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Sandia National Laboratories

The Evaluation of Offshore Wave Climates along the Alaskan North Slope using K-means Clustering

Developed from Continental Shelf Research submission "The Evaluation of Offshore Wave Climates along the Alaskan North Slope using K-means Clustering" Eymold et al. in support of the DOE sponsored InteRFACE project

InteRFACE

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Arctic Coastal Dynamics: Rates, Impacts, Hazards, and Implications for the Future I AGU 2021. December 16th. Session C44A.

U.S. DEPARTMENT OF ENERGY NNSA

Motivation

Erosion and flooding impacts to Arctic coastal environments are intensifying

Accurate community bases risk assessments require high resolution predictive analyses of erosion and flooding based on

- Nearshore & onshore oceanographic conditions
- Terrestrial permafrost material properties

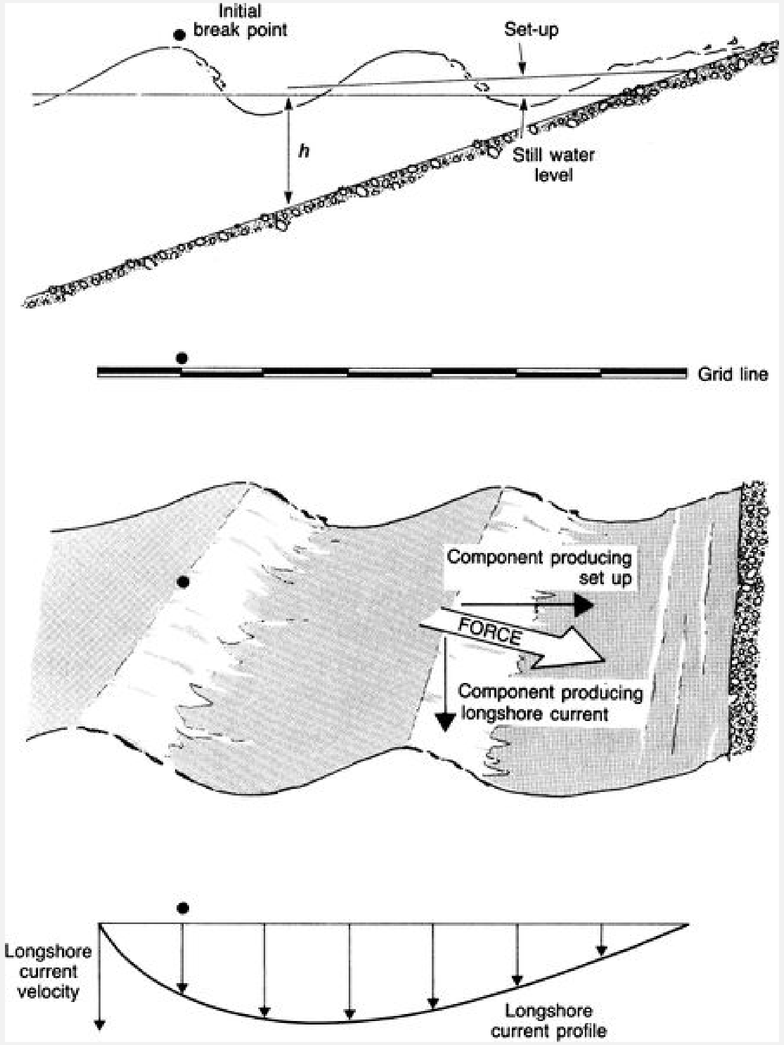
Nearshore wave propagation models are computationally expensive and depend upon:

- Offshore wave & atmospheric boundary conditions
- Local bathymetry
- Shoreline orientation

State of the Art

Circumvent the difficulty in establishing, running, and verifying advanced oceanic nearshore models by:

- Analytic simplifications in the Arctic
  - Assume fetch-limited shallow water wave development from wind field (no advanced model) (Barnhart et al., 2014)
  - Assume surge and set-up from analytic equations based on employing wind and pressure (Barnhart et al., 2014; Ravens et al., 2012)
- Subsetting conditions in the Arctic
  - Bin wind conditions into a subset of classifications and model with advanced techniques (Ravens et al., 2012)
- Clustering Algorithms outside of Arctic
  - K-means, self-organizing maps, maximum dissimilarity algorithms off coast of France, Latin America, the United Kingdom, and the west coast of the United States (Camus et al., 2011, Abadie et al., 2006; Hegermiller et al., 2017; Reguero et al., 2013)
  - Location-independent clusters uniquely scalable to achieve location-specific average annual power flux (Bull and Dallman, 2017)



http://www.coastalwiki.org/wiki/File:ChadwickFig17a.jpg

Approach—define offshore typology

a set of a reduced number of oceanographic parameters that fully describe the boundary conditions for high-resolution nearshore models.

