The fast-changing coast of Tuktoyaktuk Peninsula (Beaufort Sea, Canada): geomorphological controls on changes between 1985 and 2020

Bernardo Costa (1) Gonçalo Vieira (1) Dustin Whalen (2)

(1) Centre of Geographical Studies, IGOT, University of Lisbon, Portugal

(2) Natural Resources Canada, Dartmouth, Nova Scotia, Canada

ARCTIC SCIENCE SUMMIT WEEK
26 - 31 March 2022
Tromsø, Norway
#ASSW2022
IASC

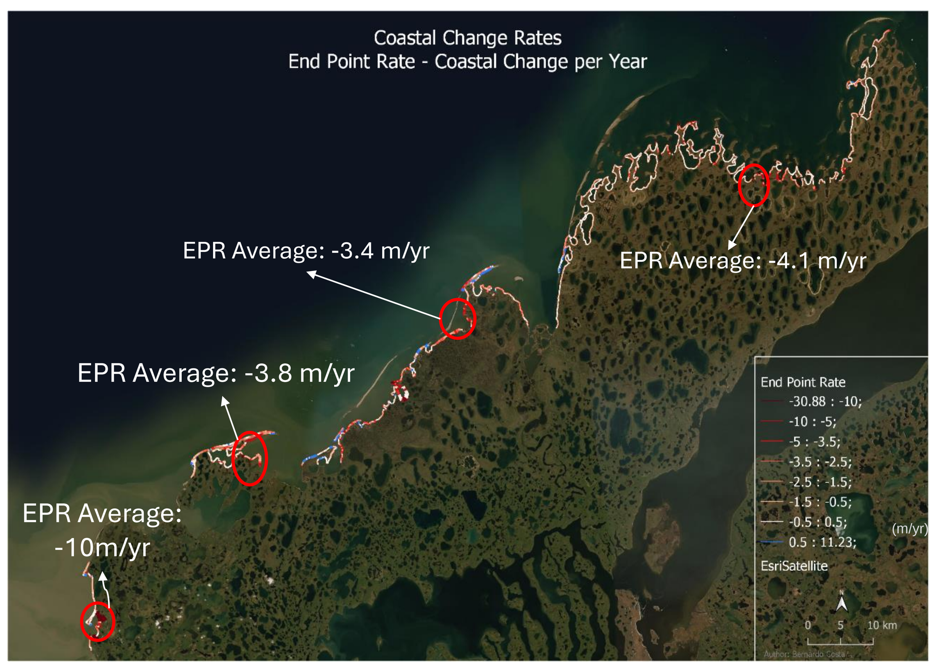
Recent Arctic Coastal Change

- Arctic permafrost coasts comprise more than 30% of Earth's coastlines. Under current climate change predictions, Arctic coastlines are likely to become one of the most impacted environments on Earth (Cunliffe et al., 2019; Jones et al., 2020; Lantuit et al., 2012).
- Coastal retreat is widespread throughout the Arctic Ocean, being one of the main processes degrading permafrost and releasing large amounts of sediment, organic matter, and nutrients to the ocean and the atmosphere (Cunliffe et al., 2019; Lantuit et al., 2012; Overduin et al., 2014; Wegner et al., 2015).
- Sea ice extent reduction and increments in the duration of the open water period and sea ice surface temperatures, along with absolute and relative sea-level rise, subsiding and warming permafrost landscapes and increased storminess and wave heights, combine promoting coastal erosion. (Barnhart et al., 2016; Biskaborn et al., 2019; Casas-Prat & Wang, 2020; Jones et al., 2020; Joyce et al., 2019; Kim et al., 2021; Lim et al., 2020; Perovich et al., 2020; Timmermans & Labe, 2020)

