Coastal Typologies for Modeling Coastal Erosion on the North Slope of Alaska

By the Coastal Erosion Team (D.Bull, A.Bennett, V.Alexeev)

Introduction

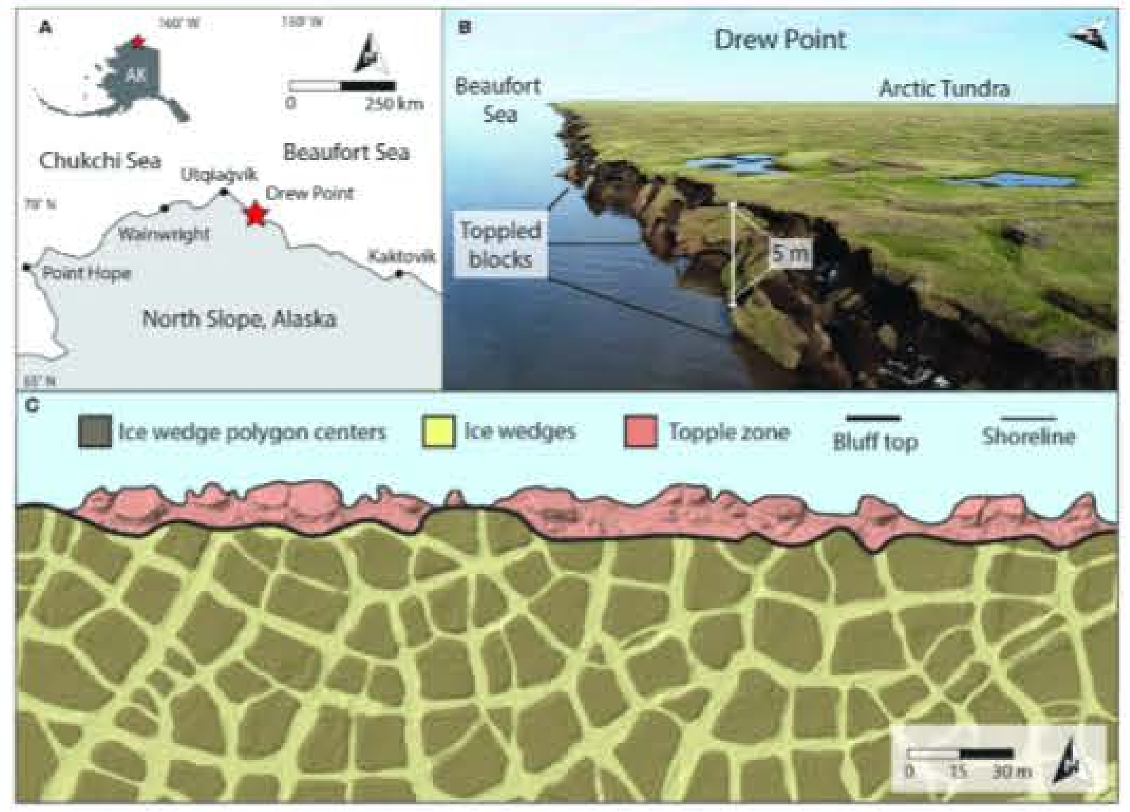
In the Arctic, coastal systems are critically important for environmental dynamics and due to the high density of socio-economic activity. With the loss of perennial sea ice, the Arctic has undergone arguably the largest physical transition of any region on Earth over the last 50 years, significantly impacting natural and human environments. Coastal erosion is happening at unprecedented rate on the North Slope of Alaska.

Objectives:

- Develop typological understanding of Arctic coastline (terrestrial and oceanographic) to upscale models of erosion and flooding
- ACE Model implementation with representative terrestrial configurations
- Offshore wave environment typology

What are typologies?

