ARCTIC MODELING

CLIMATE CHANGE AND ARCTIC SYSTEMS

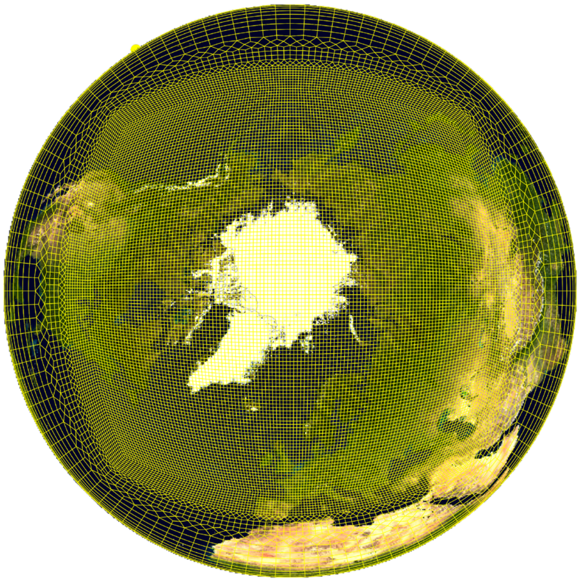
The Arctic's climate is changing at an unprecedented rate, with warming much faster than in the rest of the world resulting in the disappearance of multi-year sea ice and land-ice, permafrost thaw, and changing ecosystems. These environmental changes can impact many interconnected social systems, including infrastructure, security, economy, governance, and technology development. Informed policy and decision-making within this rapidly evolving system is rooted in a robust and quantitative assessment of these anticipated environmental changes.

ARCTIC MODELING CAPABILITIES

Sandia National Laboratories' scientists work with members of the Department of Energy (DOE) labs and university partners to develop and improve regional Arctic and Earth System models. Improved models can provide stakeholders with projections, such as the probability of regional temperature or precipitation changes, which can then be applied to anticipate energy consumption demands, security concerns, infrastructure risks, and other community or sector-specific concerns.

Sandia's Arctic modeling efforts build on our expertise in modeling, high performance computing, and climate measurements to improve our understanding of complex natural processes. Our nuclear weapons stockpile stewardship role also supports uncertainty quantification, data management and fusion, and verification and validation protocol development. Examples of Sandia's contributions to Arctic modeling include:

- **Ice sheet and sea-ice dynamics** – Sandia is developing two models, Albany Land-Ice for ice-sheet dynamics and the Discrete Element Model for Sea Ice (DEMSI) for sea-ice dynamics, for performance portability on next-generation computing architectures. Albany Land-Ice simulates the evolution and mass loss of polar ice sheets to better account for sea-level rise, while DEMSI advances the treatment of sea-ice deformation in response to ocean and atmospheric forcing to increase accuracy of sea-ice loss projections.
- **Atmospheric dynamics** – The High-Order Methods Modeling Environment (HOMME) code was developed by Sandia to model atmospheric dynamics with variable resolution atmospheric meshes. These high-resolution meshes can resolve critical physics and meteorological phenomena like Arctic storms, which disperse heat and water across the globe, making them an essential component of the Earth's weather system.
- **Arctic Coastal Erosion (ACE) Model** – Developed in partnership with the University of Alaska Fairbanks, Integral Consulting, University of Texas at Austin, and the United States Geological Survey (USGS), the ACE model consists of oceanographic and atmospheric boundary



Regional Refined Model (RRM) meshes of the Arctic can help predict the timing, amount, and cycles of rain that impact society and the economy.

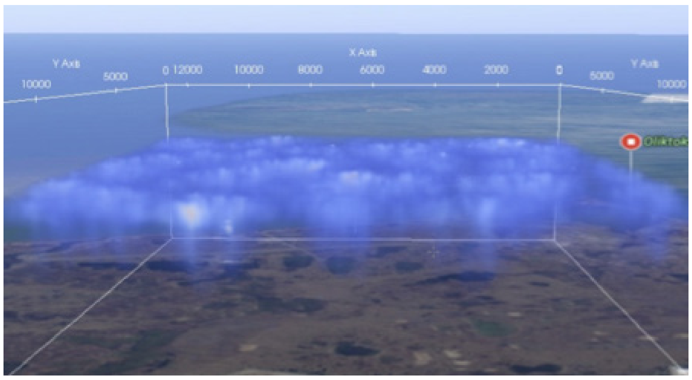
conditions that force a coastal terrestrial permafrost multi-physics finite element environment to model erosion. This model can inform scientific understanding of coastal erosion processes, contribute to estimates of geochemical and sediment land-to-ocean fluxes, and facilitate infrastructure susceptibility assessments.

