Proceedings of the 9th International Conference on Physical Modelling in Coastal Engineering (Coastlab24)

Delft, Netherlands, May 13-16, 2024

Extended Abstract**,** DOI: 10.59490/coastlab.2024.796

Coastlab24
13-16 May 2024, Delft University of Technology, NL

ARCTIC COASTLINE EROSION: NOVEL EXPERIMENTAL AVENUES HELP UNDERSTAND ITS RESPONSE TO A CHANGING CLIMATE

NILS GOSEBERG[1,2], NILS MICHALKE[1], JUSTUS GIMSA[3,4], DAVID SCHÜRENKAMP[1], ROLAND KRUSE[5], RALF JÄNICKE[5], HUGUES LANTUIT[3,4]

[1] *Leichtweiß-Institute for Hydraulic Engineering and Water Resources; Division of Hydromechanics, Coastal and Ocean Engineering; Technische Universität Braunschweig; Beethovenstraße 51a, 38106 Braunschweig, Germany. d.schuerenkamp@tu-braunschweig.de, n.goseberg@tu-braunschweig.de, n.michalke@tu-braunschweig.de*

[2] *Coastal Research Center, Coastal Research Center, Joint Research Facility of Leibniz Universität Hannover and Technische Universität Braunschweig, Hannover, Germany, goseberg@fzk.uni-hannover.de*

[3] *Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam, Germany. justus.gimsa@awi.de, hugues.lantuit@awi.de*

[4] *Institute of Geosciences, University of Potsdam, Potsdam, Germany*

[5] *Institute of Applied Mechanics, Technische Universität Braunschweig, Braunschweig, Germany, r.kruse@tu-braunschweig.de, r.janicke@tu-braunschweig.de*

KEYWORDS: Arctic coastline, coastal erosion, experimental methods

1 INTRODUCTION

Permafrost coastlines represent a large portion of the world's coastal area and these areas have become increasingly vulnerable owing to the changing climate and its strong dynamics observed over the past decades (Irrgang *et al.*, 2022). The predominant mechanism of coastal erosion in these areas has been identified through several observational studies as thermomechanical erosion—a joint removal of sediment through the melting of interstitial ice (thermal energy) and abrasion from incoming waves (mechanical energy). Longer summer seasons where -due to a much lower ice cover- waves can more freely propagate towards Arctic coastlines have exacerbated coastal erosion (Overeem *et al.*, 2011) and which is projected to increase inline with Arctic warming (Nielsen *et al*., 2022). Erosional effects have long been a subject of the coastal engineering community, however, the combined effect of wave attack on shorelines, in combination with thermomechanical processes has largely been overlooked. The implications of Arctic coastline erosion are plenty: local communities face relocations of whole settlements, loss of valuable property or cultural heritage while acceleration in thaw causes a much higher influx of environmental contaminants and nutrients into the Arctic Ocean. It is hence crucial to engage this pressing challenge with long established and novel methods originating from the coastal engineering community. This work provides an overview over novel avenues that are useful for a better understanding of the processes and interactions of ocean waves and Arctic coastlines. It also presents some of the recent erosional observations from a cold room flume and micro CT measurements.

2 MATERIAL AND METHODS

A first study, conceptually contributing to the understanding of the interaction between ocean waves and permafrost coastlines has been presented by Kobayashi *et al*. (1999) who described the thermal-mechanical process in an analytical model. In more recent literature, the overall process has been delineated into thermo-denudation and thermo-abrasion; experimental observations helping to accurately determine process-describing variables such as the convective heat transfer coefficient, niche growth rates and loose sediment transport towards the open ocean remain scarce. This is not least because useful experimental setups require strong control over all environmental conditions that influence the physical processes under consideration. In that context, Korte *et al*. (2020) was the first to provide a generational model approach (GMA) and framework to assess the suitability of experimental setups for Arctic coastline experimentation. The model approach includes 6 model generations, comprising 2D and 3D approaches to observe Arctic coastline erosion experimentally (see Fig. 1).

Sample experiments have been conducted in a cold room installation at the Leichtweiß-Institute for Hydraulic Engineering and Water Resources (LWI) of Technische Universität Braunschweig, where an 8 m long wave flume has been installed. The installation can be classified to be a GMA1-level experiment, with freshwater, regular wave conditions, homogeneous frozen sediment specimen, controlled constant air and water temperature in a 2D setting. We explicitly note that these conditions are not intended to model reality but to build fundamental knowledge, aiming to contribute process-based understanding of the thermomechanical response to wave attack. The cliff was in constant contact with the water, with no slope installed. Still water levels have been kept constant for the erosion observations. Erosion observation is performed through side-view camera observation and a frontal solid-state lidar scanner installation, that allows to record the overall erosional development and niche growth rate. Internal specimen temperature was measured through a set of installed PT1000 thermocouple sensors.

