Response to referee Gregor Luetzenburg

We would like to thank the reviewer for evaluating our manuscript and for the useful comments, which helped to improve it. In the following, we provide a reply to the points discussed by the reviewer as well as changes in the manuscript.

The comments of the reviewer are written in **bold**, the extracts of the manuscript in *italics* with changes highlighted in blue and line numbers referring to the revised manuscript.

The novelty of this work lies in measuring coastal cliff top retreat on Svalbard over 50 years on a high spatial resolution. Overall, most interpretations and conclusions are supported by the evidence, the assumptions are valid, the methodology is sound, the evidence is adequate, and the conclusions logically follow the results. However, the authors do not present any data to build a relationship between the measured retreat rates and potential environmental driving factors that can explain the increase in cliff top retreat and they cannot fulfill their third objective. Therefore, the final conclusion of the manuscript (retreat rates increase with climate change) remains highly speculative (although likely) and the manuscript lacks important scientific progress. Currently, the manuscript requires major improvements to make a substantial progress for the research field.

Overall, I agree with the comments from RC1. Therefore, I will focus on some suggestions to improve the manuscript. Although it takes an effort to incorporate all the suggested changes, I highly encourage the authors to go the extra mile and improve this manuscript. I think, if revised properly, this could become an important contribution for the field of Arctic coastal dynamics. I have six general suggestions to improve this study:

First, the authors mention coastline retreat throughout the manuscript, but they measure cliff top retreat. I agree with the authors that the cliff top can be detected more easily from historical aerial images, but I don't agree with the statement: 'we are confident that the shift of the top of the cliff is representative of the coastal retreat'. The authors do not provide a reference or any data to corroborate this statement. In contrast, a recent study has found that the cliff top is eroding with a higher magnitude, but a lower frequency compared to the cliff toe that is eroding with a lower magnitude but a higher frequency (Swirad et al. 2022, https://doi.org/10.1016/j.geomorph.2022.108318). Additionally, if the cliff is not a plunging cliff, which remains unclear in the authors description of the study site, the beach fronting the cliff plays an important role in the coastline retreat as well. The easiest solution would be to write cliff top retreat instead of coastline retreat throughout the manuscript. However, the most interesting solution would be to establish a relationship between coastline retreat and cliff toe as well as cliff top retreat. The latter is directly leading to the next point.

We agree with the reviewer that a better explanation was needed why we used the cliff top retreat as a proxy for coastal erosion along Brøgger peninsula. To follow the suggestion of the reviewer, we added a new analysis in the revised manuscript. It is explained in the methods (Sect. 3.3), has an own new section in the results with two new figures (Sect. 4.2) and is mentioned at the beginning of the discussion (Sect. 5.1). The changes are as following:

Explanation in the methods:

Line 178: *The coastline was digitized along the top of the cliff (Fig. 1), which is slightly retreated compared to the actual shoreline, i.e. the boundary between water and land, due to unconsolidated sediments on top of the bedrock (Sect. 2). The top of the cliff has been used as a proxy for the shoreline in previous studies (e.g. Irrgang et al., 2018). However, it is important to note that the cliff top and the cliff foot can erode at different rates, and that the presence of frontal beaches can affect the erosion processes (Swirad and Young, 2022). To address this, we conducted an analysis to confirm the suitability of the cliff top retreat as a proxy for coastal retreat at our field site. To do so, we compared the distance between the cliff top and the shoreline, as well as the width of the frontal beaches for 53 cross-sections along the coast with a proximate distance of 100* m. *Hereby, we used the orthoimages from 2010 and 2021 since the shoreline could not be reliably detected in the orthoimages from 1990 and 1970.*

The new section in the results:

Line 282: ***4.2 Cliff top retreat as a proxy for coastal retreat***

The analysis of 53 cross-sections along the investigated coastline of Brøgger peninsula shows that the distance between the cliff top and the shoreline changed only slightly by less than 0.10 m *between 2010 and 2021. An example of a representative cross-section is given in Fig. 4. Here, the distance from the cliff top to the shoreline was 32.35* m *in 2010 and reduced marginally to 32.19* m *in 2021. Meanwhile, the width of the beach increased slightly from 2.82* m *in 2010 to 3.05* m *in 2021. This example showcases that the cliff top retreats at similar rates as the shoreline.*

The mean distance for all cross-sections was 17.44 m *in 2010 and reduced marginally to 17.35* m *in 2021. The change in distance of 0.09* m *is considerably smaller than the uncertainty associated with the digitization of the coastline (Table 2), i.e. the position of the cliff top. Also, the distribution of the distances is comparable between those two years with clusters of cliff top-shoreline-distances around 4* m, *12* m *and 24* m *(Fig. 5).*