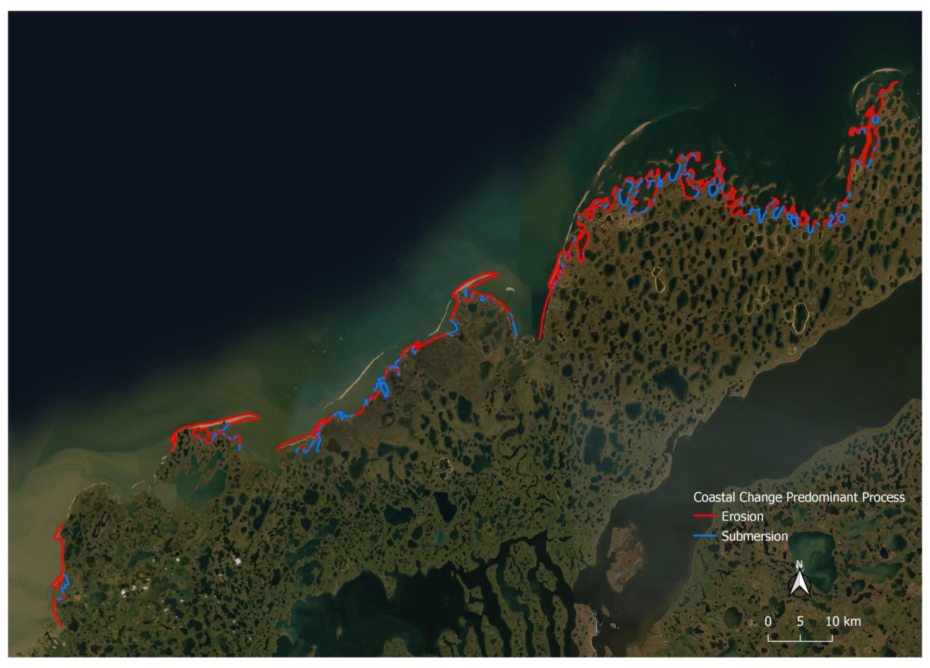
The Tuktoyaktuk Peninsula's Changing Environment

- The Tuktoyaktuk Peninsula is located in the Inuvik Region of the Northwestern Territories of Canada, in the Inuvialuit Settlement Region.
- The region is composed of Holocene – Late Pleistocene sedimentary deposits overlaying continuous ice-rich permafrost. (Angelopoulos et al., 2020; Solomon, 2005; Zwieback et al., 2018).
- The Tuktoyaktuk Peninsula has high ground ice content in coastal areas, being more vulnerable to thaw and erosion as temperature increases (Bush et al., 2014).
- Thermokarst lakes expanded from ancient river channels, abandoned throughout the Laurentide deglaciation and partially layered by eolian sand formations during the last glacial and early Holocene (French, 2007; Wolfe et al., 2020).

