Arctic Coastal Erosion (ACE) Model

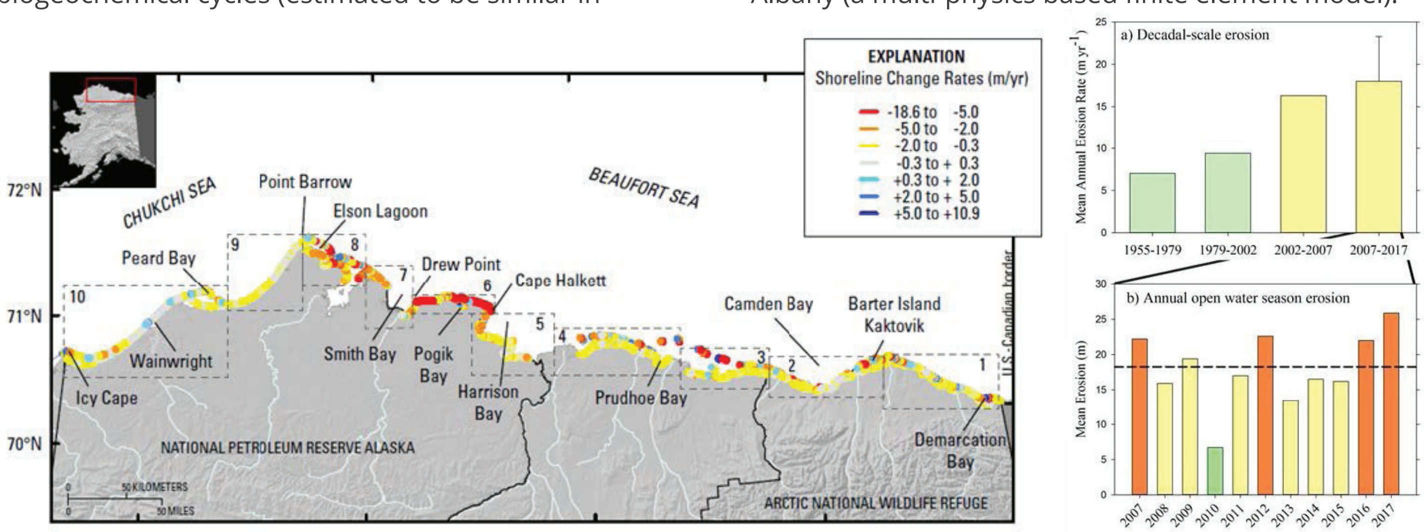
Rising temperatures (atmosphere, ocean, and permafrost) (Arctic Report Card, 2018), declining sea ice (Overland et al., 2018), and longer ice-free seasons resulting in more energetic Arctic oceans (Barnhart et al., 2014), are all coupling to increase the vulnerability of Arctic coasts to erosion. During the 21st century, multiple Arctic coastal sites have experienced increased erosion, with a few experiencing 20 meters of erosion in a single year (Jones et al., 2018), making those some of the fastest eroding coasts in the world.

Increasing Arctic coastal erosion rates have put critical infrastructure and native communities at risk, while also mobilizing ancient organic carbon into modern carbon cycles. In Alaska, this loss of coastline threatens six active U.S. Department of Defense sites (DoD, 2016) and 30 coastal villages (USGAO, 2009). This loss of coastline in Alaska threatens six active U.S. Defense Departments sites (DoD, 2016) and 30 coastal villages (USGAO, 2009) with potentially large economic and cultural ramifications. In addition, coastal erosion represents a significant pathway for carbon and nitrogen trapped in permafrost to enter modern biogeochemical cycles (estimated to be similar in magnitude to riverine export into Arctic Ocean), where it may fuel food webs and greenhouse gas emissions in the marine environment (Bristol et al., 2021).

