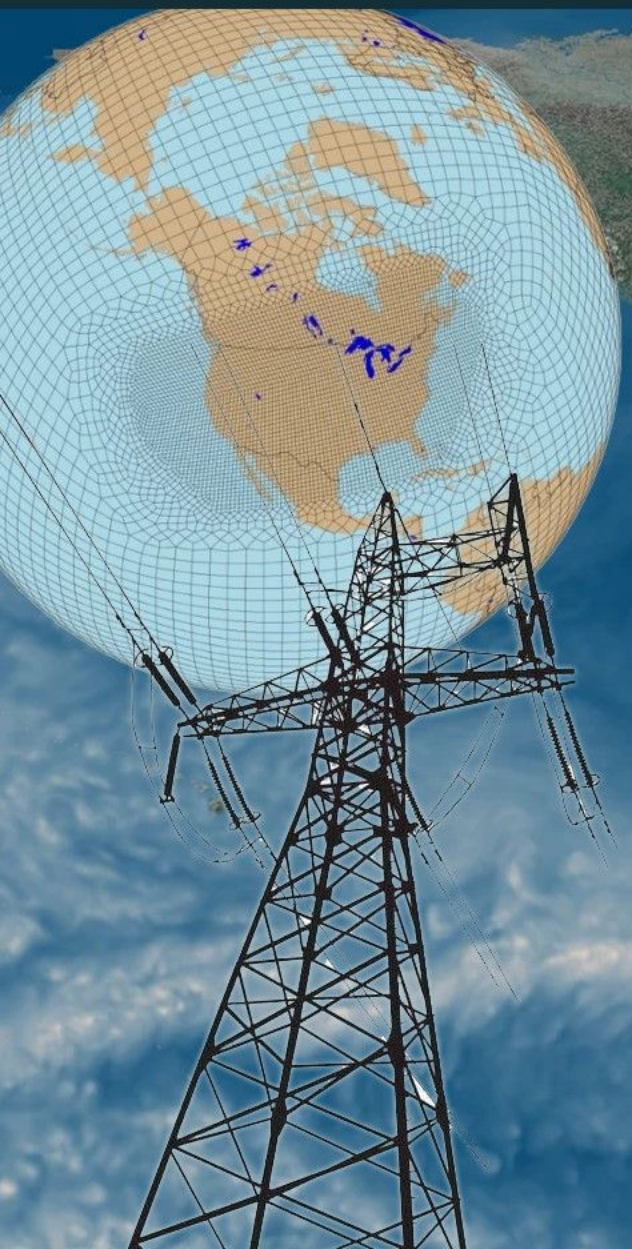
U.S. DEPARTMENT OF ENERGY

Earth and Environmental Systems Modeling



Earth System Model Development (ESMD) Overview

Xujing Jia Davis
Earth and Environmental Systems Modeling (EESM)
Earth and Environmental Systems Sciences Division (EESSD)

Rockville, MD
August 6th 2024

EESM
EARTH & ENVIRONMENTAL SYSTEMS MODELING

U.S. DEPARTMENT OF ENERGY | Office of Science

*Nation's **largest** federal sponsor of basic research in the physical sciences*