Location-Dependent

- Multiple geographically disperse sites
- Statistical representations of wave energy in joint-probability diagrams for Historical & Future time periods
- Subset full statistical representations using k-means clustering to cull the representative conditions

Location-Independent

- Average cluster centroids across geographically disperse sites
- Adjust cluster centroids according to:
  - Each centroid contribution to AAP < 40%
  - Adhere to constant steepness contours

Typology

- For each Location-Independent centroid, determine representative values from distributions of:
  - wave direction,
  - water level,
  - wind speed, and
  - wind direction
- Use guidelines prioritizing diversity in directionality, wind speed, and water level
- Estimate salinity and temperature changes through mean and std

Time-apportion Typologies

- Reestablish location-dependence for each simulated typology at each site by weighting nearshore results to match their unique statistical occurrence in an average year
  - i.e., representing the fraction of time that the centroid would occupy over a representative year at specific site

Offshore Oceanographic Modeling

INPUTS

Historical (2007-2019 July-November)
-ASRv2 & ERA5 & GOFS
Future (2020 -2040 June-December)
-SNAP downscaled GFDL-CM3 RCP8.5
ETOPO1 1 Bathymetry

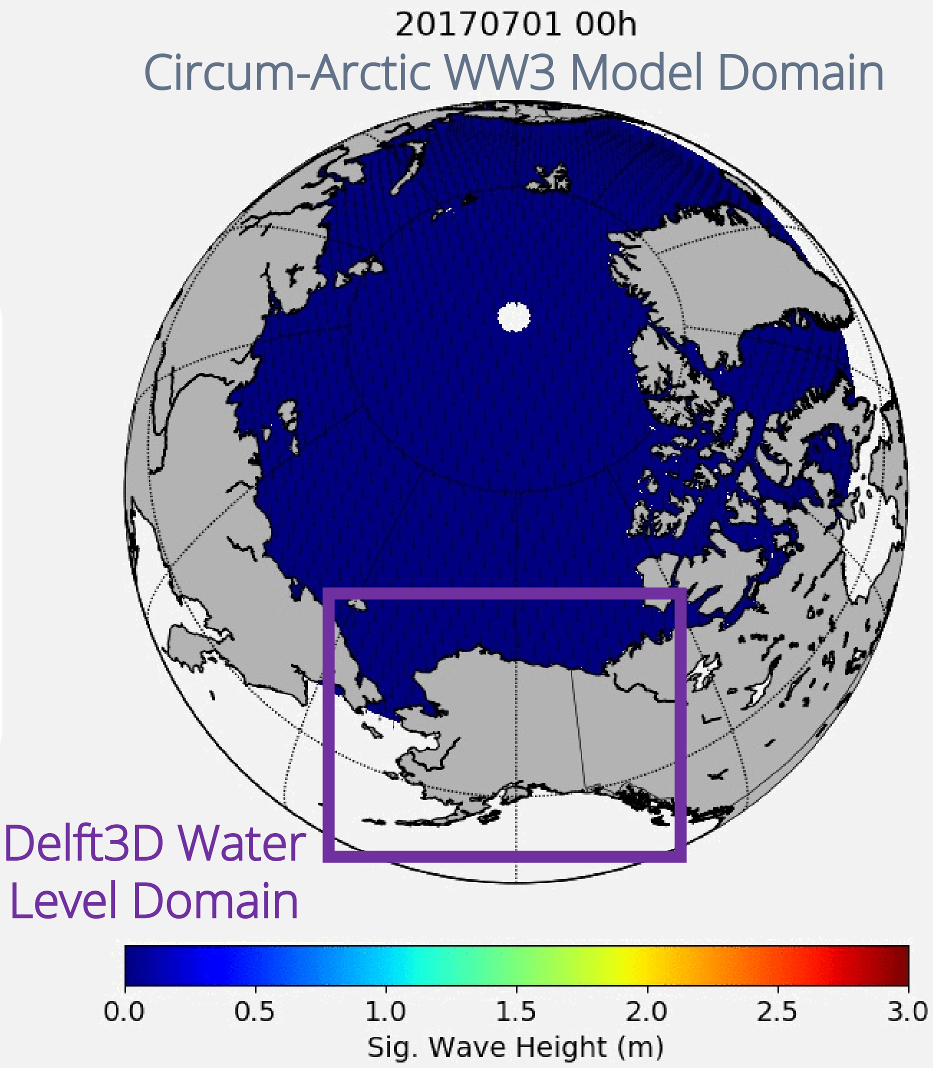
MODELS

WW3 – Development of wave field in the Arctic to develop nearshore BC's
- Surface winds
- Ice cover

Delft3D – Circulation around Alaska to develop water level BC's
- Wind and pressure forcing
- Tidal forcing
- Ice cover