- **Terrestrial and submarine permafrost simulation** – Scientists at Sandia are using PFLOTRAN, the most advanced simulator for multi-phase subsurface flow and transport processes, to improve regional and global simulation capabilities for terrestrial and submarine permafrost evolution. In collaboration with the U.S. Naval Research Laboratory, we can produce probabilistic maps of simulation results via sampling on machine-learned maps of marine sediment characteristics.

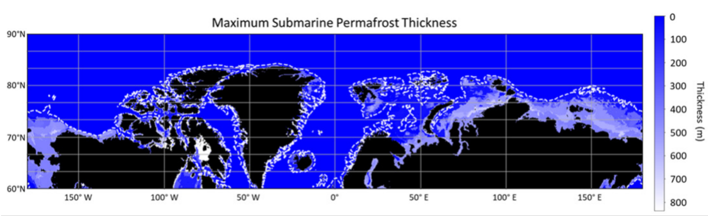
REGIONAL MODELING CAPABILITIES

Sandia develops and validates regional Earth system models in collaboration with other national laboratories. Examples include:

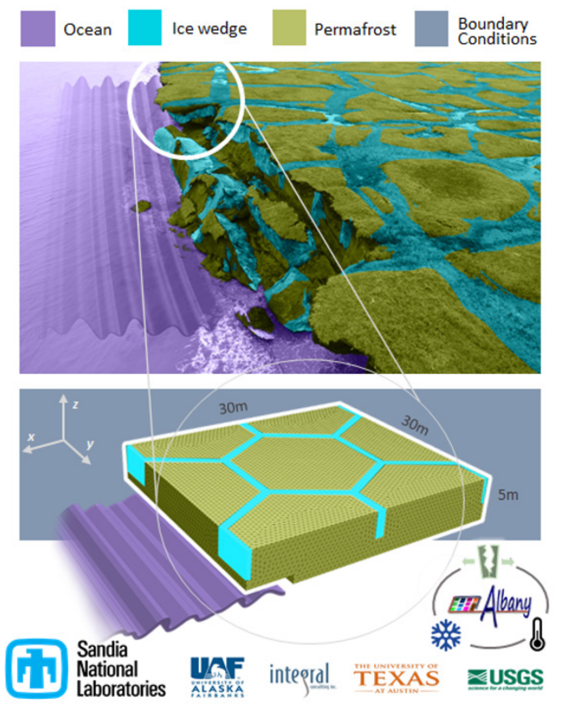
- **Regional Refined Models (RRMs)** – RRMs provide insight into regional climate model behavior by enabling focus on regions of interest. Users can examine regional earth system behaviors without implementing the global model at a high resolution, allowing users to view and validate regional models faster. RRM meshes may help predict the timing, amount, and cycles of rain that impact society and the economy.
- **Software Modernization** – Sandia can improve earth system models, expediting the development of trusted, high-fidelity models.
- **Large Eddy Simulation (LES)** – Regional LES of low clouds in the Arctic illustrate how and where improvements can be made in future, higher resolution global climate models.
- **Coastal erosion** – Sandia does high-fidelity simulation of local erosional processes with failure modes developing from constitutive (rather than empirical) relationships enabling failure from any allowable deformation (e.g., block failure, thermo-denudation, thermo-abrasion).



Revealing precipitation large enough to fall, this large-eddy simulation (LES) enhances understanding of the physical processes in the Arctic cloud that determine its optical properties and lifetime. This knowledge can lead to more accurate atmospheric Earth systems predictions. Such predictions could then support planning for national energy and sector-specific needs, such as the development of water-availability projections.



Maximum modeled submarine permafrost thickness at the last glacial maximum is produced by ensemble PFLOTRAN models driven by statistical sampling of machine-learned maps of sediment characteristics from the Global Predictive Seabed Model (Photo courtesy U.S. Naval Research Laboratory).



Translation of the physical coastal environment in the Arctic into the Arctic Coastal Erosion (ACE) Model simulation domain.

CONTACT:

arctic@sandia.gov
energy.sandia.gov/arctic-modeling

U.S. DEPARTMENT OF ENERGY NNSA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2022-15428 O

Sandia National Laboratories