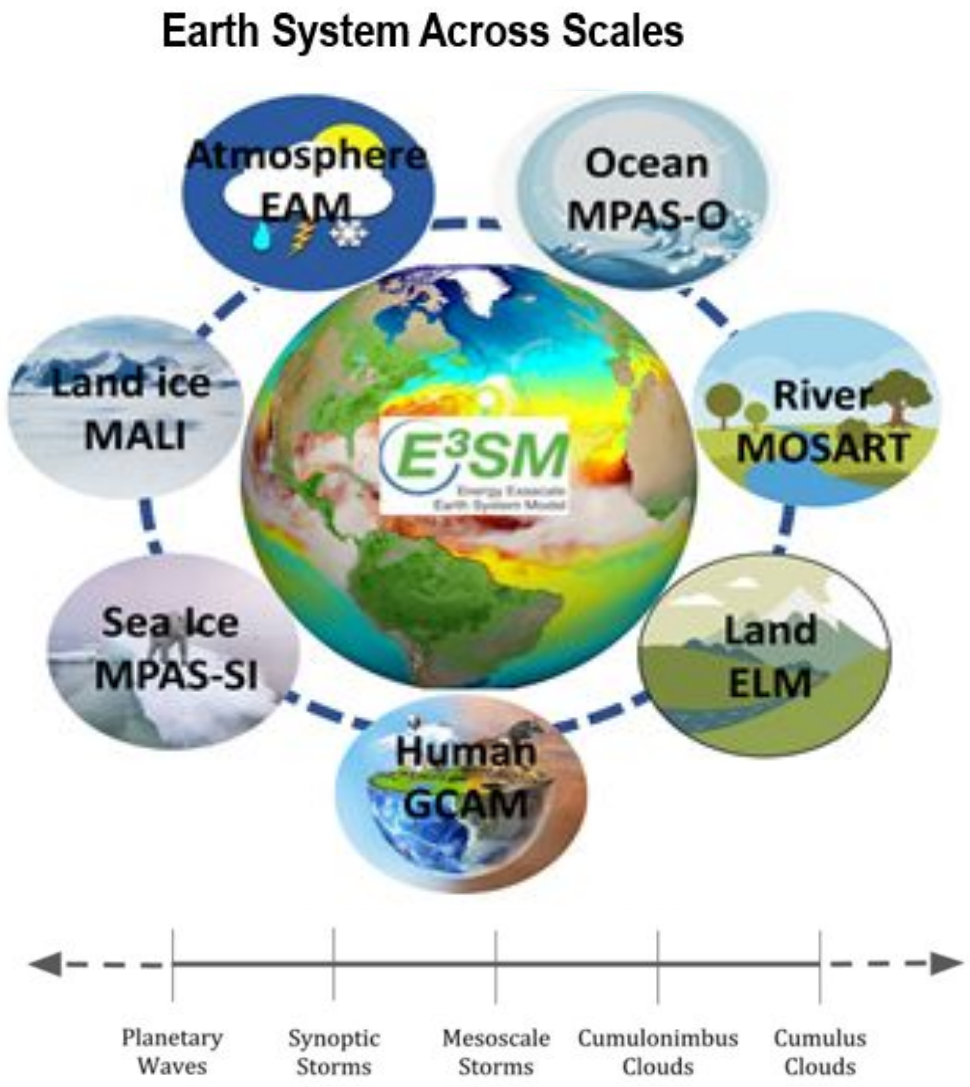
- Basic Energy Sciences
- **Biological and Environmental Research (BER)** — *Dorothy Koch*
  - **Earth and Environmental Systems Sciences Division (EESSD)** — *Gary Geernaert*
    - Atmospheric Sciences (ASR/ARM)
    - **Earth and Environmental Systems Modeling (EESM)**
      - **Earth System Model Development (ESMD)** — *Xujing Davis*
      - **Regional & Global Model Analysis (RGMA)** — *Renu Joseph*
      - **MultiSector Dynamics (MSD)** — *Bob Vallario*
    - Environmental System Science (ESS/EMSL)
    - Data Management
  - **Biological System Sciences** — Todd Anderson
- High Energy Physics
- Nuclear Physics
- Fusion Energy Sciences
- **Advanced Scientific Computing Research (ASCR)**

SciDAC — Scientific Discovery through Advanced Computing

ESGF — Earth System Grid Federation

ESMD in Support of E3SM

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



Goal: *Support the development of E3SM including 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 drivers 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 DOE/ASCR HPC capabilities
- Innovative mathematical, computational methods, tools, algorithms, technologies (e.g., ML/AI)

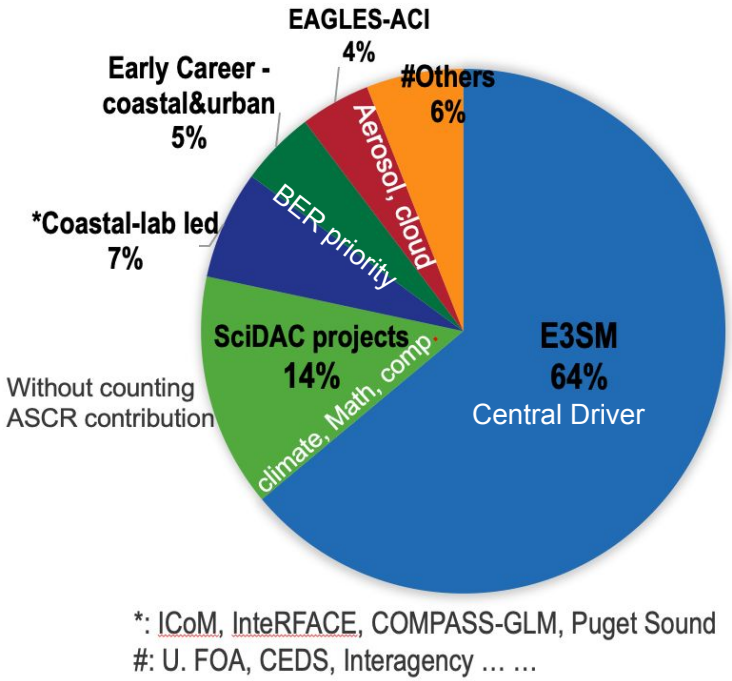
EAM: E3SM Atmosphere Model; **ELM:** E3SM Land Model **; GCAM:** Global Change Assessment Model; **MOSART:** Model for Scale Adaptive River Transport; **MPAS-SI:** Model for Prediction Across Scales (MPAS) – Sea Ice; **MPAS-O:** MPAS – Ocean; **MALI:** MPAS-Albany Land Ice Model.