Coastline Change Analysis

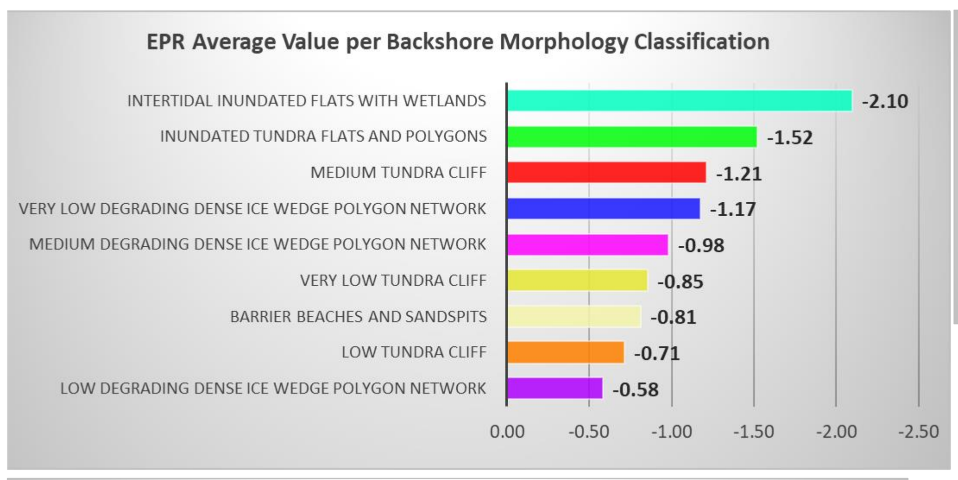


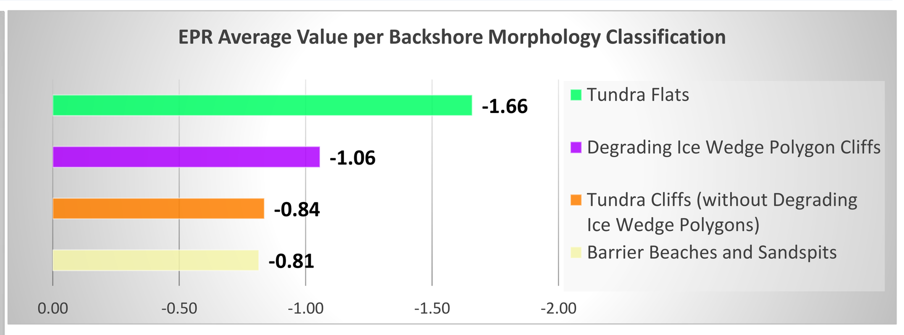
- Average EPR Value: -1.06 m/yr

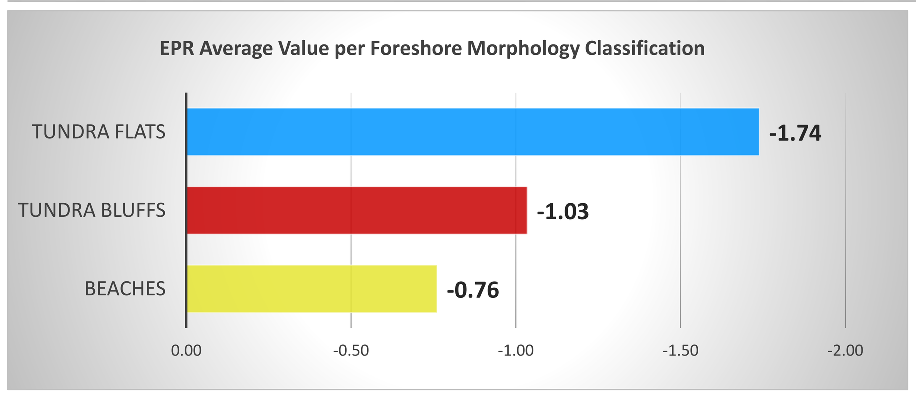


- Submersion represent 65% of retreat cases above 4 m/yr – High shoreline retreat do not necessarily suggest volume losses and carbon emitted.

Geomorphological Controls on Shoreline Dynamics







Backshore Morphology:

- Intertidal Inundated Flats with Wetlands is the class with the highest average EPR value: -2.12. m/yr – Submersion
- Medium Tundra Cliffs, Inundated Tundra Flats with Wetlands, Barrier Beaches and Sandspits and Very Low Dense Degrading Ice Wedge Polygon Networks all have values above average (-1.06 m/yr).
- Tundra Flat morphologies are the ones in which the shoreline retreats more on average (-1.66 m/yr) – mostly submersion.

Foreshore Morphology:

- Foreshore beaches may have a hindrance effect to retreat, when comparing with Active Tundra Bluffs and Tundra Flat foreshore.
- Tundra Flats present no barrier to incoming storm surges and sea level rise – promoting submersion and permafrost thaw.

