Simulating future changes in coastal tundra retreat along the Alaskan Chukchi Sea

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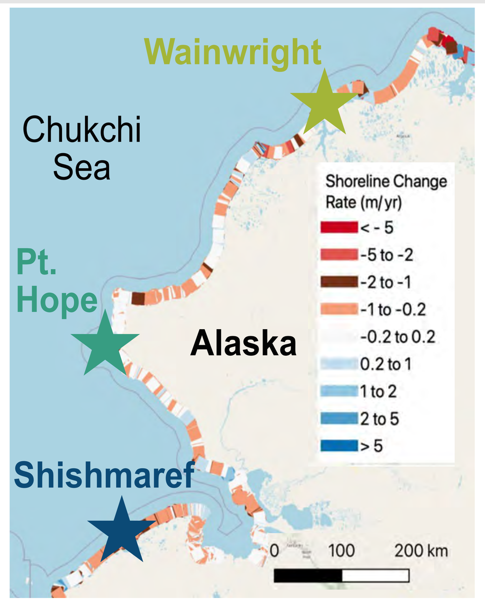
Background

Study Sites

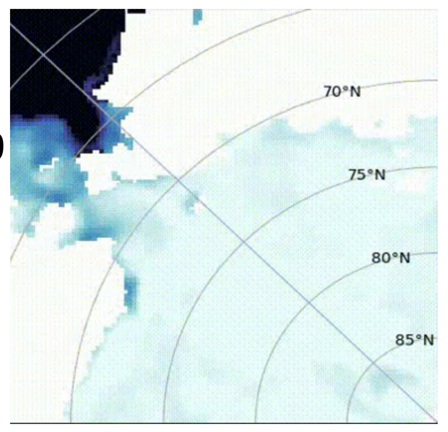


Rapid environmental change in the Arctic is driving considerable coastal land loss and flooding hazards. These coastal hazards put people, infrastructure, and local culture at risk. Quantitative tools designed for cold region settings, including ice and thermal processes, are necessary for constraining future risk and designing suitable adaptation options. Ongoing work at the US Army Engineer Research and Development Center (ERDC) is focused on developing predictive technologies to simulate future ice, ocean, and morphological states in response to future climate forcings. A demonstration of these in-development capabilities for select sites located within the Chukchi Sea along the Alaska, USA coastline is shown here.