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

ESMD 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 23 Budget Distribution



*: ICoM, InteRFACE, COMPASS-GLM, Puget Sound
#: U. FOA, CEDS, Interagency … …

Note: Univ. scientists across ESMD projects

See detail about ESMD Projects

FY 23: $49 M

ESMD Funding Instruments:

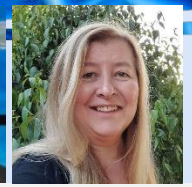
- **1. Lab-led projects** including Scientific Focus Area (**SFAs**, e.g., **E3SM**); **2.** Scientific Discovery through Advanced Computing (**SciDAC**) Awards; **3. Early Career Awards** and **4.** Other projects: e.g., **U. FOA**, Interagency activities (e.g, USGCRP/IGIM, USCLIVAR CPTs, CICE Consortium…)
- **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

E3SM: Cross Laboratory Initiative in Earth System Modeling

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

E3SM Leadership Team: Cross Laboratory Initiative

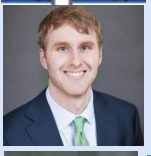
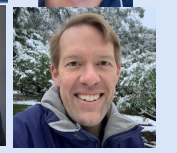




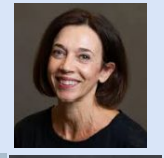


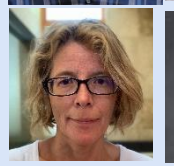


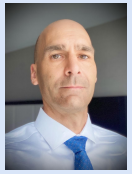












E3SM Executive Committee

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

LLNL
PNNL
Sandia
LANL
LBNL
BNL
ANL
ORNL

COMPONENT DEVELOPMENT

■ S. Xie
■ S. Burrows

Requirements

Atmosphere	Land	OMEGA*	Sea Ice & Land Ice
	■ P. Thornton ■ G. Bisht	■ L. Van Roekel ■ S. Brus ■ M. Petersen ■ P. Jones	■ E. Hunke ■ D. Comeau

EAMxx

■ P. Caldwell
■ S. Burrows

*OMEGA: Ocean Model for E3SM Global Applications

INTEGRATION

■ C. Golaz
■ W. Lin

Coupled System

Infrastructure, Performance & Data

■ R. Jacob
■ J. Zhang

Performance Coordinator
■ S. Sreepathi

ML/AI Coordinator
■ A. Salinger

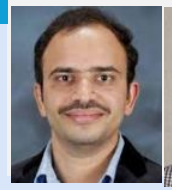
Capabilities

SCIENCE SIMULATION CAMPAIGNS

Water Cycle Changes and Impacts
■ B. Harrop
■ C. Tebaldi

Human-Earth System Feedbacks
■ B. Bond-Lamberty
■ J. Holm
■ N. Jeffery
■ Q. Zhu

Polar Processes, Sea-Level Rise and Coastal Impacts
■ Stephen Price
■ Andrew Roberts




Earth system science  Computational science

E3SM overview and Update:
Plenary on Tue, Wed & All Breakout sessions

ESMD Portfolio: BER-ASCR SciDAC Partnership Projects

Program Managers: Xujing Davis (BER) and Lali Chatterjee (ASCR) $70M from 2022-2027




PI	Insti.	Title	Topic	Other Insti.	SciDAC Inst.
Benedict, Jim	LANL	Improving the Quasi-biennial oscillation (QBO) through surrogate-accelerated parameter optimization and vertical grid modification	Atmosphere Variation	LLNL,SNL, NCAR	FASTMath
Wan, Hui	PNNL	Physical, Accurate, and Efficient Atmosphere and Surface Coupling Across Scales	Coupling numerics	SNL, LBNL, LLNL, BNL, RPI, UCSD, U. Wsic, U. of Arizona, Kitware Inc	FASTMath, RAPIDS
Van Roekel, Luke	LANL	Improving Projections of AMOC and its Collapse Through advanced Simulations (ImPACTS)	Ocean Circulation	ANL, ORNL, BNL, OSU, SIO, UT Austin, NCAR	RAPIDS
Hetland, Robert	PNNL	MPAS-O/ROMS Comparison, Nesting, and Coupling for Improved Representation and Parameterization of Coastal and Submesoscale Ocean Processes in E3SM	Coastal and Open ocean	ANL, LANL,LBNL, U. of Washington	FASTMath
Sulsky, Deborah	U. of New Mexico	Improved Coupled Climate Simulations in E3SM Through Enhanced Sea-Ice Mechanics	Sea ice mechanics	LANL,SNL, RPI, CSU	FASTMath
Bisht, Gautam	PNNL	Capturing the Dynamics of Compound Flooding in E3SM^	River Dycore	LANL, LBNL, U. of Alabama, U. of Buffalo, UC Boulder, Cohere Consulting LLC	FASTMath
Hoffman, Matt	LANL	Framework for Antarctic System Science in E3SM	Antarctic Ice Sheet	SNL, LBNL, BNL, RPI, U. of Michigan, UCI	FASTMath RAPIDS



Capabilities from SciDAC Institutes: ML/AI, Structured Mesh, Unstructured Mesh, Time Integration, Linear/Nonlinear Solvers, Optimization, UQ, Surrogate modeling … to tackle **major challenges of E3SM**