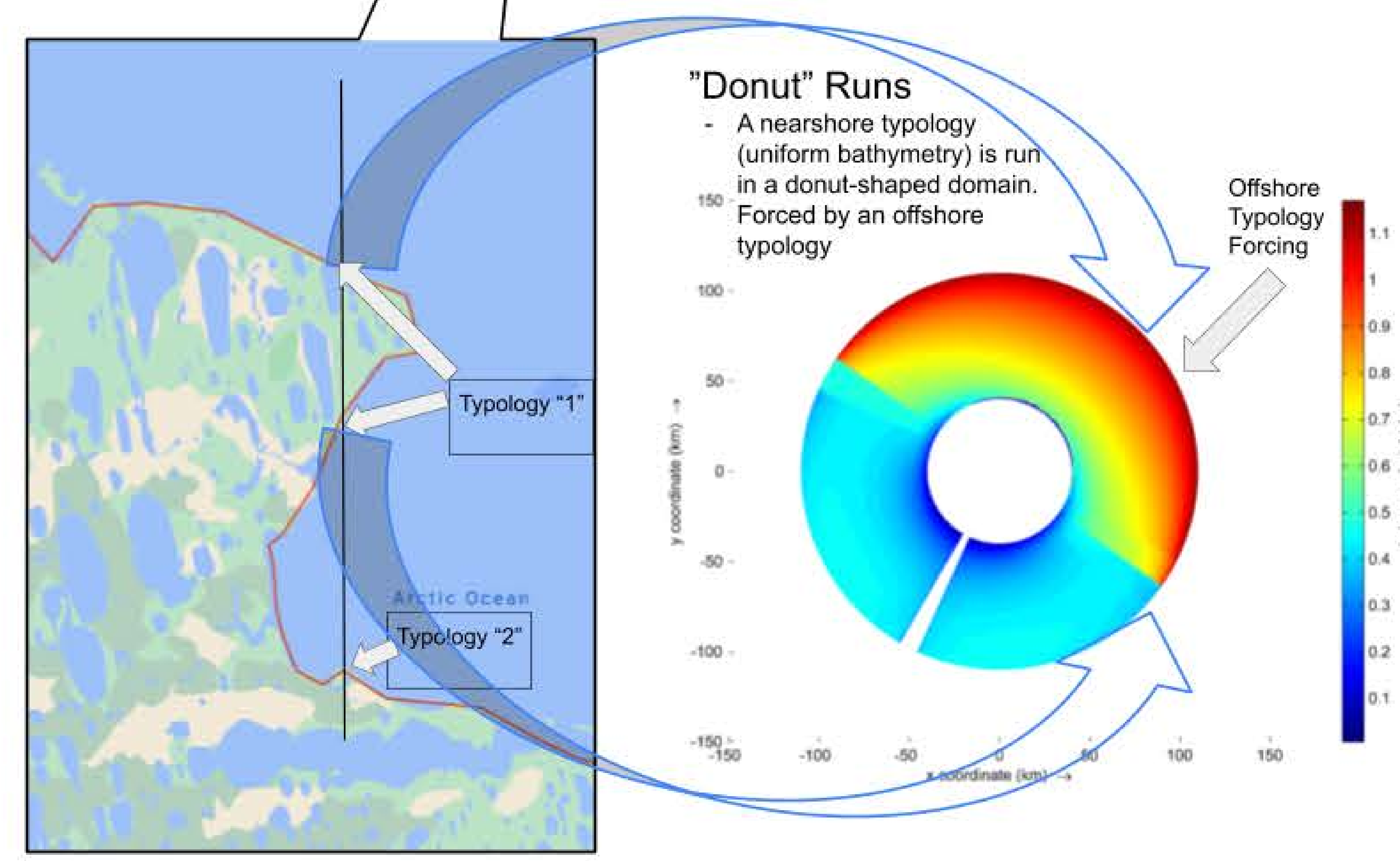
Typologies offer a way to simplify a large number of instances to a limited set of classifications. In our case, typologies are used to reduce the full dataset to a much smaller set of most prototypical members representative of the full dataset.