In addition, we analyzed the width of the frontal beaches along the 53 cross-sections. The results show that the width was only slightly reduced from 2.23 m *in 2010 to 2.09* m *in 2021. Furthermore, the characteristics of the cliff morphology did not change significantly: Seawater reaching the cliff foot directly was detected for 40 % (2010) and 42 % (2021) of the cross-sections, while 47 % (2010) and 45 % (2021) had frontal beaches with a high potential of inundation during stormy conditions (as the example given in Fig. 4), and only 7 % (2010, 2021) had extended frontal beaches, which could limit the effect of wave* *activity on the cliff foot. Both the small change in beach width and cliff morphology are indicators, that the eroded material is transported away effectively from the foot of the cliff and that no significant accumulation of eroded material occurs. Furthermore, we can conclude that the potential for wave activity is not affected due to changes in the cliff morphology over the years.*

As our results suggest that the average distance between the cliff top and the shoreline or the width of the beach does not change significantly over time, we are confident that the retreat of the cliff top is an applicable proxy for the coastal retreat at our field site.

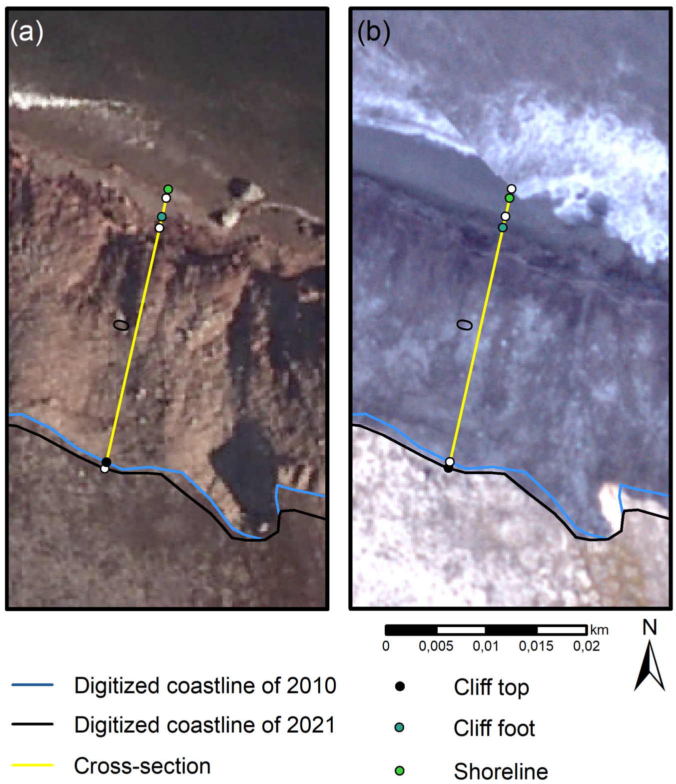

Figure 4. *Cross-section with cliff top, cliff foot and shoreline for (a) 2010 and (b) 2021. The background shows the respective orthoimages. Source of the orthoimage: (a) Norwegian Polar Institute, https://geodata.npolar.no/; (b) Svalbard Integrated Arctic Earth Observing Systems SIOS, not publicly available.*

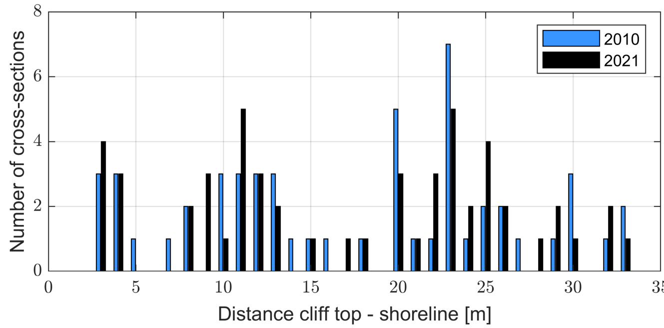

Figure 5. *Number of cross-sections that show a certain distance between cliff top and shoreline for 2010 and 2021. The distribution only changes slightly with clusters around 4* m*, 12* m *and 24* m.

At the beginning of the discussion, we added the following statement:

Line 370: *In this study, we analyzed the retreat of the cliff top along the lithified coast of Brøgger peninsula. We showed that this rate is representative of the coastal retreat (Sect. 4.2) so that a comparison with the erosion along other coastlines on Svalbard and in the Arctic can be drawn.*

Second, the authors investigate cliff top retreat in 2D. Compared to low lying coastal environments like deltas and spits, coastal cliffs are unique because of their abrupt change in elevation. To fully understand the dynamics of coastal cliffs, including cliff toe, cliff face and cliff top retreat, the investigation requires 3D data. Based on cross-cliff elevation profiles derived from 3D elevation data, a relationship between cliff morphometrics (e.g. beach width and slope, cliff top and toe elevation, and cliff face slope) and cliff retreat rates can be built. Depending on those relationships, environmental driving factors (overland flow, ground temperature, wave run-up, sea-ice content, sea-level change etc.) can be detected and changes over time can be discussed. 3D data (point clouds, DEMs etc.) of coastal cliffs in the Arctic is rare, but necessary to advance the understanding of coastal cliff dynamics in the Arctic. Without 3D change observations, this study lacks progress in the field as 2D retreat rates of cliffs are investigated already at other places on Svalbard which is discussed by the authors in chapter 5.1.