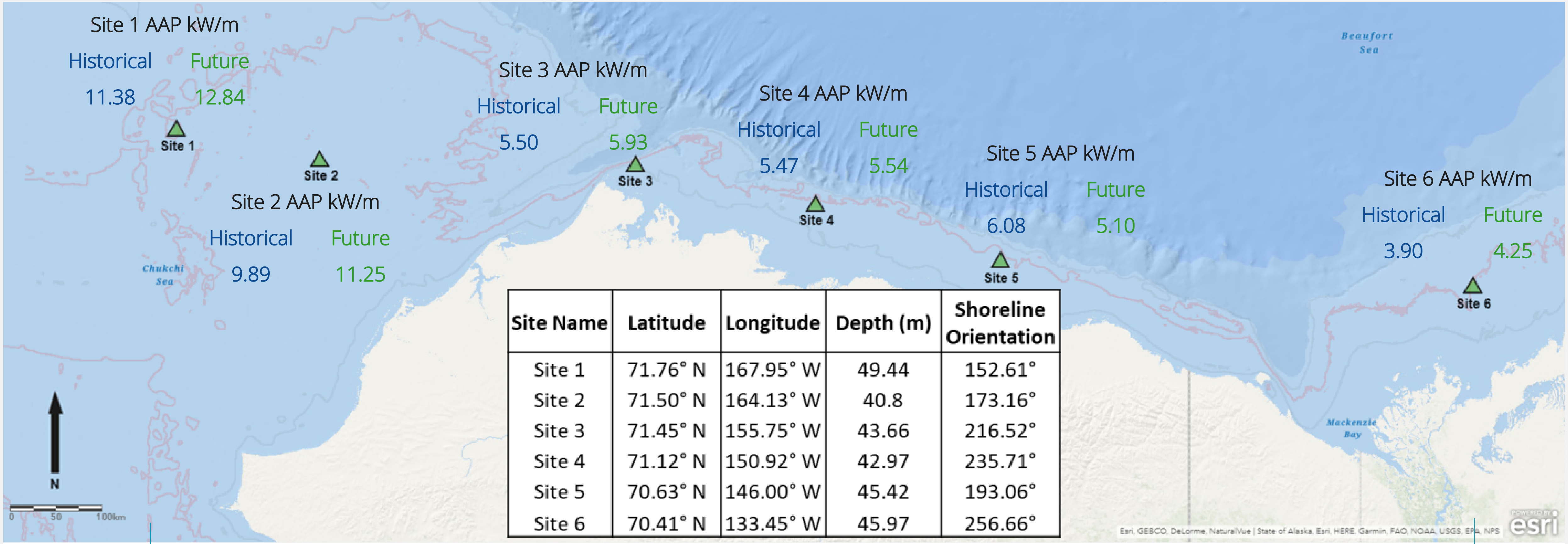
OUTPUTS

Hourly updates over ice free months of:
wave spectral properties (H_s, T_p, D_p),
water level, wind direction, wind speed
Average historic values of water temperature & salinity



WW3 polar stereographic model initially developed by NRL (Erick Rogers) and NOAA (Arun Chawla)

Analyzed sites and their Average Annual Power (AAP) Flux



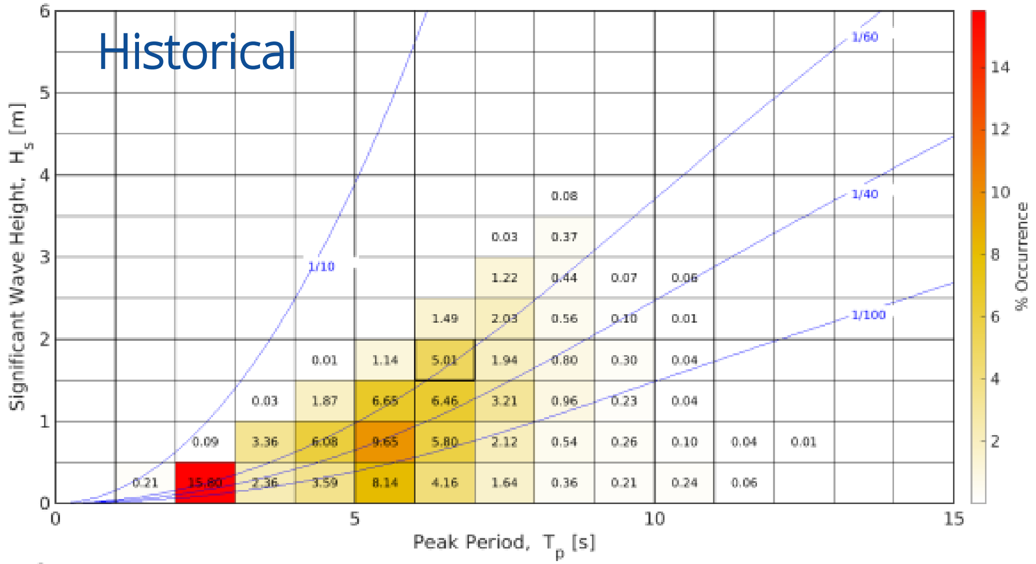
Site Name	Latitude	Longitude	Depth (m)	Shoreline Orientation
Site 1	71.76° N	167.95° W	49.44	152.61°
Site 2	71.50° N	164.13° W	40.8	173.16°
Site 3	71.45° N	155.75° W	43.66	216.52°
Site 4	71.12° N	150.92° W	42.97	235.71°
Site 5	70.63° N	146.00° W	45.42	193.06°
Site 6	70.41° N	133.45° W	45.97	256.66°

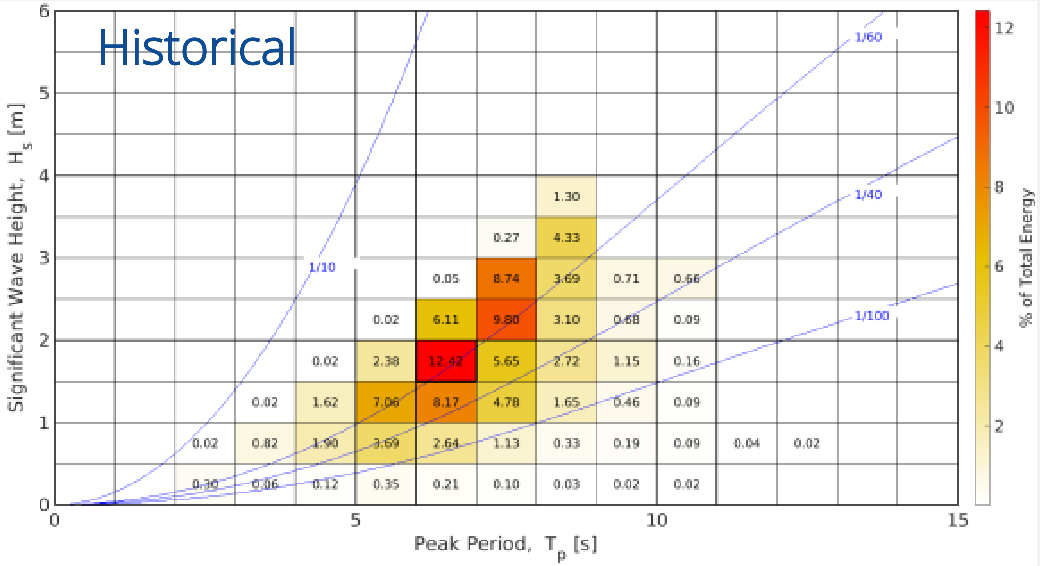
~1,250km

Statistical Representation of Wave Conditions (Site 4)