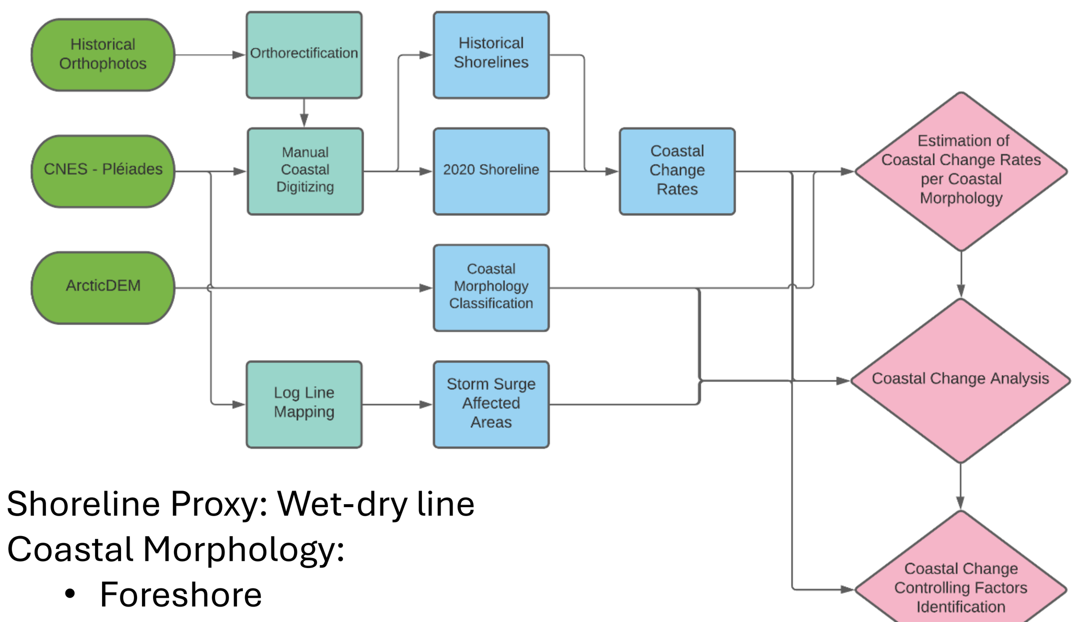
Conclusions

- **Average EPR**: **-1.06 m/yr** between **1985** and **2020**. EPR ranging between **-30.9** and **11.2 m/yr**
- The **Tuktoyaktuk Peninsula** has been **losing 48 ha/yr** for the past 35 years.
- **4 geomorphological units**: Tuktoyaktuk Harbour – Hutchinson Bay and Hutchinson Bay – Atkinson Point display higher coastal retreat. McKinley Bay display more aggradation.
- The results point to the **influence of coastal morphology and geomorphological factors** in **coastal change** – **Tundra Flats** have the **highest EPR values** (in backshore and foreshore). **Degrading ice wedge polygons** on cliffs is a local factor **enhancing coastal retreat**.
- **Local factors** need **external factors** to act, but it is **the former** which **determine** the **rate** of **coastal change** – the better **assessment** of **regional controlling factors** could also **help** to **clarify** the true **influence of local controlling factors**.

Objectives

I. **Mapping Tuktoyaktuk Peninsula's coastline at different time-steps using remote sensing imagery;**
II. **Quantifying the recent coastline change rates;**
III. **Characterizing the coastal morphology;**
IV. **Assessing coastline change dynamics according to coastal geomorphology;**