We understand the point of the reviewer that it would be beneficial to include 3D data to differentiate between the cliff toe, cliff face and cliff top. However, such 3D data (DEMs or point clouds retrieved from photogrammetry or laser scanning) is not available for the field site and investigated time span.

As no 3D data was used in our study, the reviewer questions the progress of our work. We want to emphasize that the novelty of this study lies in the long-term retreat rates over 51 years, a time frame that has not been investigated in Svalbard before. Especially as coastal cliff dynamics can show a high variability throughout the years, a long time span contributes to the understanding of the coastal cliff top retreat on Svalbard. In contrast, previous studies have investigated coastal cliff erosion through terrestrial photogrammetry or laser scanning and by doing so, they retrieved 3D data, but could only cover short time spans (we refer here to section 5.1 of our manuscript).

Third, the current discussion chapter 5.2 presents no new insights because the authors present no data to discuss the potential environmental driving factors. In the current version of the chapter, the authors describe the conceptual model explaining how those cliffs erode which is already understood. What the scientific community is lacking is data showing if the theoretical understanding is accurate and applicable. For example, the authors discuss potential differences in exposure to waves and storms of the northeast and southwest facing coastlines. The topographically downscaled ERA5 climate data could be used to create a wave rose of significant wave height. This would base the assumption in the manuscript on actual data and increase the overall strength of the manuscript, providing that the relationship between cliff retreat rate and environmental driving factors are understood. The same goes for other potential environmental driving factors, e.g. provide actual data on sea-ice changes in the study area. The available data from the downscaled ERA5 data is very interesting, but the authors do not present the data in the main results. The discussion of these results is very short.

We followed the suggestion of the reviewer and added a more detailed analysis of the potential environmental driving factors. To do so, we added a new section in the methods (Sect. 3.5) and the results (Sect. 4.5) and extended significantly the discussion (Sect. 5.2). As the reviewer stated correctly, the exposure to waves and storms as well as the sea ice are the most important drivers due to their influence on mechanical abrasion. To base our assumptions on actual data as suggested by the reviewer, we added in the main manuscript data on the increase in storminess (here we took data from a station in ca. 8 km distance as the downscaled ERA5 data showed a large scatter) and an analysis of the increase in the potential fetch. All these factors are now thoroughly discussed in Sect. 5.2.

Other minor influencing factors are presented in the appendix to not distract from the important discussion points in the main manuscript.

Changes in the methods:

Line 249: ***3.5 Analysis of climate conditions***

We analyzed trends in wind speed and changes in the distance to the sea ice edge (potential wave fetch), as these factors control the interaction between wind and water and therefore the wave field (Barnhart et al., 2014), playing an important role along the coastline of Brøgger peninsula due to mechanical abrasion through wave action. The wind speeds records were taken from the Ny-Ålesund climate station SN99910 (78°55’23” N, 11°55’55” E; Fig. A1), covering the time period 1975 to

2020 (Norwegian Centre for Climate Services, 2023). We extracted days during which mean hourly wind speeds of at least 10.8 $\mathrm{m\,s^{-1}}$ *(strong breeze or stronger) were recorded, corresponding to large waves of approximately 3 to 4* m *(NTNU, 2023).*

We also analyzed the distance to the sea ice edge in northwesterly direction (corresponding to the open Fram Strait), which is the potential distance over which waves can build up. The analysis of this potential fetch was based on data provided by the Norwegian Meteorological Institute (2023) for the time period 1997 to 2023. Hereby, we define the sea ice edge as the given category of 10 to 40 % sea ice concentration, following Meier and Stroeve (2008) and Overeem et al. (2011), who applied a threshold of 15 %. We determined the mean distance to the sea ice edge for September for which 22 ice charts per year were available on average. For trend detection, we applied a Bayesian regression analysis (Särkkä, 2013), which is explained in Appendix A. In all other cardinal directions, land is found in about 10 to 15 km *distance, so that the potential fetch is limited.*

In addition, we used hourly ERA5 reanalysis data (Hersbach et al., 2020) in conjunction with the topography-based down-scaling routing TopoSCALE (Fiddes and Gruber, 2014) to analyze trends in mean annual air temperature, annual rain- and snowfall, as well as mean annual incoming longwave and shortwave radiation. The methods and detailed results for these climatic parameters are presented in Appendix A and Appendix B.

Changes in the results:

Line 349: ***4.5 Changes in climatic conditions***

Given the lithology along the coastline of Brøgger peninsula, mechanical abrasion through wave action is likely a dominant factor for erosion. Therefore, we focus in this section on the wind conditions and changes in the sea ice cover. Other factors, such as precipitation patterns, air temperature and radiation, are presented in Appendix B.

