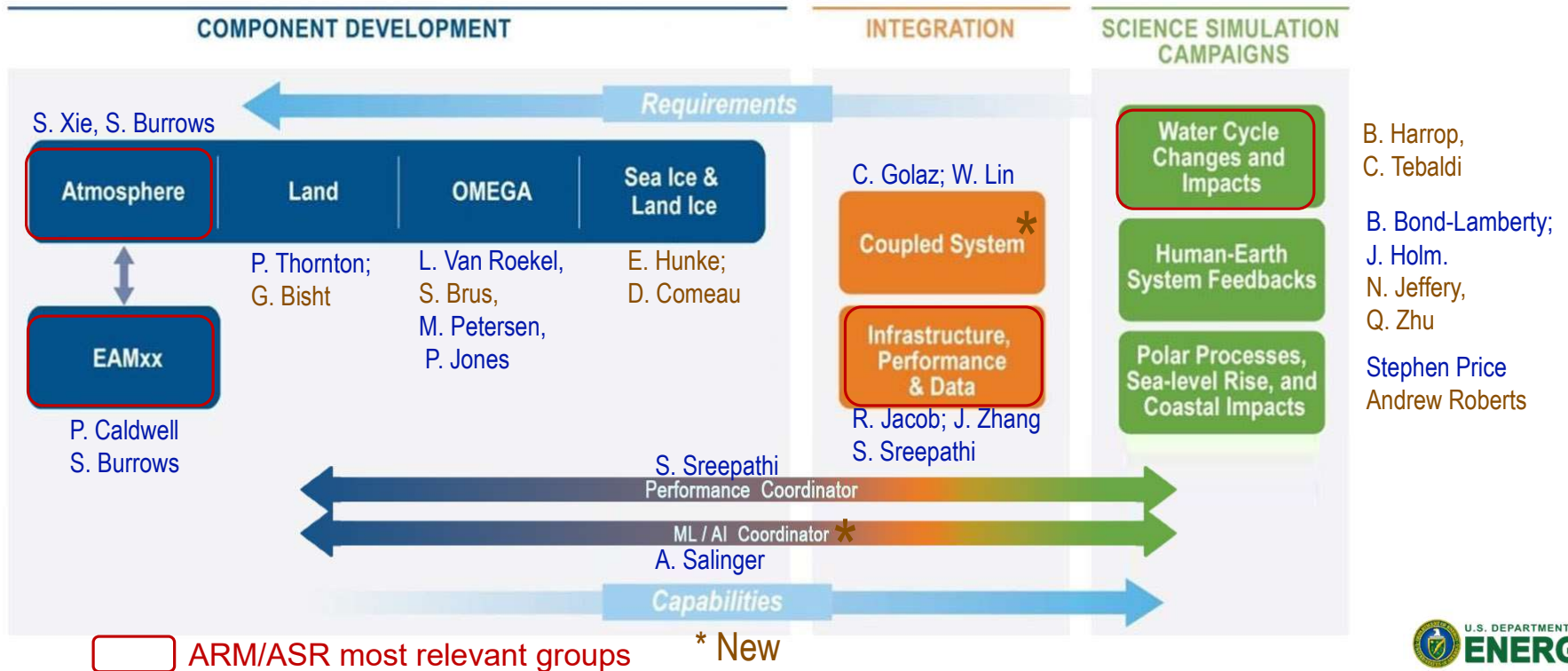
- BER Funding Opportunities- <https://science.osti.gov/ber/Funding-Opportunities>
- Earth and Environmental System Modeling (EESM) - <https://climatemodeling.science.energy.gov/>
- Annual Office of Science Graduate Student Research (SCGSR) Program - <https://science.osti.gov/wdts/scgsr>
- Annual Early Career Research Program: <https://science.osti.gov/early-career>



Phase 3 Structure & Leadership Team

E3SM Executive Committee Council

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



National

- **USGCRP: IGIM US Climate Modeling Summit (USCMS), GEWEX, NCA5:** *D. Bader, R. Leung, P. Thornton*
- **NASEM Digital Twin Workshop:** *R. Leung, M. Taylor*
- **US CLIVAR :** *R. Leung*
- **OSTP ICAMS Subcommittee on Earth System Modeling and Prediction(ESM&P) Implementation Teams:**
M. Taylor, R. Jacob, C. Golaz, P. Jones, A. Donahue, O. Guba
- **CESM Advisory Committee:** *E. Hunke, M. Taylor*

International

- **CICE Consortium:** *E. Hunke, A. Roberts*
- **International CLIVAR:** *L. Van Roekel*
- **International Workshop on Coupling Technologies for ESMs:** *R. Jacob*
- **WCRP GEWEX Global Atmospheric System Studies Panel (GASS) annual meeting:** *S. Xie*
- Association for **Computing Machinery (ACM) and the Swiss National Supercomputing Centre:** *O. Guba*

➤ **E3SM Phase 3 Review, Nov 22:** “...E3SM *poised to* push the frontiers of actionable climate science, *uniquely positioned* for international groundbreaking leadership in computationally advanced Earth system modeling, *contributed significantly to* climate modeling community ... “