Project overview and Update:
Plenary on Thu & Breakout sessions

ESMD Portfolio: Other Lab and University Projects

Lab Projects


EAGLES


ICoM*


InteRFACE*


InteRFACE*


COMPASS-GLM*


COMPASS-GLM*

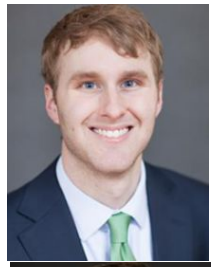

Puget Sound*

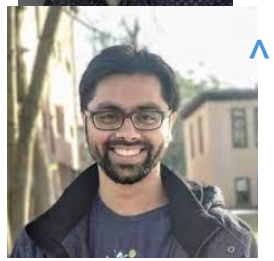

CEDS

* With RGMA and MSD

Plenary & Breakout sessions

Early Career Awards

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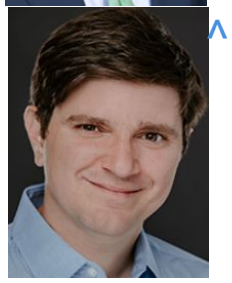
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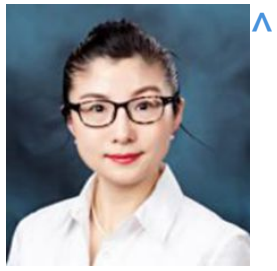