The trend analysis of wind speeds in Ny-Ålesund defined as a strong breeze or stronger (wind speeds >= 10.8 $\mathrm{m\,s^{-1}}$*, corresponding to large waves of approximately 3 to 4* m*; NTNU, 2023) shows an increase by 5.4 days per decade from approximately 65 days on average in the 1970s to 90 days in the last decade (Fig. 8a). However, due to the strong variability, the evidence in favor of a trend remains weak (Bayes factor < 0.5, Appendix A). Years with exceptionally many days of high wind speeds occurred in the early 1990s, while they decreased slightly in recent years. We emphasize that the climate station providing the data, is located approximately 8* km *away from the field area inside Kongsfjorden, where wind speeds are lower compared to the investigated field site. Wind speed measurements at the tip of Brøgger peninsula (available only since 2021) recorded 112 days with strong breezes in 2022 compared to 84 days in Ny-Ålesund (Norwegian Centre for Climate Services, 2023), thus highlighting the potential differences in wind regimes.*

In most cardinal directions, land is found in about 10 to 15 km *distance, so that the potential wave fetch over open water is limited here. However, in northwestern direction, the coastline of Brøgger peninsula is exposed to the open sea towards Fram Strait and the potential wave fetch is limited by the distance to the sea ice edge, which is displayed in Fig. 8b for the month of September. We detected an increasing trend from about 150* km *to 250* km *between 1997 and 2023, which accounts for approximately 39* km *per decade (Bayes factor 1-2, strong evidence in favor of the trend, Appendix A). The largest values with a mean distance to the sea ice edge of more than 300* km *were observed in 2020 and 2021.*

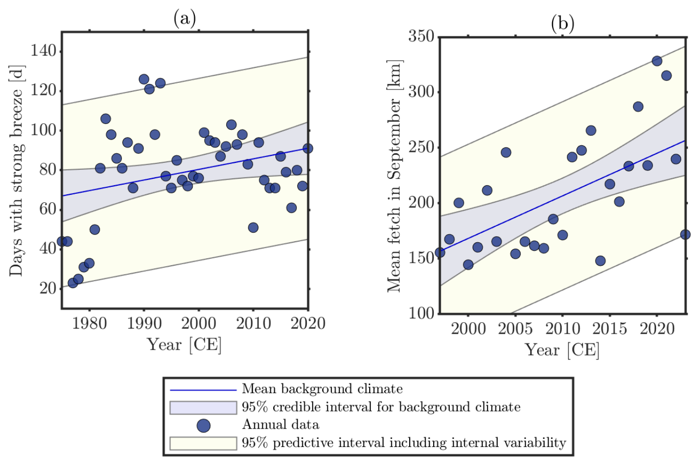

Figure 8. *(a) Days with a strong breeze (wind speeds >= 10.8* $\mathrm{m\,s^{-1}}$*) measured by the Ny-Ålesund climate station SN99910. They increased by 5.4 days per decade between 1975 and 2020. (b) Mean distance to the sea ice edge (potential wave fetch) in September in northwesterly direction. The distance to the sea ice edge increased by approximately 39* km *per decade between 1997 and 2023.*

Changes in the discussion:

Line 418: *Retreat rates of Arctic coastlines are governed by various drivers, dependent on the local coastal setting and environmental conditions (Irrgang et al., 2022). The lower part of the coastal cliffs is prone to abrasion, acting through the thermal and wave-driven mechanical energy of the sea (Are, 1988a, b) and intensive wetting-drying during open-water season (Strzelecki et al., 2017). We assume that these factors play an important role in coastal erosion along Brøgger peninsula, as overhanging rock walls with a retreated foot of the cliff can be observed (Fig. 1c). Abrasion is especially effective during stormy weather, which likely intensified in the area around Brøgger peninsula during the past decades, showing a positive trend of days with a strong breeze in the last decades (Fig. 8a). Furthermore, extreme cyclone events regularly occur in the Arctic North Atlantic, with 20 to 40 events during winter. In Ny-Ålesund, an increasing trend of six cyclones per decade was detected from 1979-2015, which can be related to a decreasing sea ice extent in the region and large-scale atmospheric circulation changes*

(Rinke et al., 2017). Single weather events like this can support landsliding and consequently, they can have a localized but pronounced influence on the retreat rates.