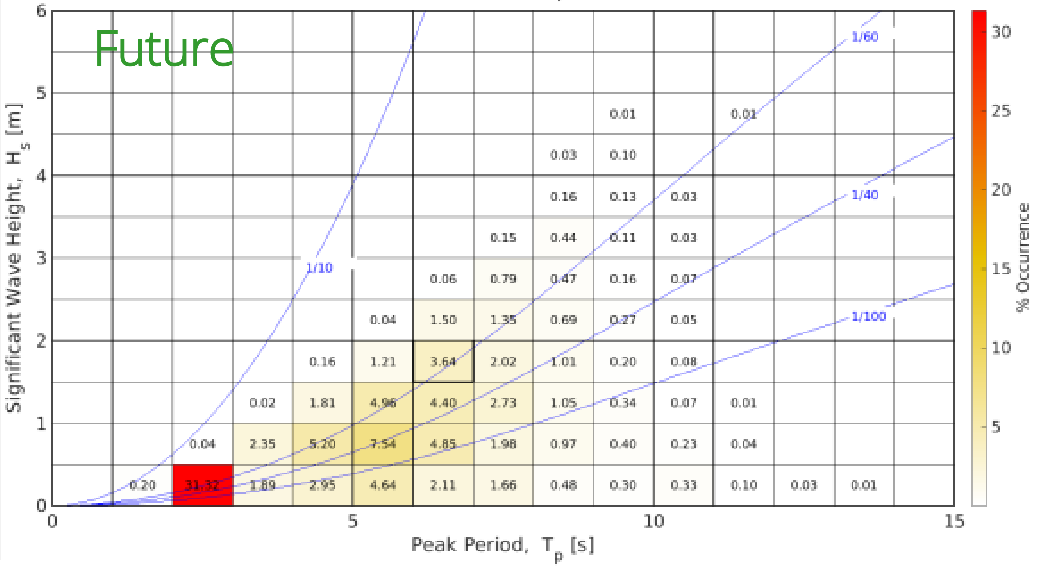
Occurrence | Energy-Weighted Occurrence

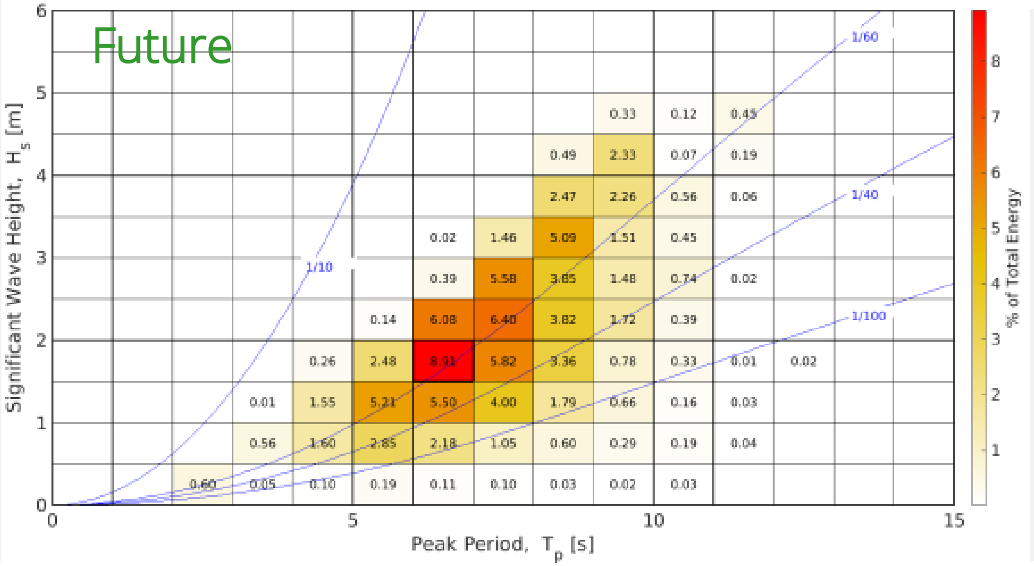
47,736 Samples





73,568 Samples

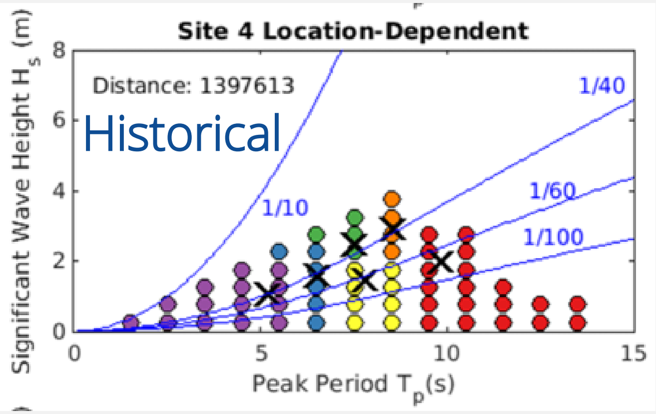


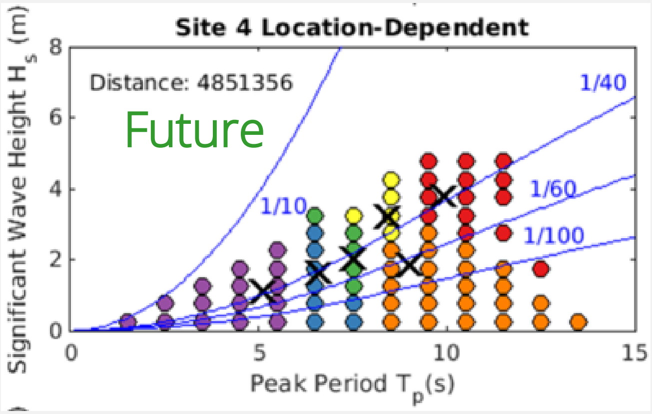


K-means Clustering

Location Dependent

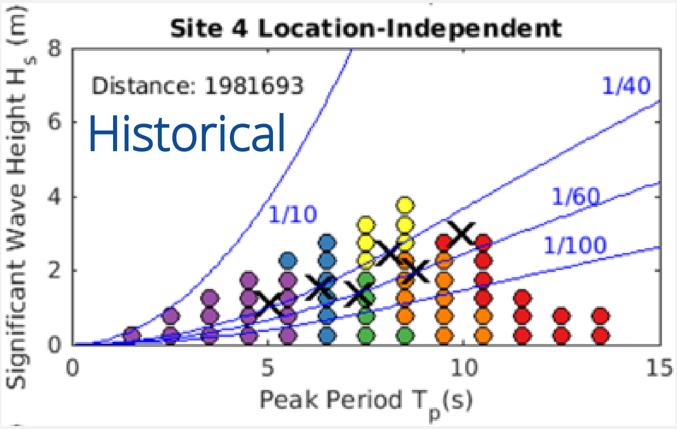
- For each site with energy-weighted JPD as base
- Select 6 cluster centroids of Hs-Tp values by minimizing squared Euclidian distance for 100 iterations of the algorithm