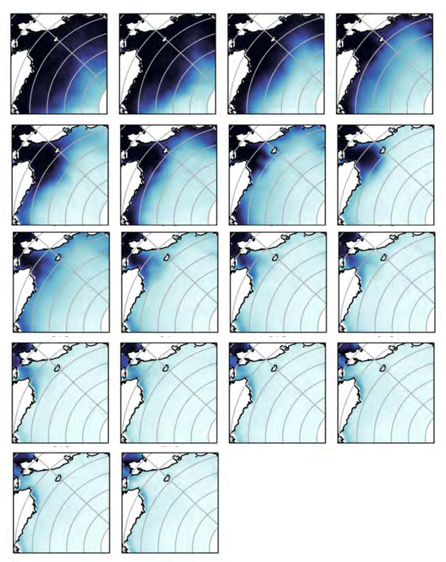
Methodology

Stochastic Sea Ice Generator

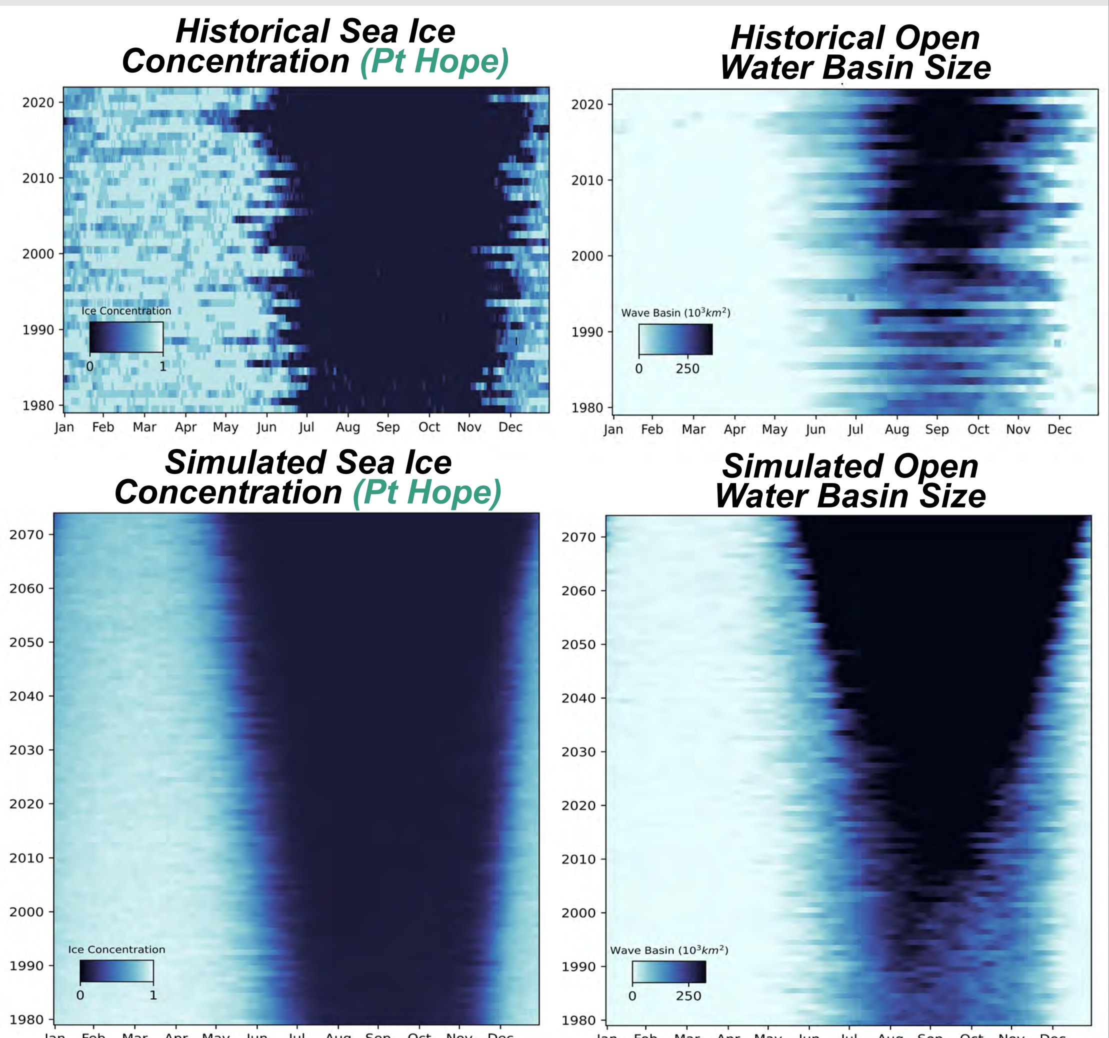
Step 1. Source daily sea ice concentrations (SIC) from 1979 to present sourced from National Snow and Ice Data Center.



Step 2. Representative SIC fields developed using (1) K-means clustering for < 10% ice (9 bins) and (2) spatial means for fields with 20-100% ice (9 bins)

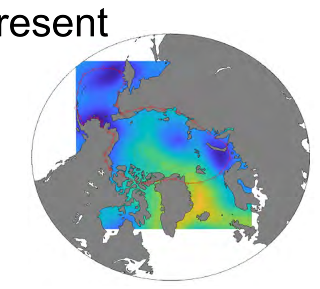


Step 3. Model temporal variability in SIC using auto-logistic regression and discrete Markov chains following approach of May et al. (2023).