However, the impact of windiness and wind-induced wave action is expected to vary along the coastline of Brøgger peninsula. The northeast facing coastline is characterized by a relatively sheltered position within the Kongsfjorden system, with land in most cardinal directions within a range of 10 to 15 km. *This likely restricts the fetch and consequently wave activity, which may explain the lower coastal retreat rates in this sector. In contrast, the southwest facing coastline is more exposed to the open sea, especially in westerly and northwesterly directions in which the potential wave fetch is controlled by the distance to the sea ice edge in Fram Strait, which has clearly increased in the last decades (Sect. 4.5). Previous studies have shown that an increasing fetch results in wave growth (Casas-Prat and Wand, 2020b), increasing the capability for wave-driven erosion (Casas-Prat and Wang, 2020a). Therefore, the increasing distance to the sea ice edge towards the open Fram Strait likely increase the wave activity and thus mechanical abrasion along southwest sector of Brøgger peninsula, likely explaining the higher erosion rates found here.*

In addition to the large-scale sea ice conditions in Fram Strait, local sea ice coverage around the Brøgger peninsula can influence the thermal regime of the rock walls (Schmidt et al., 2021) and potentially also wave action and mechanical abrasion (Barnhart et al., 2014). Dahlke et al. (2020) provides an overview of sea ice extent around Svalbard from 1980 to 2016. The results show a considerable decrease in sea ice coverage during winter and spring in Forlandsundet (where the southwest facing coastline is located), decreasing from 50-70 % until the early 2000s to below 10 % in recent years. Kongsfjorden (where the northeast facing coastline is located) experienced an increase in sea ice extent from around 40 % to 60 % in the 1990s and a subsequent decrease to around 10 %. However, as our field area is located in the outer parts of Kongsfjorden (NE sector) and near the open Arctic ocean (SW sector) where typically less sea ice develops, even lower percentages of sea ice coverage are likely, with mostly ice-free conditions in the last decade.

Fourth, the only reason to include the rock surface temperature data in the manuscript is to directly couple it to cliff retreat rates. It would be super interesting to show a relationship between seasonal cliff retreat and rock surface temperature (e.g. cliff retreat is faster when rock surface temperature is higher). Without this data, I would delete chapter 4.3.

As we are investigating long time spans based on aerial images from 1970, 1990, 2010 and 2021, the temporal resolution of our data does not allow us to analyze seasonal changes in cliff retreat. However, we are still convinced that the data on the rock surface temperature gives a better understanding of the local permafrost conditions. There are plenty of studies describing the permafrost conditions around Ny-Ålesund (ca. 8 km distance to our fieldsite), however, they are typically not considering the permafrost conditions in the rock walls. Schmidt et al. (2021) (https://doi.org/10.5194/tc-15-2491-2021) described rock surface temperatures close to Ny-Ålesund and showed that coastal cliffs can feature higher rock surface temperatures than in-land permafrost. The data presented in this study shows that the rock surface temperatures are falling into a temperature range with decreased stability (as discussed in Sect. 5.2). Therefore, adding this data on the permafrost conditions along Brøgger peninsula can be valuable for the interested reader, even though it is out of the scope of this study to link it to seasonal changes in cliff retreat.

Fifth, in chapter 5.2 the authors discuss 'Coastal retreat rates under a warming climate'. Please rephrase to 'Coastal cliff retreat rates…'. It is generally understood that the warming climate is leading to the melting of the icecaps and glaciers which in turn will lead to rising sea-levels. However, Svalbard is experiencing postglacial isostatic rebound which might outpace the regional sea-level rise. More importantly, the melting of the Greenland Ice Sheet is leading to a gravitational sea-level lowering around Svalbard because of their proximity (< 2.200 km). Lastly, due to the melting of the Greenland Ice Sheet, the rotational axis of the earth will move towards the area of mass loss which will also lead to a regional decrease of sea-levels around Svalbard. For more information see Slangen et al. 2022, e.g. figure 1 (https://doi.org/10.1175/JCLI-D-17-0110.1). Please include these considerations in your discussion on coastal cliff retreat rates under a warming climate as they are interconnected. You are welcome to get some inspiration from my recent paper discussing the same dynamic on a coastal cliff in Greenland (https://doi.org/10.1029/2022JF007026).

In the revised version, the showed that the cliff retreat rates are a suitable proxy for coastal retreat rates along Brøgger peninsula (Sect. 4.2) as suggested by the reviewer. Given the new information, we decided not to rephrase the title of this section.

We included the isostatic rebound in the discussion of our revised manuscript and cited as well the two articles mentioned by the reviewer.

Line 448: *The increasing influence of wave activity due to intensified storminess and sea ice retreat may to some extent be counteracted by a lowering of relative sea level by -4.5±0.4* $\mathrm{mm\,a^{-1}}$ *in Ny-Ålesund (Hanssen-Bauer et al., 2019). On Svalbard, the global mean sea level rise, caused mainly by changes in seawater density and land ice mass (Slangen et al., 2017), is outpaced by the isostatic uplift of the land and changes in the gravitational field following deglaciation (Slangen et al., 2017; Kavan and Strzelecki, 2023). This phenomenon is dynamic in space and time (Hanssen-Bauer et al., 2019) and due to its heterogeneity, the effect on the coastal cliff erosion is difficult to quantify (Luetzenburg et al., 2023). However, we assume that the influence of the increasing wave activity on coastal cliff erosion is stronger than the relative sea level lowering.*