^

Coastal and Urban Modeling

^ With RGMA

Plenary on Friday

University Awards


^ +
Marine BGC


Radiation


Atm Dycore


Ocean, Sea ice


&
PPE

& With RGMA & ASR

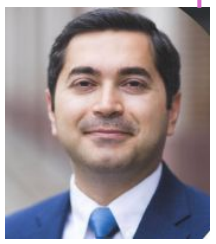

^ +
Extreme Events


Wildfire


Radiation


Clouds

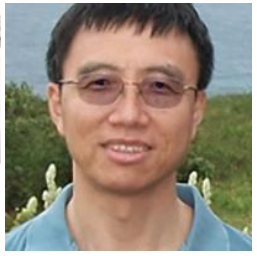

Coastal


+
Snow, Drought


+
Marine BGC


Microphysics


Microphysics

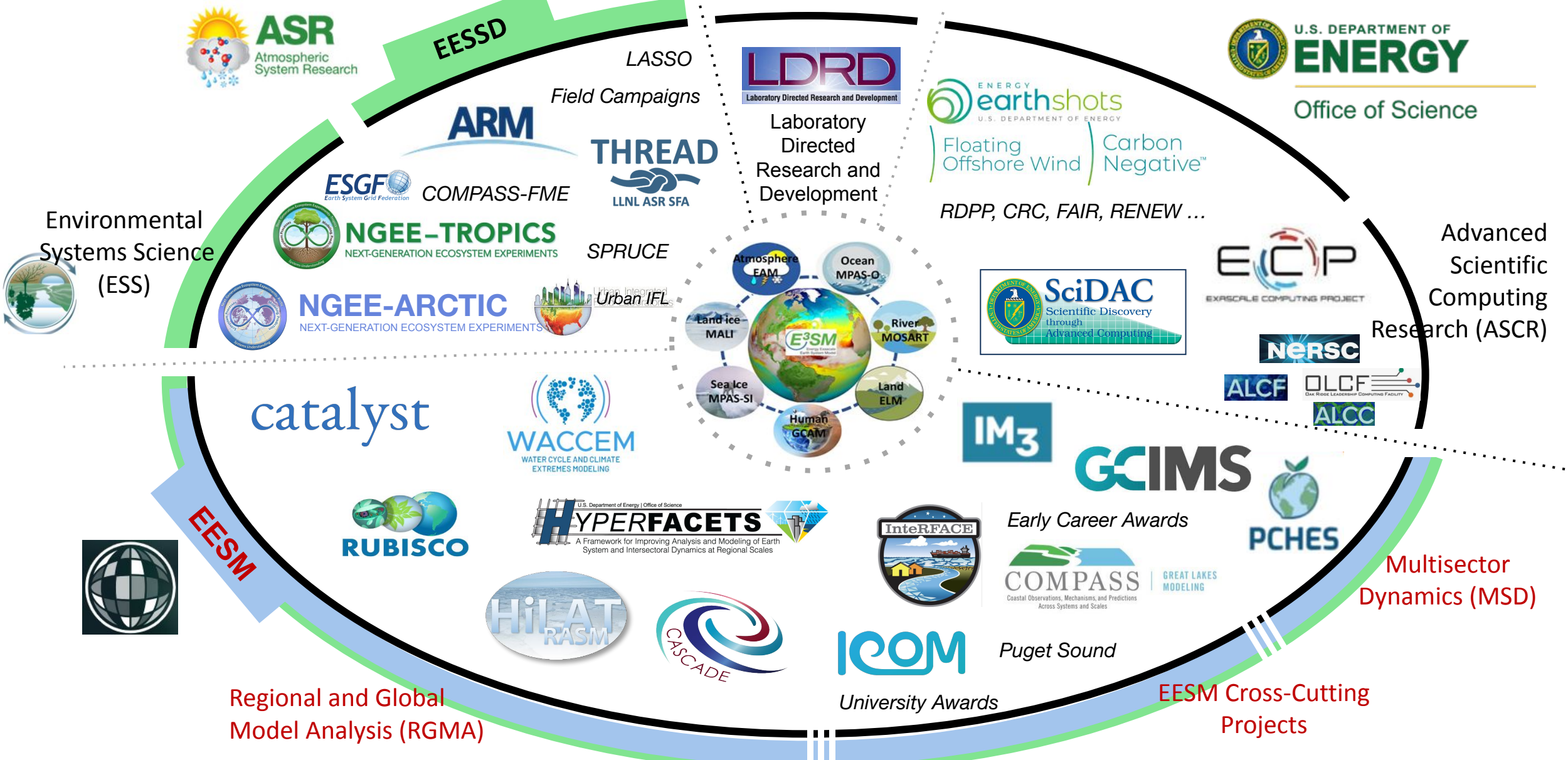

Precipitation

+ new awards
^ with RGMA

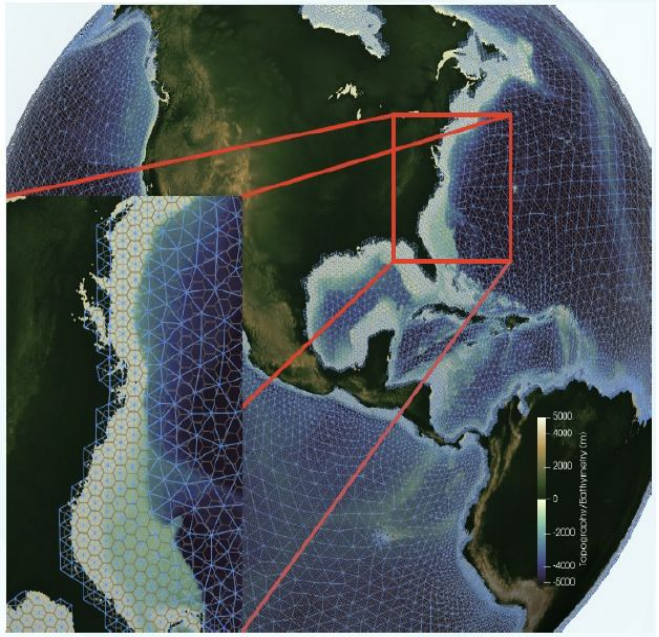
Breakout sessions

E3SM in its Ecosystem: Foundational Capabilities and an Integrator

Earth System Model



E3SM Coastal Capabilities - Integrated Efforts of EESM Efforts



A new, unstructured wave modeling mesh capability for Wavewatch III with new algorithm for perfect overlap of the ocean and wave meshes near the coast (inset) to ensure accurate transmission of fluxes between components.

E3SM is the first ESM to run coupled global simulations with an unstructured wave component.

Efforts from E3SM, InteRFACE and ICoM, HiLAT-RASM and other projects:

Ocean

- Addition of a wave model
- Implemented sea state dependent fluxes (so the waves can influence the fluxes between components)
- Explicit barotropic oceanic tides in E3SM

River

- A network-based MOSART river-routing capability to couple with the Advanced Terrestrial Simulator for detailed permafrost hydrology.
- Developed and tested MOSART-Urban routing model for a single watershed;
- Riverine inputs to the Arctic basin

BGC (Ocean, Land)

- A column prototype of seafloor sediment biogeochemistry being implemented in MPAS-Ocean.
- Representation of unique vegetation and biogeochemistry characteristics of coastal tidal wetlands and Great Lakes wetlands in the E3SM Land Model (ELM), with coupling to advanced redox chemistry in PFLOTRAN.

Polar

- Arctic coastline, island, and critical passage resolution (using RRM capabilities), all Arctic shipping channels are now open in E3SM V2 and daily navigability output is standard across all E3SM
- Sea ice, atmos., ocean coupling; sea ice ridging in models; sea ice and ocean BGC
- Snow on sea ice (important to energy balance, surface ponding)

Coupling

- Two-way land-river-ocean coupling, new unified mesh for land-river-ocean coupled runs aligns mesh elements with streams, creates smooth river-ocean transition

Science Community Leadership and Service

National

- **USGCRP**: **IGIM** US Climate Modeling Summit (USCMS), **GEWEX**: *D. Bader, R. Leung*
- **NASEM Digital Twin** Workshop: *R. Leung, M. Taylor*
- **NCA5:** *R. Leung, P. Thornton, C. Tebaldi, P. Ullrich*
- **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 Chair: *E. Hunke, M. Taylor*
- *CESM* Atmosphere Model Working Group co-chair: *Hui Wan*