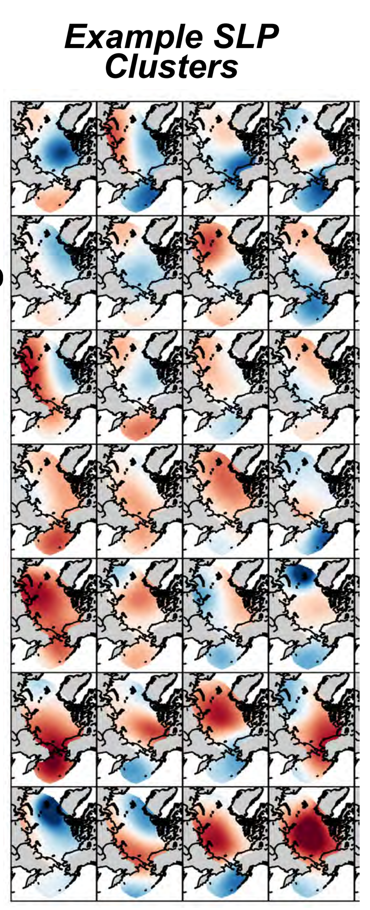


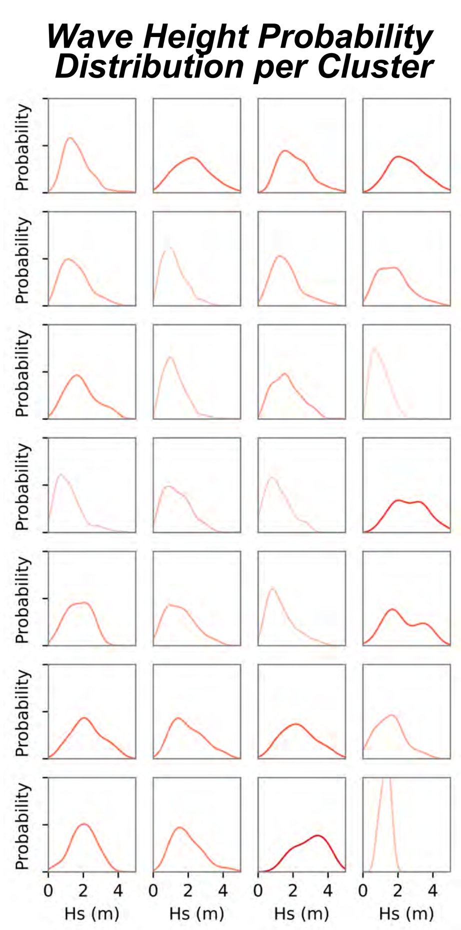
TESLA Forcing Emulator

Step 1. Source spatial sea level pressure (SLP) fields from NCEP CFSR from 1979 to present



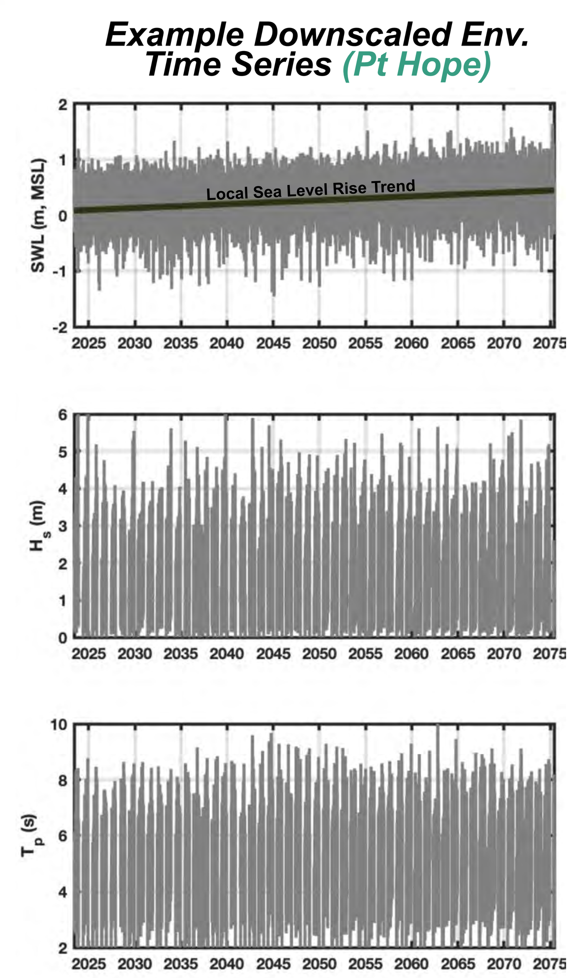
Step 2. Use K-means clustering to develop representative spatial SLP fields (Anderson et al, 2019)