(A) Location of the Drew Point study area (red star) along the north coast of Alaska, USA. (B) Oblique aerial view acquired by unmanned aerial vehicle (UAV) showing toppling mode block failure that is typical along the coastline at Drew Point. (C) UAV orthophoto mosaic showing the permafrost terrain configuration at Drew Point consisting of ice wedges, ice wedge polygon networks, and the topple zone. Roughly 75% of the block failures in this example occurred along an ice wedge, whereas 25% occurred in an ice wedge polygon center.

(Figure from Thomas et al, 2020)

New coastline (1km resolution), "Donut" Runs



Orientation of the coastline is important! The new approach is taking this into account by running a nearshore typology with uniform bathymetry forced by an offshore typology in a circular domain.

Offshore typologies

Objective

- Develop an offshore typology along the Alaskan North Slope consisting of the boundary conditions required for high-resolution nearshore models

Site Name	Latitude	Longitude	Depth (m)	Shoreline Orientation
Site 1	71.76° N	167.95° W	49.44	152.61°
Site 2	71.50° N	164.13° W	40.8	173.16°
Site 3	71.45° N	155.75° W	43.66	216.52°
Site 4	71.12° N	150.92° W	42.97	235.71°
Site 5	70.63° N	146.00° W	45.42	193.06°
Site 6	70.41° N	133.45° W	45.97	256.66°

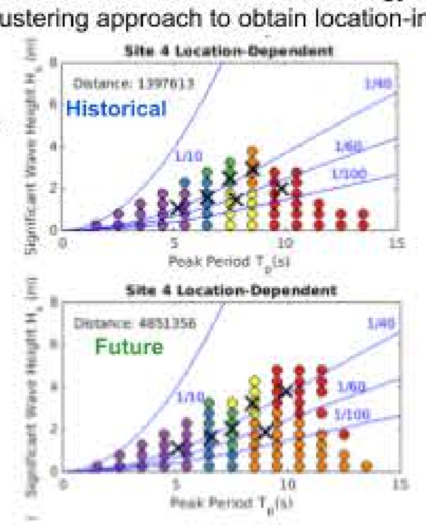
~1,250km

Research

- Employ statistical representations of offshore wave energy conditions
- Modify the k-means clustering approach to obtain location-independent wave energy parameters

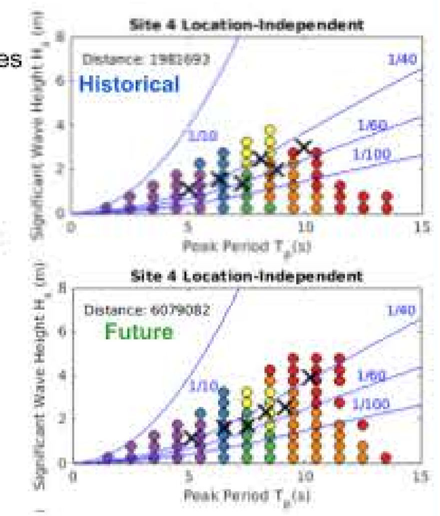
Location Dependent

- For each site with energy-weighted JPD as base
- Select 6 cluster centroids of Hs-Tp values by minimizing squared Euclidian distance for 100 iterations of the algorithm