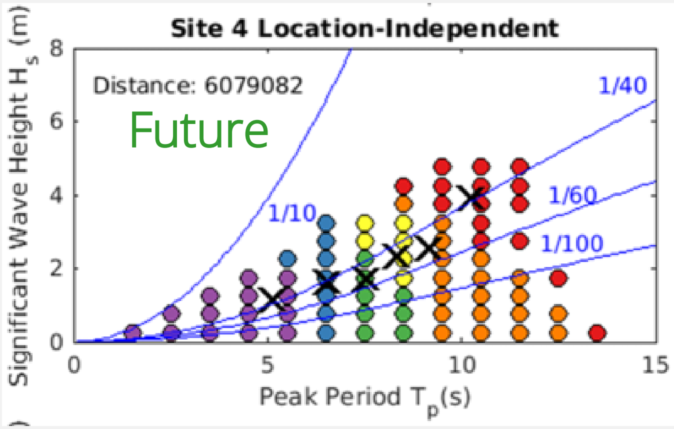




Location Independent

- 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





Evaluating distributions for cluster selection

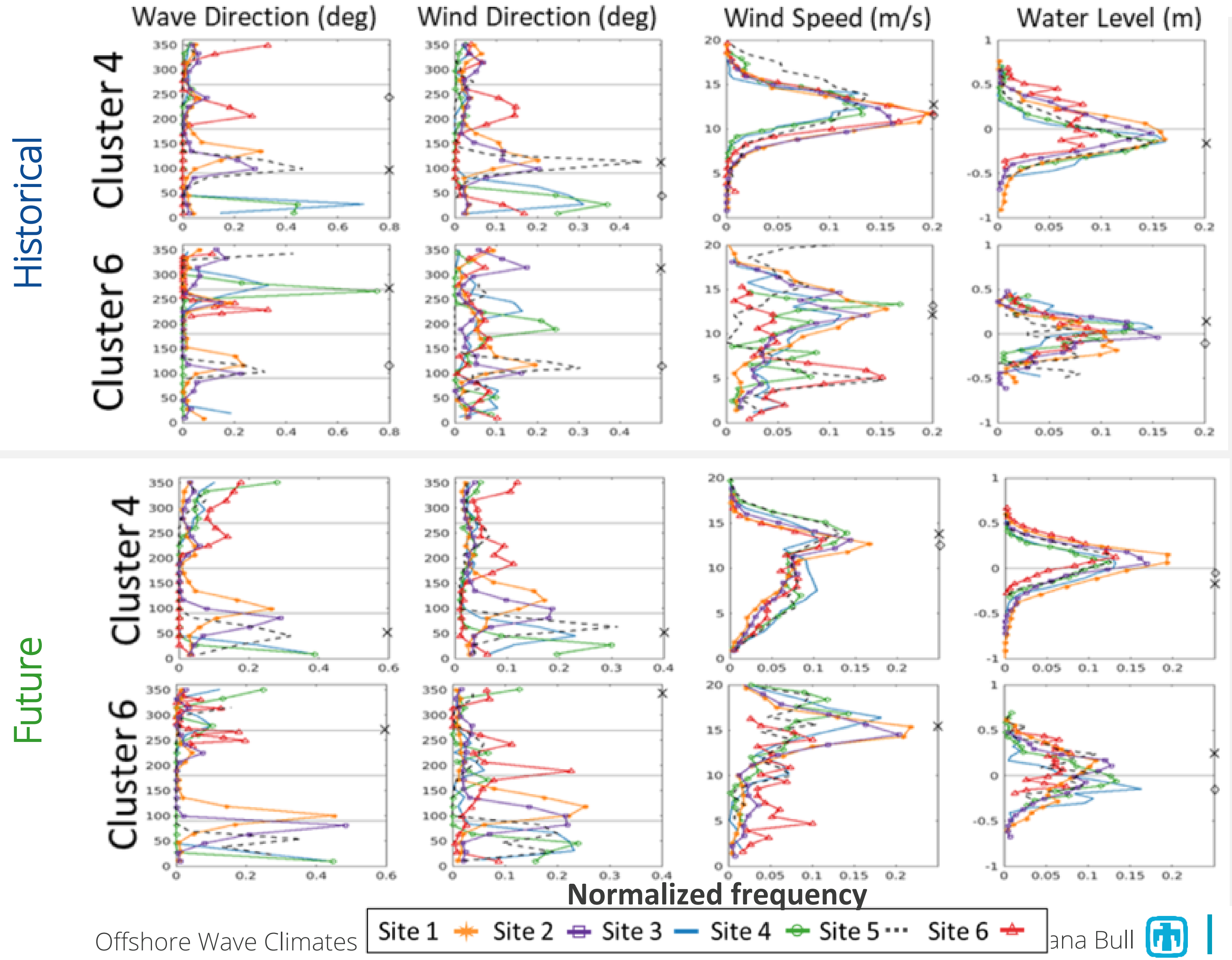