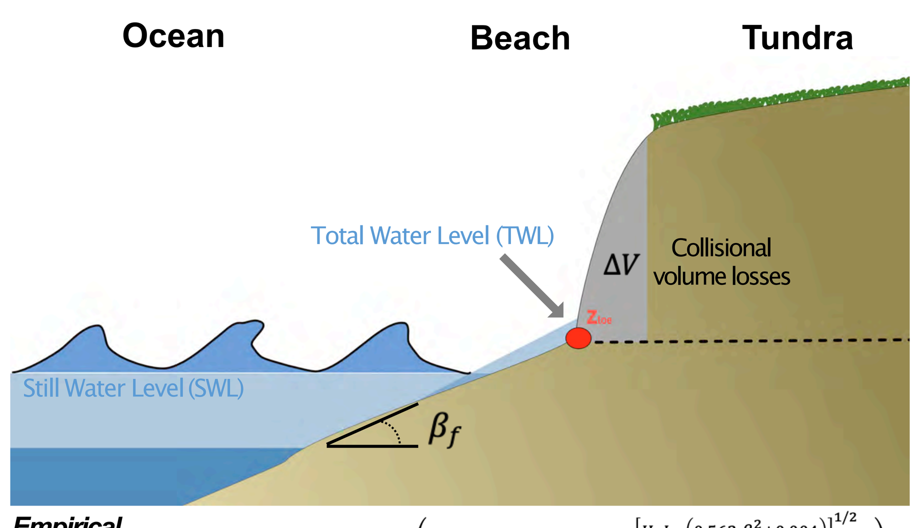


Step 3. Develop local probability distributions of wave (ERA5) and water level (NOAA tide gauges) parameters for each cluster

Step 4. Use Markov chains to simulate time evolution of daily SLP fields and develop time series of env forcing using joint dependencies (including SIC) between variables



Tundra Retreat Model



Empirical Water Levels

$$TWL = SWL + 1.1\left(0.35\,\beta_f (H_o L_o)^{1/2} + \frac{[H_o L_o (0.563\,\beta_f^2 + 0.004)]^{1/2}}{2}\right)$$

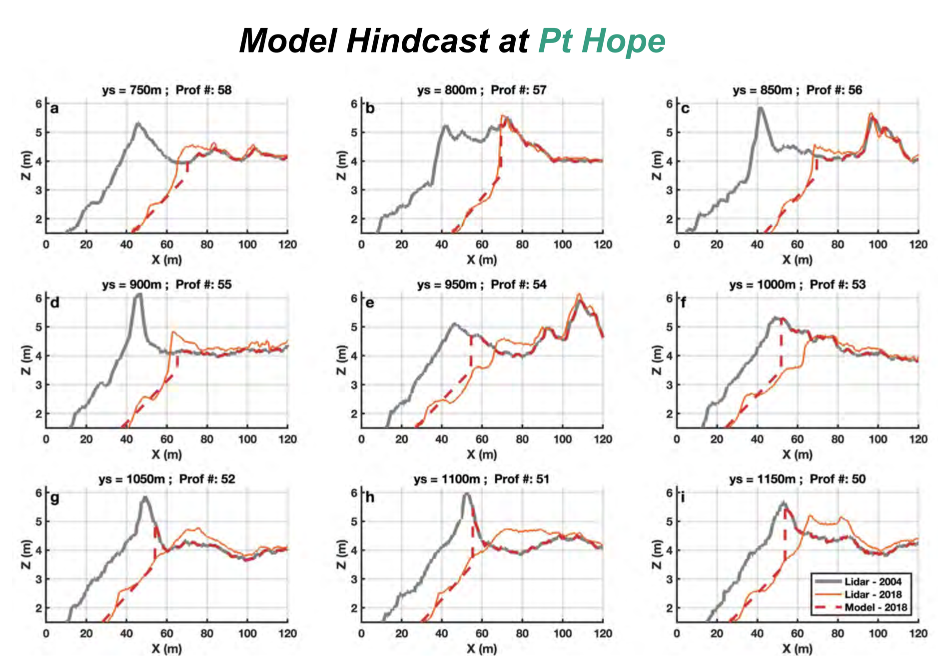
Stockdon et al. (2006)