Sixth, the manuscript lacks appropriate referencing of relevant literature and is presented as a regional case study with little interest for a broader, pan-Arctic audience. I would suggest putting a greater effort into discussing the broader applicability of the results for all of Svalbard and compare the findings with studies from similar Arctic coastlines (e.g. Greenland and Nunavut). Below some suggestions for literature to consider:

The comparison and applicability of the study on Svalbard is discussed in Sect. 5.1. We followed the suggestion of the reviewer to widen the perspective and include more references from similar studies worldwide. To do so, we added information in the introduction and placed our results in an international context in the discussion. The following changes were made in the manuscript:

Line 21: *Therefore, Arctic coasts are often eroding more rapidly than coasts in temperate regions and the average retreat rate is estimated to 0.5* $\mathrm{m\,a^{-1}}$ *(Lantuit et al., 2012). However, the variability of coastal retreat rates across the Arctic is pronounced, both on a regional and local scale. Lantuit et al. (2012) present a circum-Arctic database, where the highest rates are detected in the Laptev Sea (0.73* $\mathrm{m\,a^{-1}}$*), the East Siberian Sea (0.87* $\mathrm{m\,a^{-1}}$*), the US Beaufort Sea (1.15* $\mathrm{m\,a^{-1}}$*) and the Canadian Beaufort Sea (1.12* $\mathrm{m\,a^{-1}}$*). Numerous regional studies corroborate these numbers, for example with retreat rates along the Bykovsky peninsula (Laptev Sea) of 0.59* $\mathrm{m\,a^{-1}}$ *between 1951 and 2006 (Lantuit et al., 2011), along the US Beaufort Sea of 1.8* $\mathrm{m\,a^{-1}}$ *between 1940 and 2010 (Gibbs and Richmond, 2017) and along the Canadian Beaufort Sea with 0.7* $\mathrm{m\,a^{-1}}$ *(Irrgang et al., 2018). The highest erosion rates are often found in ice-rich permafrost bluffs and barrier islands. Jones et al. (2018) present a maximum of 48.8* $\mathrm{m\,a^{-1}}$ *in such a setting along the US Beaufort Sea from 2007 to 2008.*

Line 376: *The calculated retreat rates are lower than the average change in Arctic coastlines of 0.5* $\mathrm{m\,a^{-1}}$ *(Lantuit et al., 2012). This is expected as high retreat rates are typically found along unlithified coasts, which account for 65 % of the Arctic coastline (Irrgang et al., 2022). In contrast, the coastline along Brøgger peninsula is formed by bedrock, being characterized by a higher resistance against mechanical abrasion compared to unlithified coasts, and the unconsolidated sediments on top are not exposed to wave action. However, we detected higher retreat rates compared to other lithified coasts in the Arctic, e.g. the Canadian Archipelago with 0.01* $\mathrm{m\,a^{-1}}$ *(Lantuit et al., 2012). This can be explained by the long open water season at the western coast of Svalbard (Sect. 5.2), resulting in the high importance of mechanical abrasion by wave action (Sect. 5.2). Other contributing factors might be the highly fractured bedrock, decreasing the resistance of the material towards erosion and the permafrost conditions, which show a temperature range with decreased bedrock stability (Sect. 5.2).*

We included the majority of the suggested papers in our revised manuscript.

Barnhart, K. R., Overeem, I., & Anderson, R. S. (2014). The effect of changing sea ice on the physical vulnerability of Arctic coasts. The Cryosphere, 8(5), 1777–1799. https://doi.org/10.5194/tc-8-1777-2014

We included this reference in the revised manuscript.

Boisson, A., Allard, M., & Sarrazin, D. (2020). Permafrost aggradation along the emerging eastern coast of Hudson Bay, Nunavik (northern Que´bec, Canada). Permafrost and Periglacial Processes, 31(1), 128–140. https://doi.org/10.1002/ppp.2033

As permafrost on Svalbard is known to be degrading, in contrast to the permafrost conditions presented in the suggested paper, we decided not to include this reference in our manuscript.

Bourriquen, M., Baltzer, A., Mercier, D., Fournier, J., Pérez, L., Haquin, S., Bernard, E., & Jensen, M. (2016). Coastal evolution and sedimentary mobility of Brøgger Peninsula, northwest Spitsbergen. Polar Biology, 39(10), 1689-1698. https://doi.org/10.1007/s00300-016-1930-1

We included this reference in the revised manuscript.

Bourriquen, M., Mercier, D., Baltzer, A., Fournier, J., Costa, S., & Roussel, E. (2018). Paraglacial coasts responses to glacier retreat and associated shifts in river floodplains over decadal timescales (1966-2016), Kongsfjorden, Svalbard. Land Degradation & Development, 29(11), 4173-4185. https://doi.org/10.1002/ldr.3149

We included this reference in the revised manuscript.