Guidelines for Cluster Selection

Consistent wave and wind cardinal directions

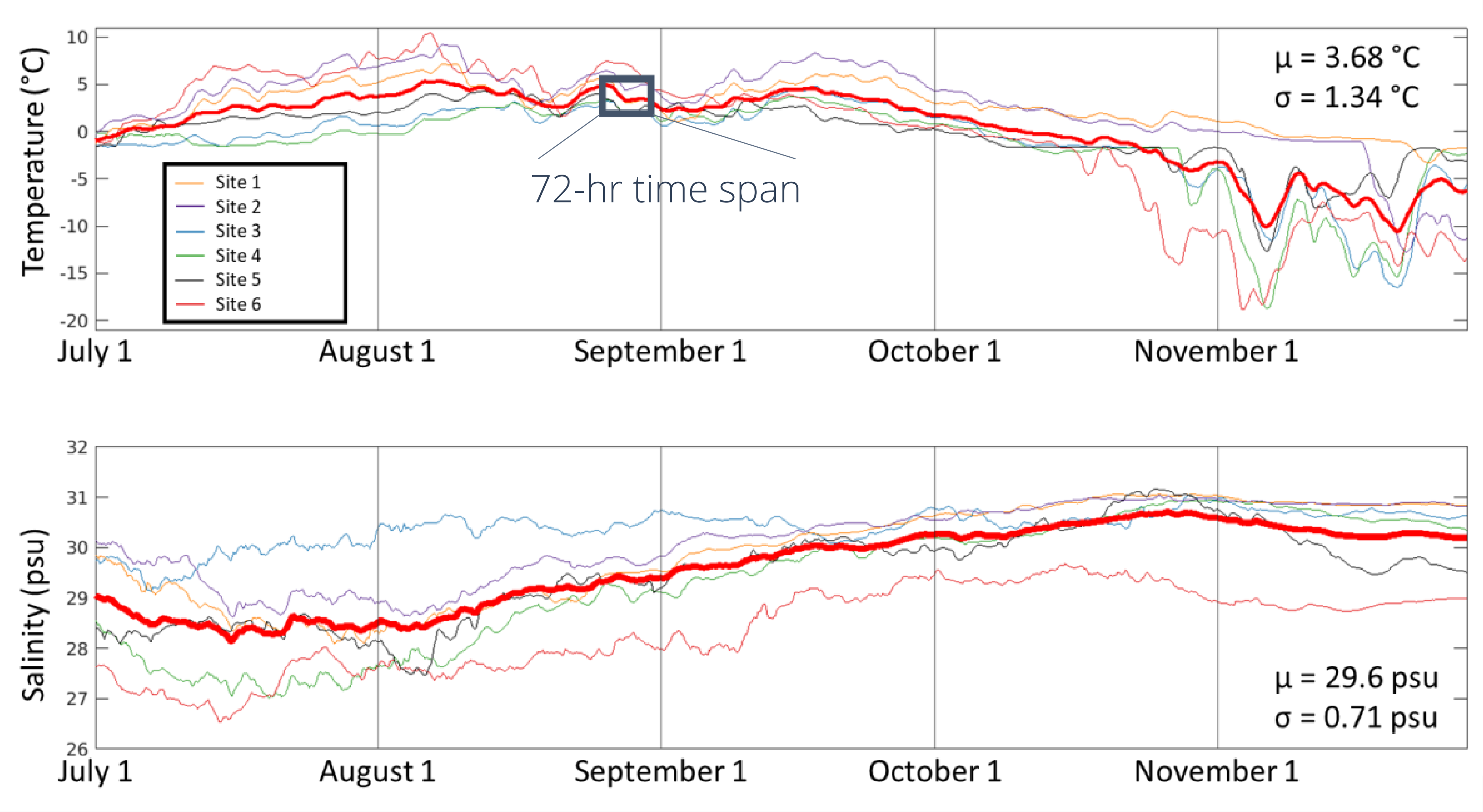
Wind directions influence water level: westerly winds raise water levels