Tundra Volume Losses

$$\Delta V = 4C_s(TWL - z_{toe})^2 \frac{t}{T}$$

Palmsten and Holman (2012)

Use offshore environmental forcings to drive analytical tundra retreat model that includes shoreline change rates and has been validated against topographic change data in he Chukchi Sea (Cohn et al., 2022)



Model Setup

Inputs

Environmental

- Hourly TESLA-generated wave height, wave period, tide, and storm surge from present to 2075
- 500 scenarios at each site with and without sea level rise from linear regression through Red Dog Dock tide gauge data

Morphological

- USGS long-term shoreline change rate (SCR) imposed at shoreline
- Most recent airborne lidar to represent profile shape
- Tundra toe elevation estimated based on break in slope

Free Parameters

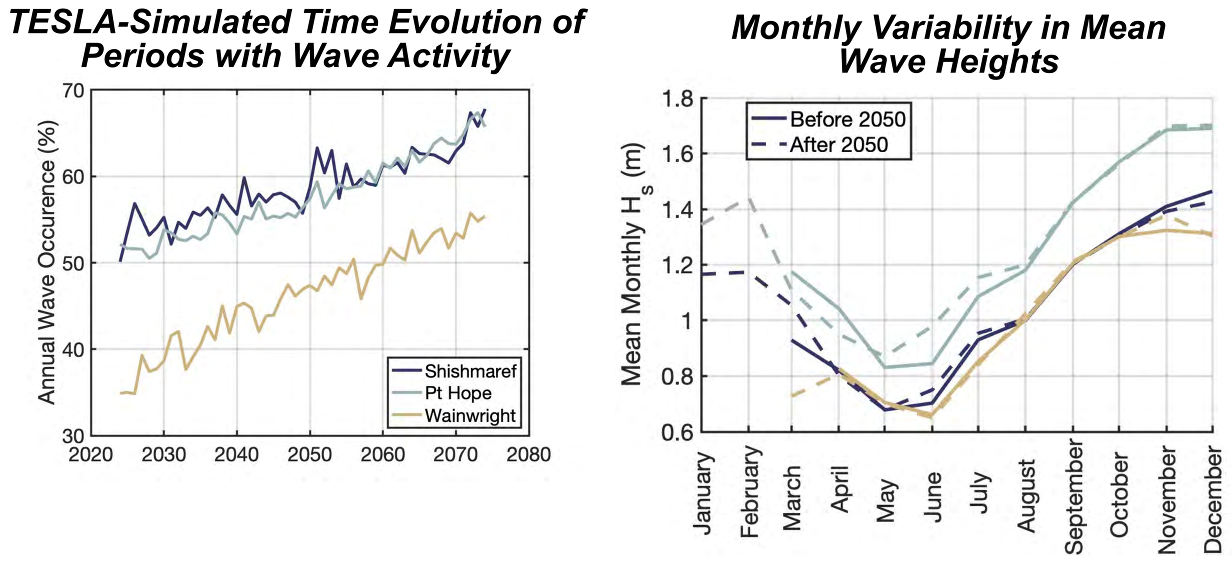
- Sediment erodibility (can be thermally dependent)
- Tundra toe trajectory