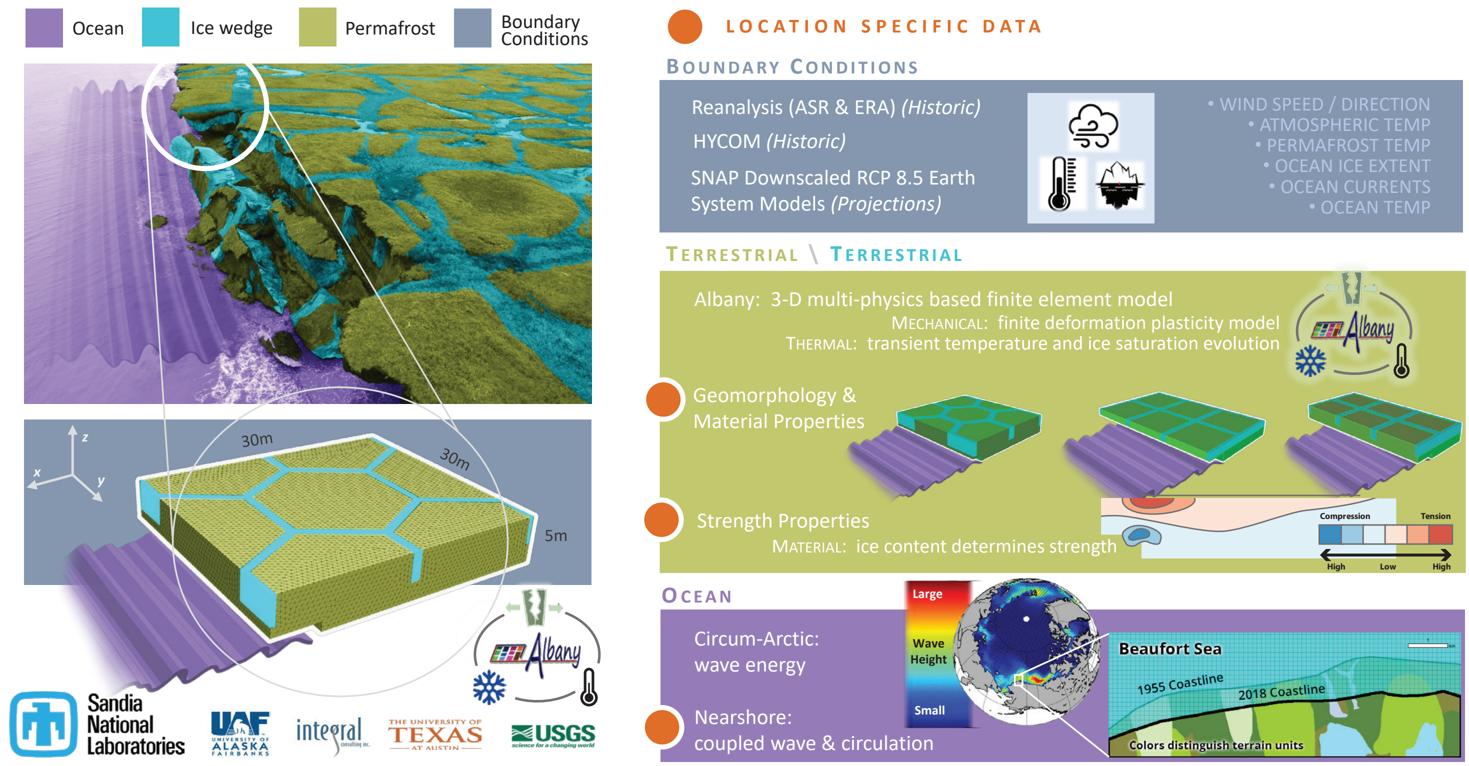
Although the Arctic comprises one-third of the global coastline and has some of the fastest eroding coasts, current tools for quantifying permafrost erosion are unable to explain episodic, storm-driven erosion events. Models developed for the lower latitudes have limited applicability because ice in permafrost acts as the consolidating material, making erosion in the Arctic fundamentally a thermal-chemical-mechanical process.

SANDIA SOLUTION

To solve the limitations of current coastal erosion tools, researchers from Sandia National Laboratories and its partners are building a field-validated predictive model of thermal-chemical-mechanical erosion for the Arctic coastline. The Arctic Coastal Erosion (ACE) Model consists of oceanographic and atmospheric boundary conditions that force a coastal terrestrial permafrost environment in Albany (a multi-physics based finite element model).



Coastal erosion rates in northern Alaska are highly variable (Gibbs and Richmond, 2015) due to coastal geomorphology, permafrost material properties, and local wave energy characteristics. At select locations, like Drew Point AK, erosion rates are accelerating, with linear losses equivalent to two football fields in a decade (Jones et al., 2018).



ACE Model details and experimental data set can be found in Bull et al., 2020. Methods to upscale these model results are currently being explored.

An oceanographic modeling suite (consisting of WAVEWATCH III, Delft3D-FLOW, and Delft3DWAVE) produces time-dependent surge and run-up boundary conditions for the terrestrial model. In the terrestrial model, a coupling framework unites the thermal and mechanical aspects of erosion. 3D stress/strain fields develop in response to a plasticity model of the permafrost that is controlled by the frozen water content determined by modeling 3D heat conduction and solid-liquid phase change. This approach enables failure from any allowable deformation (block failure, slumping, etc.) to be modeled.

Extensive experimental work has underpinned ACE Model development, including field campaigns to measure in-situ ocean and erosion processes, geomechanical experiments to determine thermally driven strength properties, and physical composition and geochemical analyses to enable estimation of organic matter fluxes into the ocean. ACE Model development was led by Sandia National Laboratories with contributions from project partners at the University of Alaska Fairbanks, Integral Consulting, the University of Texas at Austin, and the United States Geological Survey.

THE BENEFITS OF THE SANDIA SOLUTION

The ACE model and experimental results offer the most comprehensive and physically grounded treatment of Arctic coastal erosion available in the literature, dramatically improving scientists' ability to predict circum-Arctic erosion. This work can be used to inform scientific understanding of coastal erosion processes, contribute to estimates of geochemical and sediment land-to-ocean fluxes, and facilitate infrastructure susceptibility assessments. Ultimately, this will help scientists and policymakers better respond to current coastline loss in Alaska and prepare for any occurrences in the future.

CLIMATE SECURITY AT SANDIA

Sandia is integrating capabilities from across the Labs to support our missions and address the national and global security threats associated with the rapidly evolving climate crisis. Our vision is to advance climate security through science, technology, and action.

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