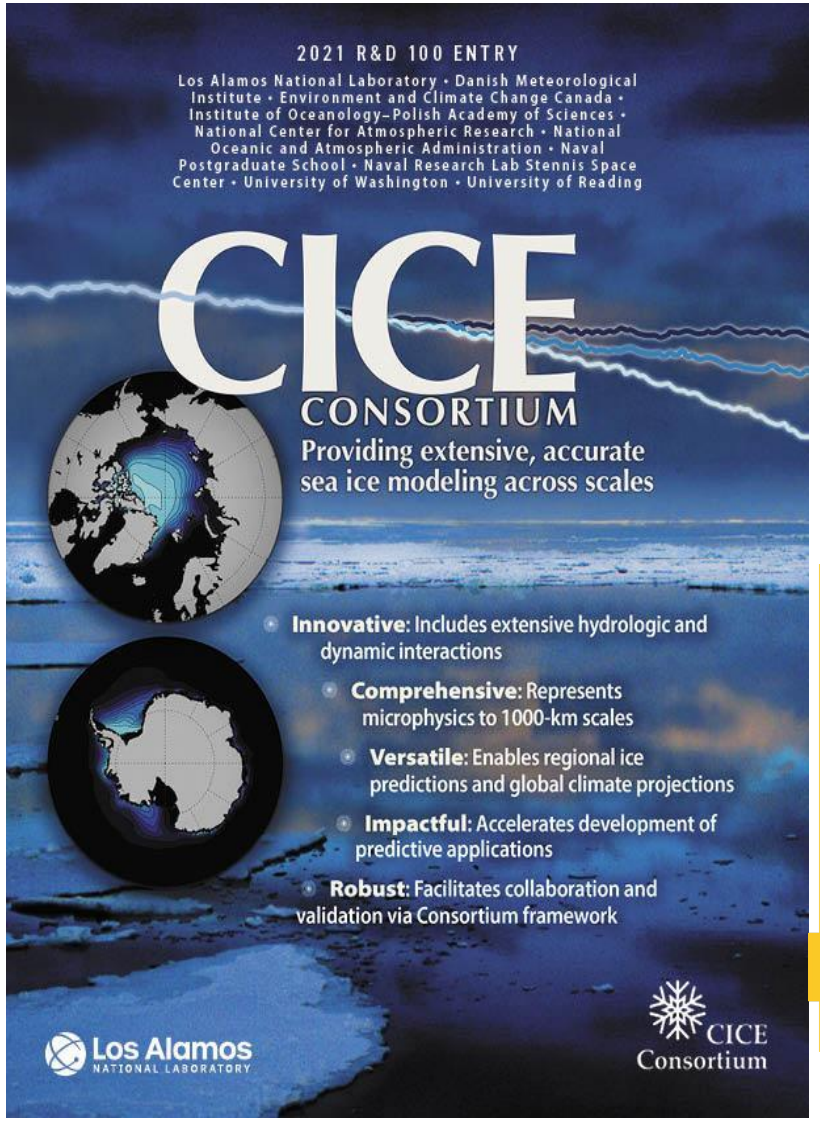
International

- **CICE Consortium**: *E. Hunke, A. Roberts*
- **International CLIVAR**: *L. Van Roekel*
- **International Workshop on Coupling Technologies for ESMs**: *R. Jacob*
- ***WCRP: GEWEX, GPEX****: Xubin Zeng;* ***ESMO/WGNE****: S. Sreepathi;* **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 contributes to national and global endeavor in advancing Earth System Predictability while addressing the DOE mission

CICE Consortium

- A multi-agency and international cooperation to enhance software and modeling capabilities



Goal: to enhance sea ice model development for and by the community by

- Acceleration of scientific development
- Acceleration of R&D transfer to operational use
- Vehicle for collaboration and sharing

Product: a computational model that represents changes to sea ice and its interactions with the polar environment and ecosystems.

Originally developed for use in DOE's climate simulations, CICE is now the most widely used sea ice model in the CMIP. Of the 138 CMIP6 simulation experiments by institutions, CICE was used in 47 (34%).

2021 R&D 100 WINNER

A R&D World's top 100 innovation awardee for 2021 and the Gold Medal for Corporate Social Responsibility winner!

Highlighted in a new book by Dr. Jeanne M. Fair entitled "Scientific Collaboration: Strategies for Successful Research Teams", 2023.

DMI Danish Meteorological Institute

Environment and Climate Change Canada

E3SM Major Timelines and Achievements

E3SM is at its 10th year!

Realizing Exascale vision

Oct 2014
Project begins

Apr 2018
E3SMv1 Release, open development project

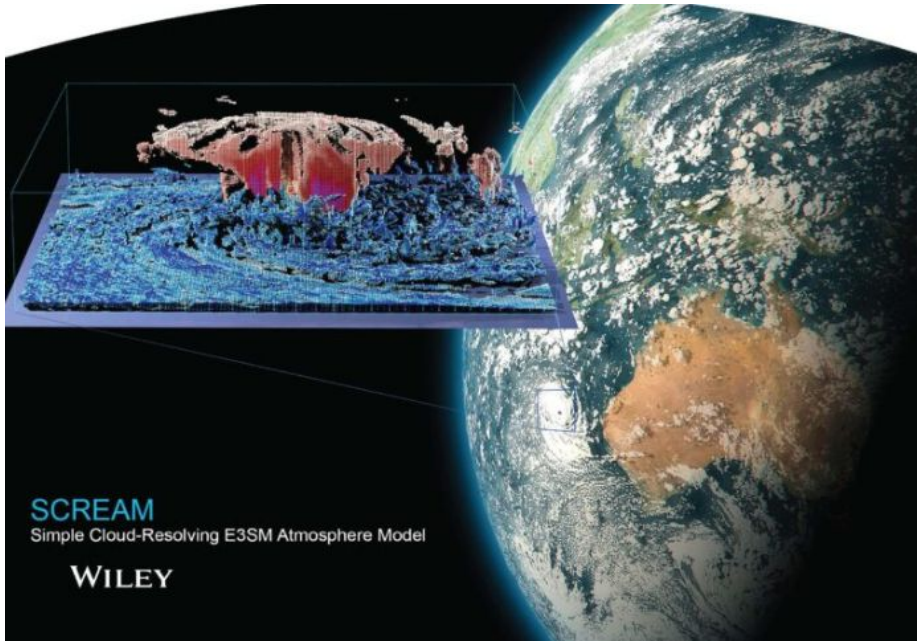
Sep 2021
E3SMv2 release, better, faster, RRM; **SCREAMv0** developed

Feb 2023
SCREAMv1
EAMxx on GPU Frontier

Mar 2024
E3SMv3 tagged, exciting advancements

2027
E3SMv4, GPU enabled, fully coupled, foundation for Digital Twins

Phase 1 — *Phase 2* — *Phase 3* — *Phase 4*



Nov 2023: E3SM SCREAM wins Inaugural Gordon Bell - Climate Modeling Prize!