Outputs

- Time evolving beach slope and TWL
- Tundra volume change
- Tundra toe retreat

Results

TESLA Wave Outputs

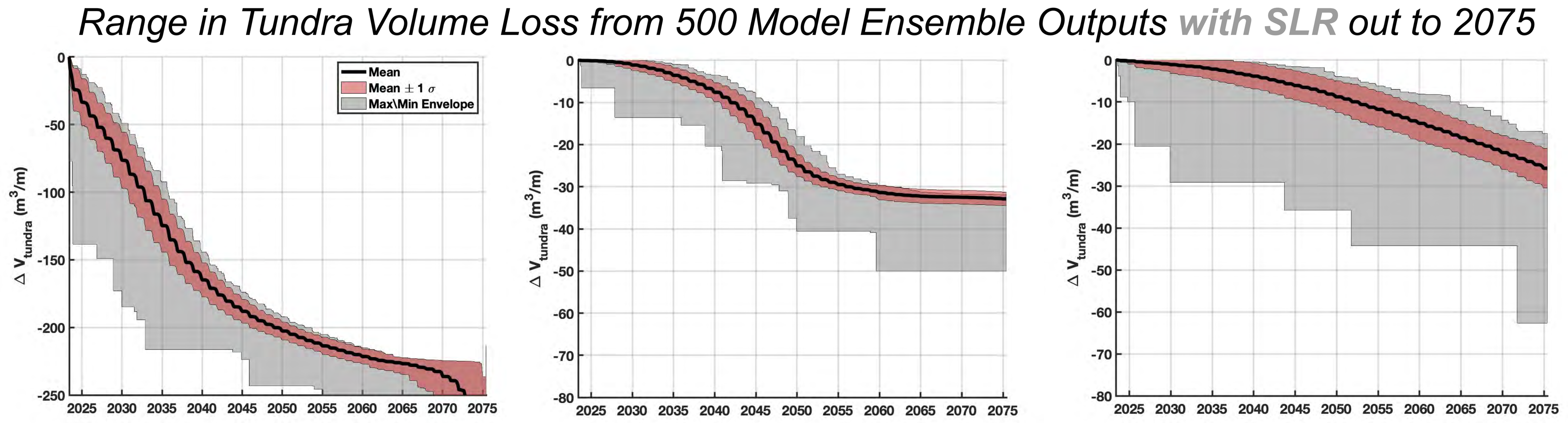


Outputs from TESLA include time evolution in wave energy associated with changing SIC patterns into the future. Both Shishmaref and Pt Hope show an increase of open water conditions with waves from 50% at present to 65% in 2075. Due to Wainwrights more northerly latitude, there is more ice coverage and fewer days with waves simulated throughout the record. As climate change driven changes to weather patterns, including wind speeds, are not included in this application, then the mean monthly wave conditions do not change considerably between 2023-2050 and 2050-2075. However, at both Wainwright and Pt Hope there becomes the potential for waves in all months of the year by 2075 due to shifting sea ice coverage patterns.