Casas-Prat, M., & Wang, X. L. (2020a). Projections of extreme ocean waves in the Arctic and potential implications for coastal inundation and erosion. Journal of Geophysical Research: Oceans, 125(8), e2019JC015745. https://doi.org/10.1029/2019J

We included this reference in the revised manuscript.

Casas-Prat, M., & Wang, X. L. (2020b). Sea ice retreat contributes to projected increases in extreme Arctic Ocean surface waves. Geophysical Research Letters, 47(15), e2020GL088100. https://doi.org/10.1029/2020GL088100

We included this reference in the revised manuscript.

Jones, B. M., Irrgang, A., Farquharson, L. M., Lantuit, H., Whalen, D., Ogorodov, S., et al. (2020). Coastal permafrost erosion. https://doi.org/10.25923/e47w-dw52

We included this reference in the revised manuscript.

Kavan, J., & Strzelecki, M. C. (2023). Glacier decay boosts the formation of new Arctic coastal environments—Perspectives from Svalbard. Land Degradation & Development. https://doi.org/10.1002/ldr.4695

We included this reference in the revised manuscript.

McCrystall, M. R., Stroeve, J., Serreze, M., Forbes, B. C., & Screen, J. A. (2021). New climate models reveal faster and larger increases in Arctic precipitation than previously projected. Nature Communications, 12(1), 6765. https://doi.org/10.1038/s414 021-27031-y

We included this reference in the revised manuscript.

Nielsen, D. M., Pieper, P., Barkhordarian, A., Overduin, P., Ilyina, T., Brovkin, V., et al. (2022). Increase in Arctic coastal erosion and its sensitivity to warming in the twenty-first century. Nature Climate Change, 12(3), 263–270. https://doi.org/10.1038/s41558-022-01281-0

We included this reference in the revised manuscript.

Sessford, E. G., Baeverford, M. G., & Hormes, A. (2015). Terrestrial processes affecting unlithified coastal erosion disparities in central fjords of Svalbard. Polar Research, 34(1), 24122. https://doi.org/10.3402/polar.v34.24122

We included this reference in the revised manuscript.

St-Hilaire-Gravel, D., Bell, T. J., & Forbes, D. L. (2010). Raised gravel beaches as proxy indicators of past sea-ice and wave conditions, Lowther Island, Canadian Arctic archipelago. Arctic, 63(2), 213–226. https://doi.org/10.14430/arctic976

The paper discusses gravel-dominated coastlines, so that we decided not to include this reference in our revised manuscript.

St-Hilaire-Gravel, D., Forbes, D. L., & Bell, T. (2012). Multitemporal analysis of a gravel-dominated coastline in the central Canadian Arctic archipelago. Journal of Coastal Research, 280, 421–441. https://doi.org/10.2112/jcoastres-d-11-00020.1

The paper discusses gravel-dominated coastlines, so that we decided not to include this reference in our revised manuscript.

Zago´rski, P., Rodzik, J., Moskalik, M., Strzelecki, M. C., Lim, M., Błaszczyk, M., et al. (2015). Multidecadal (1960–2011) shoreline changes in Isbjørnhamna (Hornsund, Svalbard). Polish Polar Research, 36(4), 369–390. https://doi.org/10.1515/popore-2015-0019

We included this reference in the revised manuscript.

L9 Mention the cliff top retreat increase in percent between the three periods of investigation instead of the absolute values in the abstract.

We think that the absolute values of coastal cliff retreat are important in the abstract, so that the reader knows the order of magnitude we are talking about. However, we see the point of the reviewer that the increase in percentage is also an important information. Therefore, we added this in the revised manuscript.

Line 8: *This is true for both the northeast facing coastline, with retreat rates increasing from 0.04±0.06* $\mathrm{m\,a^{-1}}$ *(1970-1990) and 0.04±0.04* $\mathrm{m\,a^{-1}}$ *(1990-2010) to 0.06±0.08* $\mathrm{m\,a^{-1}}$ *(2010-2021) and the southwest facing coastline, where retreat rates of 0.26±0.06* $\mathrm{m\,a^{-1}}$ *(1970-1990), 0.24±0.04* $\mathrm{m\,a^{-1}}$ *(1990-2010) and 0.30±0.08* $\mathrm{m\,a^{-1}}$ *(2010-2021) are measured. This corresponds to an increase in the most recent decade of 75 % for the northeast facing coastline and of 25 % for the southwest facing coastline.*

L51 You would also detect long-term trends in coastal retreat if you would analyze the two areas together. The second half of the sentence 'by performing separate analyses for the northeast and southwest facing coastline' does not fit to the first half 'to detect long-term trends in coastal retreat along the Brøgger peninsula'.

We changed the wording in this paragraph.