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, completed climate production simulations
- **Coupled Earth-Human Feedback**: An operational, fully coupled human systems model (GCAM + E3SM's ELM + EAM)

Inaugural Gordon Bell - Climate Modeling Prize

The Register

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 interesting
world's most powerful supercomputers starting th

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

Prize-winning submissions are expected to, amor
science and its allied fields, the effects of climate
supercomputers and parallel computing in addres

A team at the Lawrence Livermore National Labo
Department of Energy (DOE) national laboratorie
for the inaugural Association for Computing Machinery (ACM) Gordon Bell prize.

Three Finalists:

- The winner: submission by US DOE's E3SM on Frontier supercomputer
- Finalist: submission by Japan on Fugaku
- Finalist: submission by China on Sunway

News Coverage

Official ACM announcement:
https://awards.acm.org/bell-climate

HPC Trade news coverage:
https://www.hpcwire.com/2023/11/21/scream-wins-gordon-bell-climate-prize-at-sc23/
https://insidehpc.com/2023/11/llnl-led-scream-team-clinches-inaugural-gordon-bell-prize-for-climate-modeling/
https://www.theregister.com/2023/09/19/gordon_bell_climate_llnl/
https://datacenternews.asia/story/climate-researchers-triumph-in-inaugural-acm-gordon-bell-prize-for-climate-modelling
https://datacentrenews.uk/story/climate-researchers-triumph-in-inaugural-acm-gordon-bell-prize-for-climate-modelling

News compiler coverage:
https://www.miragenews.com/scream-wins-gordon-bell-climate-prize-at-sc23-1127725/
https://newsbeezer.com/zimbabwe/climate-scientists-win-the-first-acm-gordon-bell-prize-for-climate-modeling/

Local papers:
https://newmexicosun.com/stories/652470714-sandia-climate-model-wins-gordon-bell-prize

Lab highlights:
https://www.anl.gov/article/argonne-teams-climate-modeling-work-wins-gordon-bell-prize-highest-honor-in-high-performance
https://www.olcf.ornl.gov/2023/11/16/cloud-simulations-on-frontier-awarded-gordon-bell-special-prize-for-climate-modeling/
https://cs.lbl.gov/news-media/news/2023/perlmutter-played-key-role-in-two-2023-gordon-bell-prize-winning-projects/
https://www.llnl.gov/article/50341/llnl-scientists-among-finalists-new-gordon-bell-climate-modeling-award
https://newsreleases.sandia.gov/gordon-bell-prize/

University highlights:
https://math.unm.edu/news-events/news/alumna-oksana-guba-part-snl-lead-winning-team-first-acm-gordon-bell-prize-climate

Inaugural Gordon Bell - Climate Modeling Prize

Significance

- 1st global cloud-resolving model to run on an exascale supercomputer
- 1st model to break the 1SYPD barrier for cloud-resolving simulations at <5km
- 1st to run on both AMD and NVIDIA GPUs, as well as conventional CPUs.
- 1st WCRP Digital Earths Lighthouse Webinar
- Demonstrated that **DOE is an international leader** in km-scale climate modeling

Science Impacts

✔ SCREAM is **excellent at capturing extreme weather events**, as good as WRF in case studies

✔ This speed enables **many novel upcoming simulations**: DYAMOND, 4 season, CESS-Porter 13 months, and decadal simulations

✔ Serve as **an important reference for next-generation ESM** efforts, with profound scientific and societal impacts for many years to come

Celebrating a Decade of Progress

Events and

- ❑ *2023 AGU: **E3SM Town Hall: A decade of Earth System Modeling Effort at the Department of Energy**, Dec 2023*
- ❑ *1st ever **Hands-on E3SM Tutorial** , May 2024*
- ❑ *2024 AGU: **E3SM 10 Year Symposium**, Dec 8th, 2024*
- ❑ *A new **AGU E3SM Special Collection**, ongoing*
- ❑ *2024 **E3SM Newsletters Decadal Series**: Special articles, Fun Facts*
- ❑ ***New Decadal Strategic Plan**! – Under Development*

Others:

- ❑ *New E3SM Video, Gordon bell Video, E3SM Brochure, flyer, sticker, swag …*

Opportunities and Challenges

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

E3SM Long Term Goal:
Assert and maintain an international scientific leadership position in the development of Earth system models while addressing DOE mission

Challenges

- Major biases, new capabilities, transition to C++ (CPU to GPU), team retention & thriving, AI strategies … …

Opportunities

- ✔ ***Strengthen the core*** (EESM, EESSD, BER programs including SciDAC partnership)
- ✔ ***Enhance the integration*** *with other DOE programs* (ASCR, Earthshots …)
- ***Coordination & Collaboration*** OSTP/USGCRP, CLIVAR, ICAMS, IARPC, WCRP, CMIP, IPCC, private industries … …
- ***Science Community New initiatives***: ML/AI, Destination Earth (DestinE), Digital Twin, Earth Virtualization Engines (EVE), WCRP ESMO … …

What's E3SM like in 2034?