Methods



Shoreline Proxy: Wet-dry line

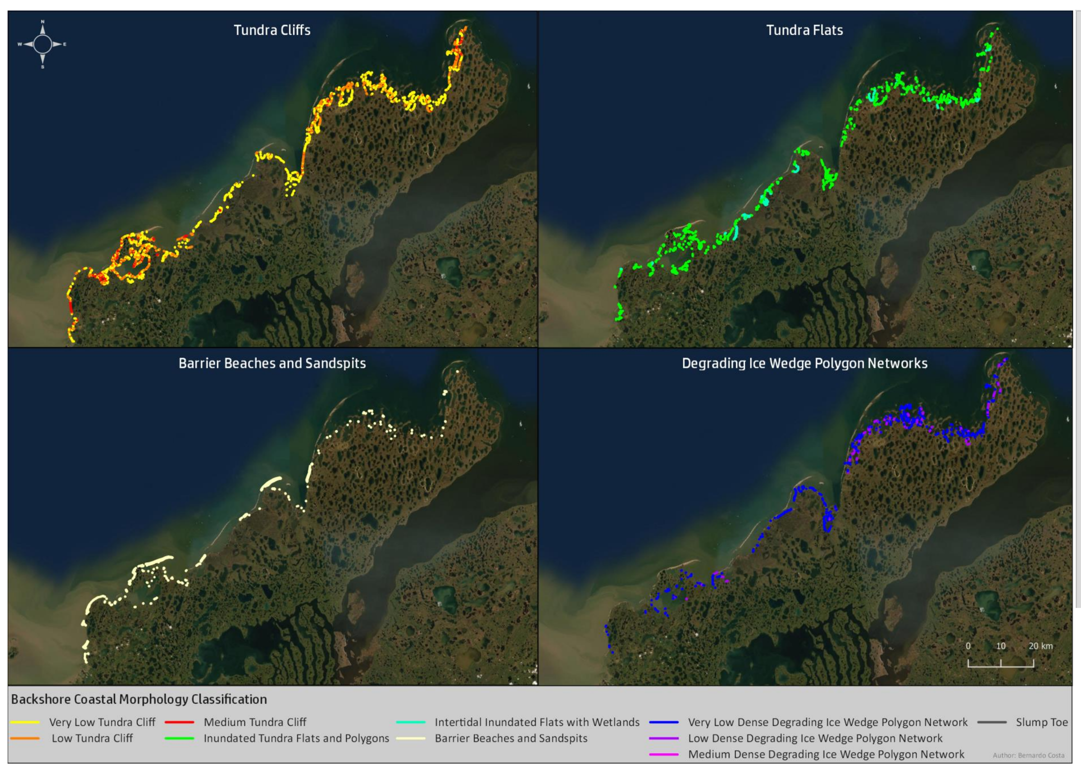
Coastal Morphology:

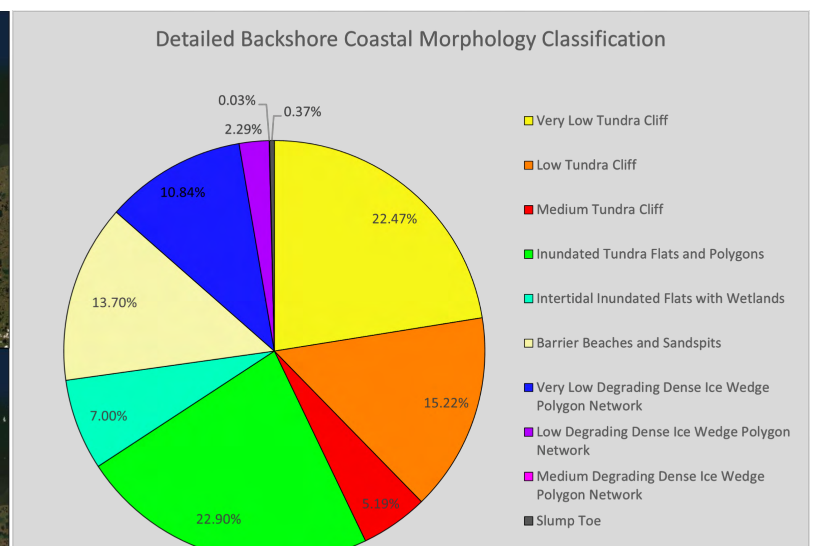
- Foreshore
  - Beach
  - Tundra Flats
  - Active Cliffs/Bluffs
- Backshore
  - Tundra Cliffs (further divided by height and ice wedge occurrence)
  - Tundra Flats (further divided by foreshore intertidal lakes existence)
  - Barrier Beaches and Sandspits

- Airbus CNESPleaides 2020 Imagery: its persistent-mode enables sequence image capturing over 12 images, 8 s apart with 0.5m resolution at a regional scale (Almar et al., 2019); this level of detail has allowed to study the Arctic's coastlines in a further detail and accuracy.
- Historical Photos were provided by the Natural Resources Canada, on which a orthorectification was made (0.76m).
- The Coastal Change Rates from 1985 to 2020 were calculated using the DSAS software package.