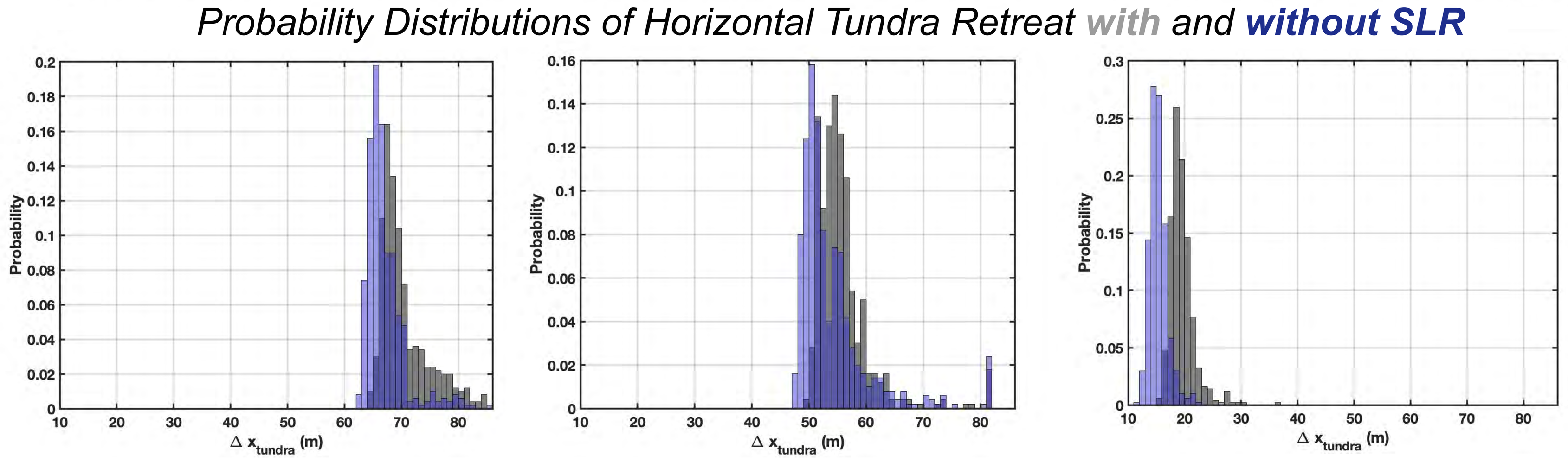
Model simulations for Shishmaref, Point Hope, and Wainwright all show that coastal tundra erosion is broadly expected on unarmored sections of coast over the coming decades. Shishmaref, with a local SCR of -1.5 m/yr has the highest rates of expected retreat. A broad range of potential tundra retreats are possible at Shishmaref depending on the magnitude and timing of potential storms. Wainwright has the lowest reported SCR (-0.3 m/yr) which contributes to the considerably less retreat expected by 2075. Unsurprisingly, including a sea level trend in the still water level is likely to exacerbate these erosional trends considerably. These collective outputs indicate that local details, including SCR, beach-tundra topography, and local wave energy, all contribute to site-specific hazards across broad spatio-temporal scales.

Shishmaref | **Point Hope** | **Wainwright**

Range in Tundra Volume Loss from 500 Model Ensemble Outputs with SLR out to 2075



Probability Distributions of Horizontal Tundra Retreat with and without SLR



Implications and Future Steps

While the timing and magnitude of future storm events, which is a predominantly driver of coastal land loss along the Alaskan Arctic, is unknown, stochastic approaches shown here provide a framework to assess the range of possible realistic future erosional outcomes. These model simulations indicate that, without interventions, the coming decades are likely to result in continued coastal tundra loss at the target sites. The magnitude of this response at a local scale is largely dependent on shoreline retreat rates, with the antecedent morphology also playing a factor in the rate of retreat. Given the magnitude of erosional problems along the periphery of the Chukchi Sea, extensive validation and improvement of ERDC-developed and other available tools for simulating Arctic coastal change hazards is critical to enable risk forecasts and design potential solutions.

Ongoing efforts as part of this work are focused on enhancing representation of offshore and landfast ice dynamics, inclusion of thermal processes into erosional tools, and developing approaches to incorporate nature-based solutions into modeling tools within this probabilistic framework.

Example Risk Based Retreat Map for Pt Hope from Model Outputs

References

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May et al. (2023). Stochastic Modeling of Sea Ice Concentration to Assess Navigation Conditions along the Northern Sea Route. *Izvestiya, Atmospheric and Oceanic Physics*

Palmsten and Holman. (2012). Laboratory investigation of dune erosion using stereo video. *Coastal Engineering*

Stockdon et al. (2006). Empirical parameterization of setup, swash, and runup. *Coastal Engineering*

U.S. ARMY

ERDC

Engineering With Nature

Funding: The stochastic sea ice generator and climate emulation techniques tuned to the Arctic Ocean have been funded by 6.2 Army research funds. Application of the modeling tools to Point Hope, AK has been supported by the ERDC Engineering with Nature R&D program.