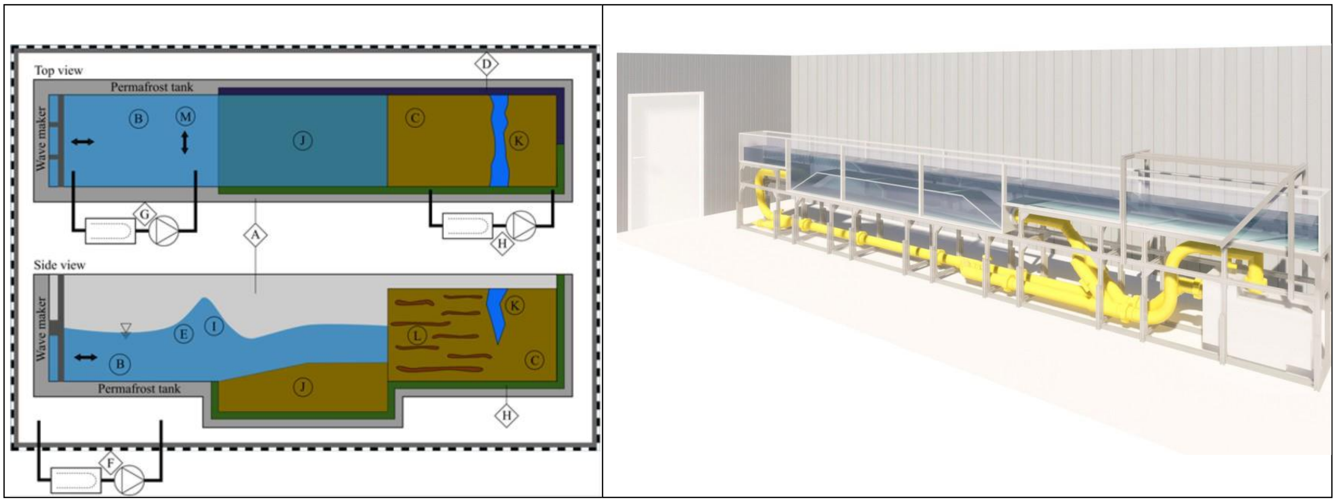

Figure 1. (Left) Framework design for investigating laboratory-based permafrost coastline erosion. Permafrost 3D-tank. For additional explanations on the figure see Korte *et al.* (2020). (Right) Visualization of the wave flume in the LWI cold room, not to scale, dimensions according to Korte *et al.* (2020).

3 RESULTS

First test observations show typical features of the erosion of frozen unconsolidated cliffs. For the test set-up, frozen specimens were artificially produced by compacting very fine uniform sand in order to produce uniform samples that can be compared to each other. The frozen samples' internal soil structure has been investigated and visualized by high-resolution micro-CT scans, revealing the grain-ice composition of samples. Thawing and subsequent erosion occurred nearly exclusively at the interface of water and sample. Wave action played an important role in defining the contact zone between water and frozen material, as well as driving the mass exchange in the erosional niche and the removal of potentially isolating unfrozen particles at the frozen zone. The tested frozen coast equivalent sediment samples are highly sensitive towards the water temperature, therefore adequate cooling installations and a sophisticated water temperature control are needed in order to get reproducible results. The results are pointing towards a high sensitivity of the process of permafrost coastal erosion against the combined action of thermoabrasion and thermodenunation, highlighting the importance of the changes permafrost coastal erosion faces with Arctic warming (Gimsa *et al*., 2023).

4 CONCLUSIONS

This work presents conceptual progress towards novel experimental procedures and provides insight into the challenges related to the observation of Arctic coastline erosion in laboratory settings. We report common pitfalls, and provide recommendations for the developments that are required of the community to better serve and facilitate future experimental work to understand the physical processes. This work also reports on early results related to the determination of the convective heat transfer coefficient and the challenges that are ahead for more accurate and precise measurements. The overall work contributes novel experimental avenues towards a better physical understanding of the Arctic coastline erosion.

REFERENCES

Gimsa, J.; Lantuit., H.; Goseberg, N.; Schürenkamp, D. Driving mechanisms of permafrost coastal erosion investigated by laboratory model experiments. In: Fernández-Fernández, J.M; Bonsoms, J.; Garcia-Oteyza, J.; Oliva, M., editors. 6th European Conference on Permafrost; 2023 Jun 18-22; Puigcerdà, Spain.

Irrgang, A.M.; Bendixen, M.; Farquharson, L.M. et al. Drivers, dynamics and impacts of changing Arctic coasts. Nat Rev Earth Environ. 2022, 3,39–54.

Kobayashi, N.; Vidrine, J.C.; Nairn, R.B.; Soloman, S.M. Erosion of frozen cliffs due to storm surge on Beaufort Sea Coast. J. Coast. Res. 1999, 15, 332–344.

Korte, S.; Gieschen, R.; Stolle, J.; Goseberg, N. Physical Modelling of Arctic Coastlines—Progress and Limitations. Water. 2020, 12, 2254.

Nielsen, D.M.; Pieper, P.; Barkhordarian, A.; Overduin, P.P.; Ilyina, T.; Brovkin, V.; Baehr, J.; Dobrynin., M. Increase in Arctic coastal erosion and its sensitivity to warming in the twenty-first century. Nat. Clim. Chang. 2022 ,12, 263–270.Overeem, I.; Anderson, R.S.; Wobus, C.W.; Clow, G.D.; Urban, F.E.; Matell, N. Sea ice loss enhances wave action at the Arctic coast. Geophys. Res. Lett. 2011, 38, 1–6.