Coastal Geomorphology of the Tuktoyaktuk Peninsula

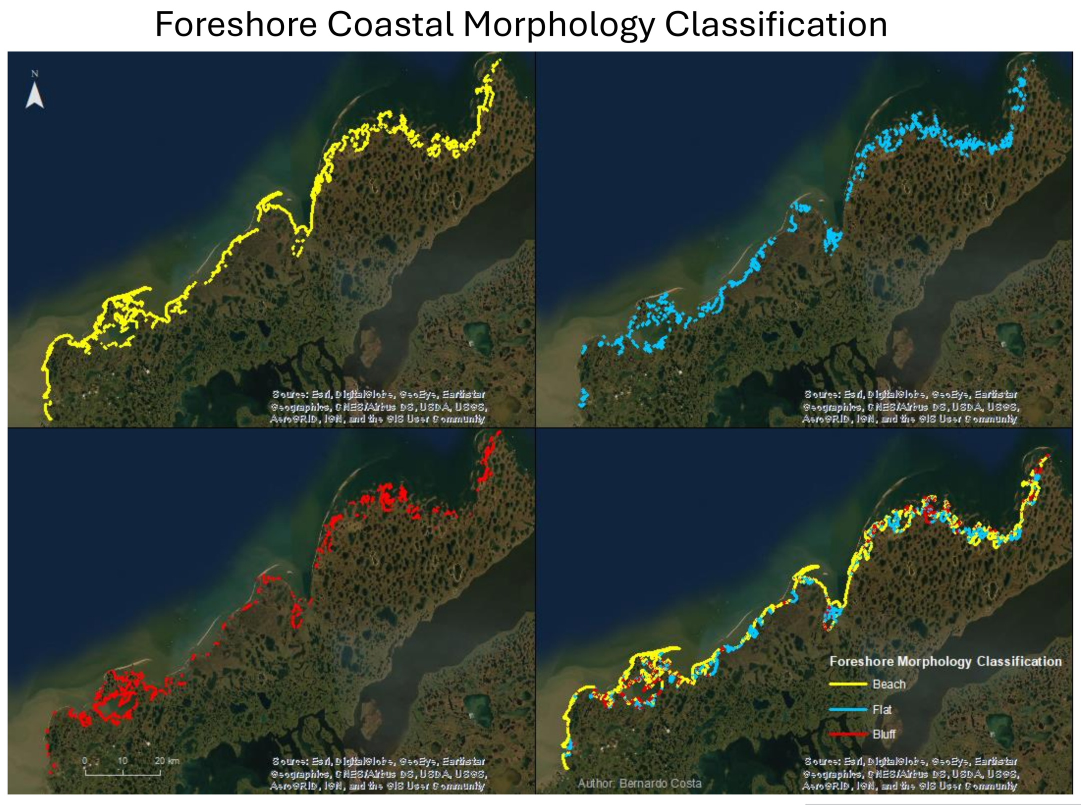
Backshore Coastal Morphology Classification





- Inundated Tundra Flats and Wetlands and Very Low Tundra Cliffs are the prevailing Backshore Coastal Morphology with similar values each (c. 23%).
- Low Tundra Cliffs (15%), Barrier Beaches and Sandspits (c. 14%) and Very Low Degrading Ice Wedge Polygon Network (c. 11%) are the remaining five most extensive classes.
- The least extensive classes are Medium Degrading Dense Ice Wedge Polygon Network and Slump Toe

Foreshore Coastal Morphology Classification



- Beach (51%) is the predominant Foreshore Morphology in the Tuktoyaktuk Peninsula.
- ~34% of the seaward edge is Tundra Flats.
- Active Bluffs compose 15%.