A majority of the AAP flux should come from the east

Ensure representation of westerly storm clusters



Temperature and Salinity



Historical = 3.68 ºC

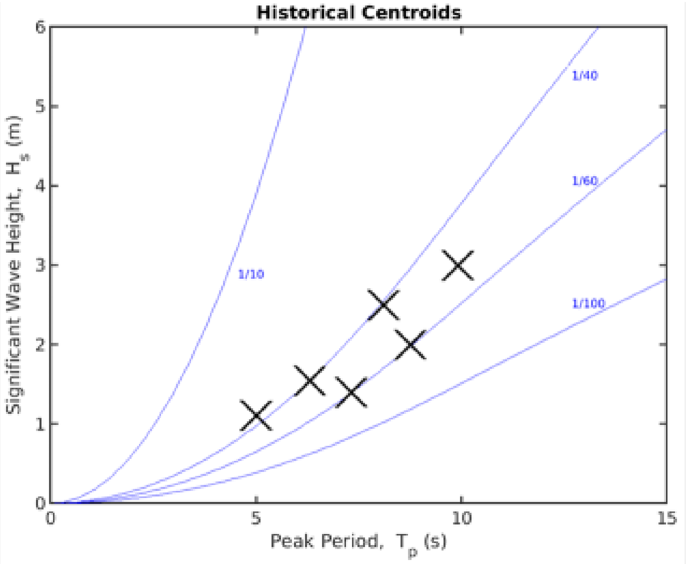
Future = 5.02 ºC
(μ+σ)

Historical = 29.50 psu

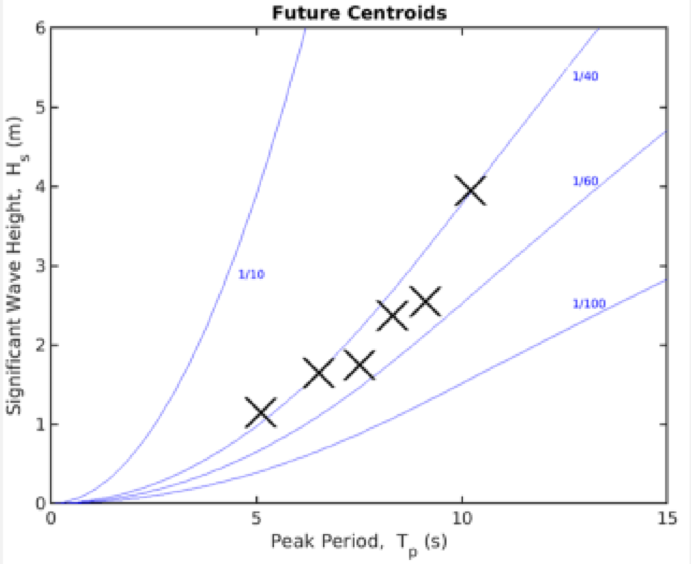
Future = 28.89 psu
(μ-σ)

Final Offshore Location-Independent Typologies

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



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	24	-0.05*	40	5.5	N-N
Cluster 2	6.50	1.65	45	-0.10*	69	7.5	E-E
Cluster 3	7.50	1.75	270	+0.15	250	6.5	W-W
Cluster 4	8.30	2.37	61	-0.20	53	14.0	E-E
Cluster 5	9.10	2.55	313	+0.10	260	5.0	W-W
Cluster 6	10.20	3.95	280	+0.30	342	16.0	W-W