2nd Decade: ESMD Portfolio Outlook (2024-2034)

Assert and maintain leadership position nationally and internationally with unique capabilities tailored to DOE mission need

Evolving BER Priorities

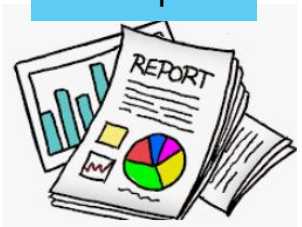
EESSD Strategic Plan (2024-2029)

- SciDAC5 Partnership (2022-2027)
- Coastal, Urban Early Career Awards (2023-2028)
- EESM Coastal projects Phase 2 (2024-2028)?
- Early Career (FY26, 29) & U. FOAs (FY26, 28)

EESSD Strategic Plan (2030-2034)

- *SciDAC6 Partnership (2028-2033)*
- Early Career (FY32, 35), & U. FOAs (FY30, 32,34)
- EESM Coastal projects Phase 3 ?
- Current and future ESM bottlenecks, emerging priorities, technologies, opportunities, EESM Framework

Your Input!



Strategic Investment

E3SM7+ versions

2nd decade: 2024-2033

2027
E3SMv4, GPU enabled, fully coupled, foundation for Digital Twins

Phase 4: *(tentative)*
White Paper: Spring 2025/6
Full proposal: Summer 2025/6
Review: Fall 2025/6

Decadal Plan ready for Phase 4 Proposal

2030/31
E3SMv5
?

Phase 5:
White Paper: TBD
Full proposal: TBD
Review: TBD, 2029

2033/34
E3SMv6
?

Realizing New Decadal Vision (?)

Phase 3 (2023-2026) → Phase 4 (2027-2030) → Phase 5 (2030-2033)

***E3SM Advances** in*:
1. ?
2. ?
3. ?
… …

*E3SM new **Decadal Strategic Plan***


Teşekkür ederim
Dank je
Aitäh
Je vous remercie
Ευχαριστώ
Ačiū
קנאדא
Дзякуй
Tak
Dziękuję Ci
Děkuji
Дякую
اركش
Danke
Gratias tibi
Tack
Takk skal du ha
Gracias
Thank You!
謝謝
Хвала вам
Спасибо
Hvala
Paldies
Kiitos
Grazie
Obrigado
Mulțumesc
고맙습니다
ありがとうございました
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ESMD Weblinks – program and major projects

ESMD: ESMD-E3SM 2020 PI Meeting Report;
https://climatemodeling.science.energy.gov/program-area/earth-system-model-development

E3SM: one stop shop: https://e3sm.org

E3SM code is open development:
https://github.com/E3SM-Project/

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)

SciDAC Partnership Projects:
https://www.scidac.gov/partnerships/bio-env-research.html
EAGLES: Enabling Aerosol-cloud interactions at GLobal convection-permitting scalES
Early Career Awards (coastal, coastal-urban)
ESMD co-funded Earth and Environmental Systems Sciences Division Coastal projects:
Integrated Coastal Modeling (**ICoM**): https://icom.pnnl.gov/
Coastal Observations, Mechanisms, and Predictions Across Systems and Scales (**COMPASS**) Great Lakes Modeling(GLM) Project:
https://compass.pnnl.gov/GLM/COMPASSGLM
Interdisciplinary Research for Arctic Coastal Environments (**InteRFACE**) project: https://arcticinterface.org/

See full list of ESMD projects here

What happened last year:

ESMD/E3SM Update Since Last August

- SCREAM– *Inaugural Gordon Bell Prize for Climate Modeling*
- GCAM coupling made good progress, see webinar
- E3SMv2 RRM, DP-SCREAM, SCREAMv1 papers published
- Data from E3SMv1 high res, E3SMv2.0, E3SMv2-RRM, v1 &v2 Large Ensembles (LENS, collab with RGMA) released
- Library of (RRM) Grids created
- V3 tagged
- E3SM-ECP effort on SCREAM Autotuning

Science

- E3SM Public Video released
- NCA5 contribution
- CICE Consortium, highlighted in a new book "Scientific Collaboration: Strategies for Successful Research Teams".
- Continued interagency activates via USGCRP, USCLIVAR, IARPC, ICAMS … …

Other

- EESM: 6 EESM Early Career Research Awards on coastal-urban; Current EESM FOA on BGC, Cloud, CDA
- 3 relevant SC Energy Earthshot awards – 2 offshore wind and 1 carbon removal
- Growing use of E3SM in EESSD, e.g., THREAD project
- LDRD science applications – wind, solar energy, grid, climate & health, security projects using E3SM, E3SM emulators … …

Ecosystem

- Return of the Dorothy Koch to BER
- SciDAC PI meeting, Sep 2023 and July, 2024
- E3SM Leadership Meeting, Nov 2023
- AGU E3SM Town Hall
- 1st ever hands-on E3SM Tutorial
- 10 year AGU Symposium is under planning

Events