Longshore currents predominantly SW-NE.

Geomorphologic Units:

- Tuk Harbour – Hutchinson Bay: sandy unit with Barrier Beaches protecting lagoons, large bays, large lakes with NE-SE orientation, more driftwood deposits. Highest retreat – Average EPR: -2.03 m/yr
- Hutchinson Bay – Atkinson Point: small lakes, coastline with SW-NE orientation, more Tundra Flats and Degrading Ice-wedge Cliffs, offshore barrier islands. Average EPR: -1.2 m/yr.
- McKinley Bay: longshore currents flow to the inner portion of the bay, large lakes with N-S orientation. Most stable unit – Average EPR: -0.77 m/yr.
- Seal Bay – Cape Dalhousie: complex and sinuous coast, breaching of thermokarst lakes, barrier islands protect coast (if the wind was from the NE = more retreat). Lakes are oval and similar in size coastline parallel to lake orientation. Average EPR: -0.8 m/yr.

Geomorphologic Units

References

Almar, R., Bergsma, E., Maisongrande, P., & de Almeida, L. (2019). Wave-derived coastal bathymetry from satellite video imagery: A showcase with Pleiades persistent mode. *Remote Sensing of Environment*, *231*(December 2018), 111263. https://doi.org/10.1016/j.rse.2019.111263
Angelopoulos, M., Overduin, P., Miesner, F., Grigoriev, M., & Vasiliev, A. (2020). Permafrost in the Northern Hemisfere. *Permafrost and Periglacial Processes*, *31*(3), 1. https://doi.org/10.1002/ppp.2082
Barnhart, K., Miller, C., Overeem, I., & Kay, J. (2016). Mapping the future expansion of Arctic open water. *Nature Climate Change*, *6*(3), 280–285. https://doi.org/10.1038/nclimate2848
Biskaborn, B., Smith, S., Noetzli, J., Matthes, H., Vieira, G.,... Lantuit, H. (2019). Permafrost is warming at a global scale. *Nature Communications*, *10*(1), 1–11. https://doi.org/10.1038/s41467-018-08240-4
Bush, E., Loder, J., James, T., Mortsch, L., & Cohen, S. (2014). An Overview of Canada's Changing Climate. Em F. Warren & D. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (pp. 23–64). Government of Canada.
Casas-Prat, M., & Wang, X. L. (2020). Projections of Extreme Ocean Waves in the Arctic and Potential Implications for Coastal Inundation and Erosion. *Journal of Geophysical Research: Oceans*, *125*(8). https://doi.org/10.1029/2019JC015745
Cunliffe, A., Tanski, G., Radosavljevic, B., Palmer, W., Sachs, T., Lantuit, H., Kerby, J., & Myers-Smith, I. (2019). Rapid retreat of permafrost coastline observed with aerial drone photogrammetry. *Cryosphere*, *13*(5), 1513–1528. https://doi.org/10.5194/tc-13-1513-2019
French, H. (2007). The Periglacial Environment. Em *The Periglacial Environment* (4th Editio). John Wiley & Sons Ltd,. https://doi.org/10.1002/9781118684931
Jones, B., Irrgang, A., Farquharson, L., Lantuit, H., Whalen, D.,... Vieira, G. (2020). Coastal Permafrost Erosion. *NOAA Arctic Report Card 2020*, 1–10. https://doi.org/10.25923/e47w-dw52
Joyce, B. R., Pringle, W. J., Wirasaet, D., Westerink, J. J., Van der Westhuysen, A. J., Grumbine, R., & Feyen, J. (2019). High resolution modeling of western Alaskan tides and storm surge under varying sea ice conditions. *Ocean Modelling*, *141*(December 2018), 101421. https://doi.org/10.1016/j.ocemod.2019.101421