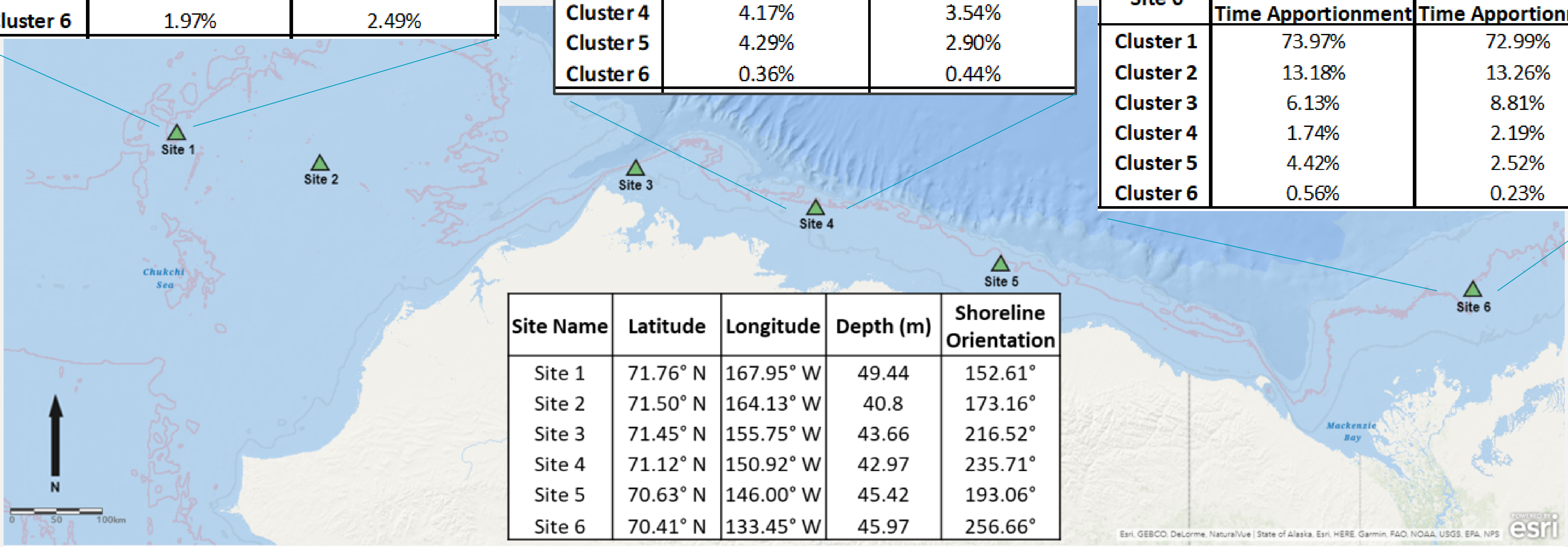


Regaining Location Dependence

Site 1	Historical Time Apportionment	Future Time Apportionment
Cluster 1	48.66%	51.82%
Cluster 2	24.93%	20.02%
Cluster 3	8.75%	13.35%
Cluster 4	10.01%	8.49%
Cluster 5	5.68%	3.82%
Cluster 6	1.97%	2.49%

Site 4	Historical Time Apportionment	Future Time Apportionment
Cluster 1	58.96%	64.27%
Cluster 2	22.94%	16.61%
Cluster 3	9.27%	12.24%
Cluster 4	4.17%	3.54%
Cluster 5	4.29%	2.90%
Cluster 6	0.36%	0.44%

Site 6	Historical Time Apportionment	Future Time Apportionment
Cluster 1	73.97%	72.99%
Cluster 2	13.18%	13.26%
Cluster 3	6.13%	8.81%
Cluster 4	1.74%	2.19%
Cluster 5	4.42%	2.52%
Cluster 6	0.56%	0.23%



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Discussion

More Energetic Future

Overall higher energy for the sea states in future

Increased values of H_s, T_p, and wind speed in future typologies

Western sea states (Clusters 3, 5 & 6) increase average occurrence slightly

Erosion

Using a case study at Drew Point as guide: winds with velocities above 5 m/s from 240° - 360° and 0° - 90° were significant factors in driving bluff erosion (Jones et al., 2018)

coastal bluffs would be subjected to potential erosion at all times in the future with this criteria

Flooding

Flooding can be expected when winds sustain a speed of 13 m/s for a duration of 20 hours during the ice-free season (Lynch et al., 2008)

Increase the number of typologies from one to two in the future that will cause flooding

Next Steps

Coastal Change: Develop typological understanding of Arctic coastline (terrestrial and oceanography) to upscale models of erosion and flooding

- ACE Model implementation
- Offshore wave environment typology

The majority of this research was funded as part of the Interdisciplinary Research for Arctic Coastal Environments (InteRFACE) project through the Department of Energy, Office of Science, Biological and Environmental Research RGMA program.

Offshore Waves

Historical	Tp (s)	Hs (m)	Wave Direction	Water Level (m)	Wind Direction	Wind Speed (m/s)	Wave-Wind Orientation
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Nearshore Wave Environment

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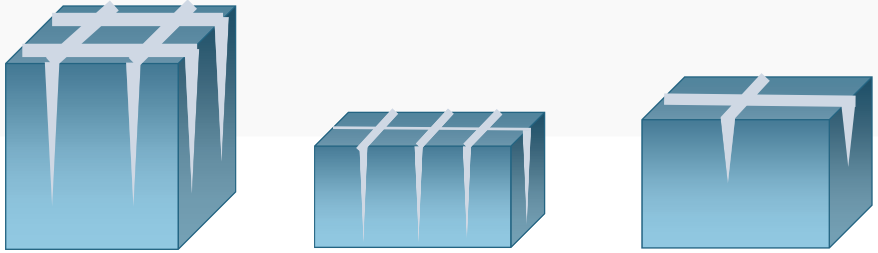
Terrestrial Configuration



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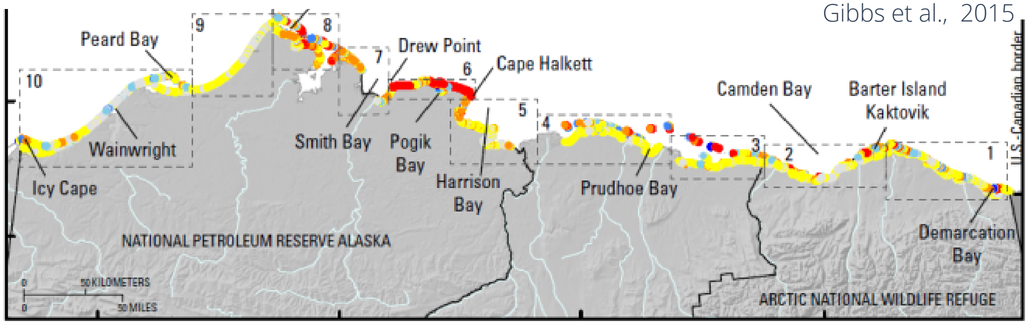

Gibbs et al., 2015