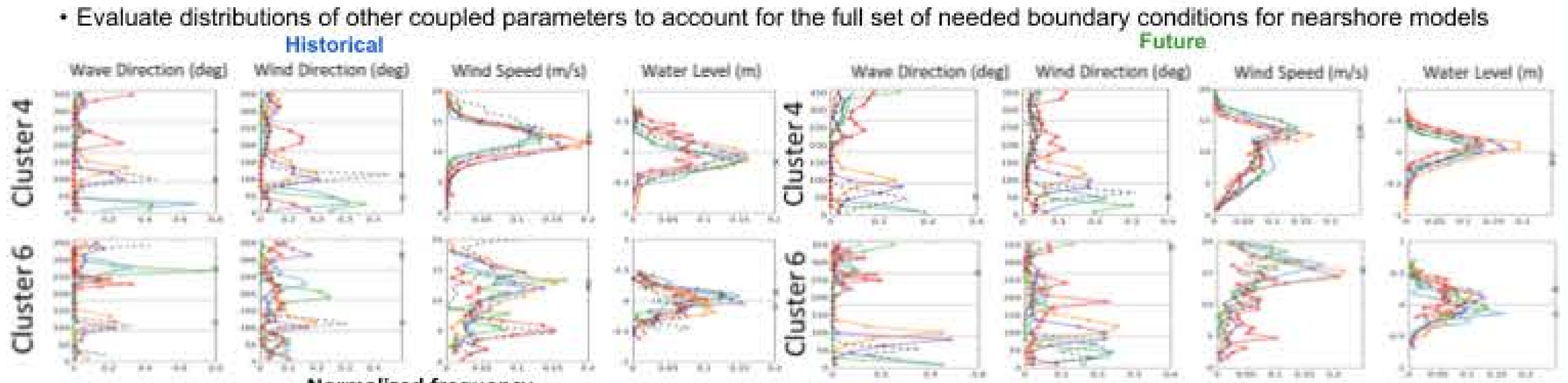


Location Independent

- Average cluster centroids across sites
- Sorted by increasing T_p
- Adjust cluster centroids
- Each centroid contribution to AAP < 40%
- Sum all power contribution from cluster members and divide by AAP
- Adhere to constant steepness contours
- Historical (inverse steepness): 35-40-60-40-60-50
- Future (inverse steepness): 35-40-50-45-50-40



- Evaluate distributions of other coupled parameters to account for the full set of needed boundary conditions for nearshore models



Impact

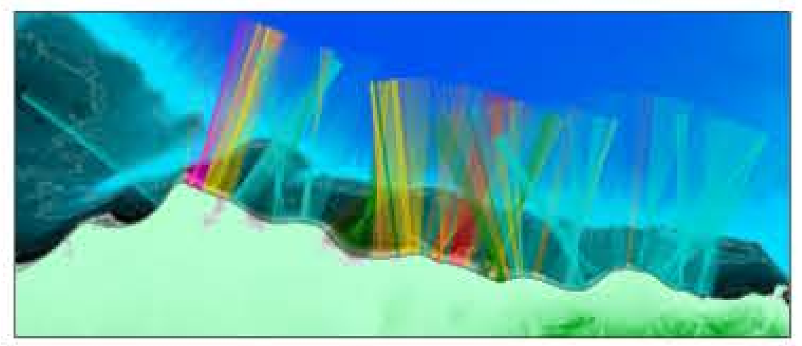
- Reduced number of simulations (down from order 10^4 – 10^5 to order 10) needed to assess nearshore oceanographic environments and hence characterize coastal processes (e.g., erosion, flooding, or sediment transport)

Historic	Tp (s)	Hs (m)	Wave Direction	Water Level (m)	Wind Direction	Wind Speed (m/s)	Wave-Wind Orientation
Cluster 1	5.00	1.11	33	-0.15	29	5.00	N-N
Cluster 2	6.30	1.55	0	-0.10	100	6.00	N-E
Cluster 3	7.30	1.40	260	-0.05	225	4.75	W-W
Cluster 4	8.10	2.50	240	-0.20	45	12.00	W-E
Cluster 5	8.75	2.00	300	+0.05	270	6.75	E-W
Cluster 6	9.90	3.00	110	-0.10	120	13.00	E-E