Kim, J., Murphy, E., Nistor, I., Ferguson, S., & Provan, M. (2021). Numerical Analysis of Storm Surges on Canada's Western Arctic Coastline. *Journal of Marine Science and Engineering*, *9*(3), 326. https://doi.org/10.3390/jmse9030326
Lantuit, H., Overduin, P., Couture, N., Wetterich, S., Aré, F.,... Vasiliev, A. (2012). The Arctic Coastal Dynamics Database: A New Classification Scheme and Statistics on Arctic Permafrost Coastlines. *Estuaries and Coasts*, *35*(2), 383–400. https://doi.org/10.1007/s12237-010-9362-6
Lim, M., Whalen, D., J. Mann, P., Fraser, P., Berry, H. B;... Woodward, J. (2020). Effective Monitoring of Permafrost Coast Erosion: Wide-scale Storm Impacts on Outer Islands in the Mackenzie Delta Area. *Frontiers in Earth Science*, *8*(October), 1–17. https://doi.org/10.3389/feart.2020.561322
O'Rourke, M. (2017). Archaeological site vulnerability modelling: The influence of high impact storm events on models of shoreline erosion in the Western Canadian arctic. *Open Archaeology*, *3*(1), 1–16. https://doi.org/10.1515/opar-2017-0001
Overduin, P., Strzelecki, M., Grigoriev, M., Couture, N., Lantuit, H., St-Hilaire-Gravel, D., Günther, F., & Wetterich, S. (2014). Coastal changes in the arctic. *Geological Society Special Publication*, *388*(1), 103–129. https://doi.org/10.1144/SP388.13
Perovich, D., Meier, W., Tschudi, M., Hendricks, S., Petty, A., Divine, D., Farrell, S., Gerland, S., Haas, C., Kaleschke, L., Pavlova, O., Ricker, R., Webster, M., & Wood, K. (2020). Sea Ice. *NOAA Arctic Report Card 2020*, 1–10. https://doi.org/10.25923/n170-9h57
Solomon, S. (2005). Spatial and temporal variability of shoreline change in the Beaufort-Mackenzie region, northwest territories, Canada. *Geo-Marine Letters*, *25*(2–3), 127–137. https://doi.org/10.1007/s00367-004-0194-x
Timmermans, M.-L., & Labe, Z. (2020). Sea Surface Temperature [in «Arctic Report Card 2020»]. *NOAA Arctic Report Card 2020*, 53–57. https://doi.org/10.25923/v0fs-m920
Wegner, C., Bennett, K. E., de Vernal, A., Forwick, M., Fritz, M.,... Werner, K. (2015). Variability in transport of terrigenous material on the shelves and the deep Arctic Ocean during the Holocene. *Polar Research*, *34*(1), 1–19. https://doi.org/10.3402/polar.v34.24964
Wolfe, S., Murton, J., Bateman, M., & Barlow, J. (2020). Oriented-lake development in the context of late Quaternary landscape evolution, McKinley Bay Coastal Plain, western Arctic Canada. *Quaternary Science Reviews*, *242*(11), 106414. https://doi.org/10.1016/j.quascirev.2020.106414
Zwieback, S., Kokelj, S., Günther, F., Boike, J., Grosse, G., & Hajnsek, I. (2018). Sub-seasonal thaw slump mass wasting is not consistently energy limited at the landscape scale. *Cryosphere*, *12*(2), 549–564. https://doi.org/10.5194/tc-12-549-2018.

EU grant agreement No. 773421

Climate Change Preparedness in the North Program

Acknowledgements: A special appreciation to the Community of Tuktoyaktuk and the Inuvialuit People for giving us the continued support to work and to better understand coastal landscape change on their lands.