Future	Tp (s)	Hs (m)	Wave Direction	Water Level (m)	Wind Direction	Wind Speed (m/s)	Wave-Wind Orientation
Cluster 1	5.10	1.15	300	-0.05	315	4.80	W-W
Cluster 2	6.50	1.65	75	+0.05	80	8.00	E-E
Cluster 3	7.50	1.75	80	+0.10	90	7.00	E-E
Cluster 4	8.30	2.37	61	-0.10	53	13.00	E-E
Cluster 5	9.10	2.55	75	+0.20	230	4.00	E-W
Cluster 6	10.20	3.95	280	-0.20	342	16.00	W-W

Eymold WK, Flanary C, Erikson L, Nederhoff K, Chartrand CC, Jones C, Kasper J, Bull DL. Typological representation of the offshore oceanographic environment along the Alaskan North Slope. Continental Shelf Research. 2022. https://doi.org/10.1016/j.csr.2022.104795

Nearshore typologies

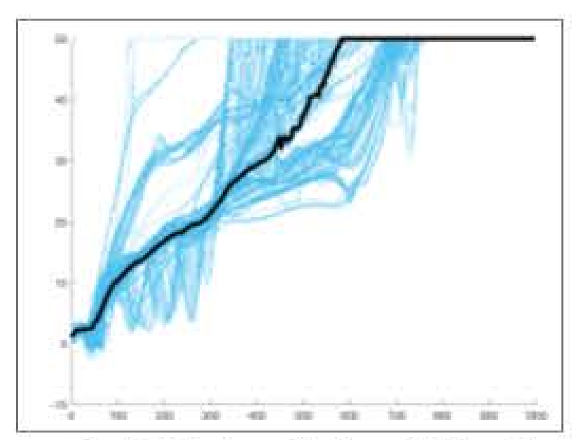


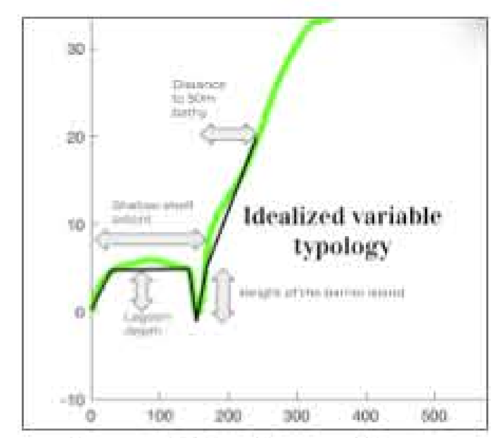
Objective:

- Develop a set of typologies for simplified modeling of nearshore wave environments

Approach

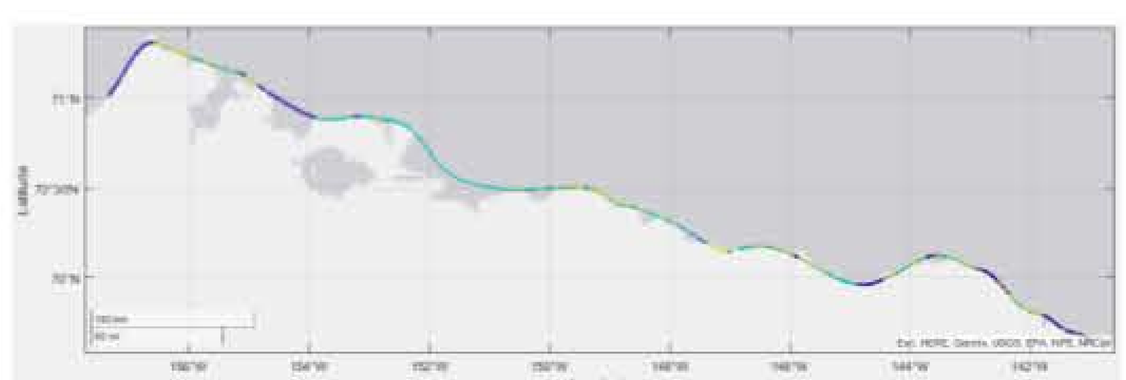
- Construct a set of 1D transects perpendicular to smoothed coast
- Apply clustering to select a set of representative nearshore environments
- Run Delft3D in a simplified setting forced by offshore typologies





Issues (picture on the left): Each profile has ~4000 points, too many degrees of freedom, and K-means centroids are not representative of members

Modified approach: Reduce # of degrees of freedom, Use variable topology (right) to calculate most critical parameters, and use those parameters to cluster typologies

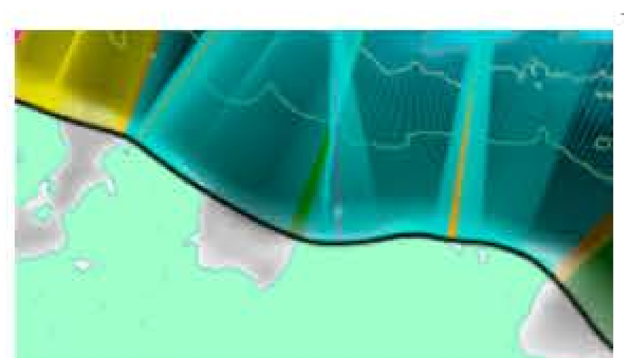


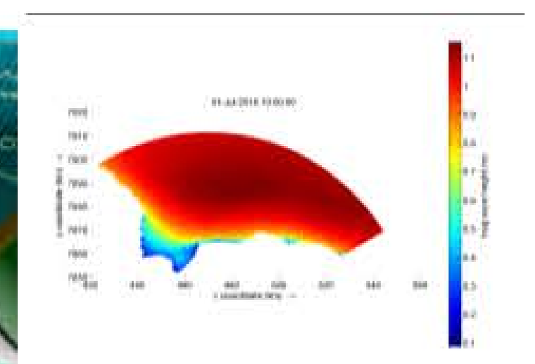
Nearshore typologies map developed based on clustering a set of 'most critical' parameters (MCP):

- Shallow shelf extent
- Presence or absence of Barrier Islands
- Lagoon depth
- Distance to 'deep ocean'

Current Nearshore typologies (left).

Typologies Excluded based on analysis of MCP: Lagoon Depth, Barrier Island Height, Barrier Island width, Barrier Island Length.





Nearshore typologies will be tested on the existing model of Drew Point (LANL) and potentially other locations (e.g. Utqiagvik).

Integration of typologies/future directions

- Currently select the terrestrial configurations using typological assignments
- Establish 6-7 terrestrial archetypes
- ACE requires unique information not available in landscape work
- 1D nearshore typologies approach to be tested using Drew Point model (Diana)
- Nearshore wave environment modeled using offshore/nearshore typologies to understand trafficability on the North Slope.
- ML techniques using these typological representations will be explored

Offshore Waves

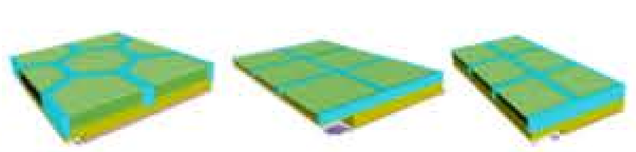
Historical	Tp (s)	Hs (m)	Wave Direction	Water Level (m)	Wind Direction	Wind Speed (m/s)	Wave-Wind Orientation
Cluster 1	5.00	1.11	33	-0.15	29	5.5	N-N
Cluster 2	6.30	1.55	113	-0.10	113	6.0	E-E
Cluster 3	7.30	1.40	270	+0.15	263	4.9	W-W
Cluster 4	8.10	2.50	98	-0.20	113	13.0	E-E
Cluster 5	8.75	2.00	330	+0.10	280	7.5	W-W
Cluster 6	9.90	3.00	280	+0.20	316	12.0	W-W

x

Nearshore Environment

x

Terrestrial Configuration



=