Line 70: *The main objectives of this study are (i) to detect long-term trends in coastal retreat along the Brøgger peninsula, separately analyzed for the northeast and southwest facing coastline, (ii) to analyze rock surface temperatures for both expositions of the coastline, and (iii) to link these changes to available climate data.*

L55 It is essential for the readers understanding to mention that the study area is located in an uplifted beach ridge system and that the topmost layer of the cliffs consists of uplifted marine terraces. Please describe the Holocene landscape evolution history of the study and mention the current day uplift rates that are measured in Ny-Ålesund.

In the revised manuscript, we mention the uplifted beach ridges and the current day uplift rates.

Line 80: *They are typically covered with several meters of unconsolidated sediments, consisting of raised beach ridges (Etzelmüller and Sollid, 1991), which are dated to the Late Weichsel (about 13.5* ka*) below 45* m a.s.l. *(Forman et al., 1987) and uplifted following the isostatic rebound of the land caused by the retreat of glaciers (Rotem et al., 2023). The current uplift rate in Ny-Ålesund is 8.0±0.3* $\mathrm{mm\,a^{-1}}$ *(Hanssen-Bauer et al., 2019).*

L72 Did you try to use the aerial images from 1936 for cliff top mapping? Geyman et al. 2022 (https://doi.org/10.1038/s41586-021-04314-4) provides high resolution orthophotos in the supplement.

We are aware of the aerial images provided by Geyman et al. (2022). It would be great to include data from 1936, however, with a resolution of 5 m, the cliff top cannot be digitized with the accuracy needed for this study. Therefore we decided, not to use this data in our study.

L210 please just mention the retreat rates in the text and not the colors you assigned to the groups in fig 4.

We followed the suggestion of the reviewer and changed the wording in the revised manuscript.

Line 317: *This is visualized in Fig. 6: while small retreat rates (< 0.05* $\mathrm{m\,a^{-1}}$*, little to no erosion) dominate in 1970-1990, the number of transects with higher retreat rates (< 0.20* $\mathrm{m\,a^{-1}}$*) increases along the entire coastline in 2010-2021.*

L222 The last sentence of the paragraph should be moved to the discussion.

We deleted the sentence from the result section. The point was added in the discussion with a different wording, so that it fits into the section.

Line 468: *The coastal cliffs stabilize the unconsolidated material on top. Analysis of DEMs generated by the orthoimages shows that the top of the cliff retreats typically in conjunction with the bedrock and consequently, the erosion of the sediments is highly dependent on the retreat of the bedrock below. Typically, retreat rates for single transects are in the same order of magnitude as the mean retreat rates. However, high retreat rates can occur locally and within only one time span. These values might be caused by large blocks being released in single events, which in return affect greatly the erosion of the overlying sediments and thus the cliff top.*

L249 In my opinion it doesn't make sense to compare your very local retreat rate to an average pan-Arctic retreat rate. I would delete the sentence.

As reviewer 1 asked for a comparison to international studies, we kept the sentence in the revised manuscript. However, we added some discussion to improve the clarity.

Line 376: *The calculated retreat rates are lower than the average change in Arctic coastlines of 0.5* $\mathrm{m\,a^{-1}}$ *(Lantuit et al., 2012). This is expected as high retreat rates are typically found along unlithified coasts, which account for 65 % of the Arctic coastline (Irrgang et al., 2022). In contrast, the coastline along Brøgger peninsula is formed by bedrock, being characterized* *by a higher resistance against mechanical abrasion compared to unlithified coasts, and the unconsolidated sediments on top are not exposed to wave action. However, we detected higher retreat rates compared to other lithified coasts in the Arctic, e.g. the Canadian Archipelago with 0.01* $\mathrm{m\,a^{-1}}$ *(Lantuit et al., 2012). This can be explained by the long open water season at the western coast of Svalbard (Sect. 5.2), resulting in the high importance of mechanical abrasion by wave action (Sect. 5.2). Other contributing factors might be the highly fractured bedrock, decreasing the resistance of the material towards erosion and the permafrost conditions, which show a temperature range with decreased bedrock stability (Sect. 5.2).*

L260 reference the studies you are referring to.

We added the references.

Line 395: *Previous studies of coastal cliff erosion on Svalbard determined the retreat rate with either terrestrial photogrammetry or laser scanning (Wangensteen et al., 2007; Lim et al., 2020).*

L264 true, but you are also only looking at one geographically small, geologically homogenous area, and not several study sites all across the archipelago. I would rather investigate a smaller area in 3D than a larger area in 2D.

The aim of our study is to present long-term retreat rates for coastal cliffs on Svalbard. For these time spans, we only have 2D data available (see answer to major reviewer comment above). Our approach gives the best approximation for long-term retreat rates with the available data.

L312 Did you not observe an icefoot in spring in front of the cliff and what effect does this have for the cliff erosion dynamics?

In the revised manuscript, we mention the development of ice foot.

Line 96: *In winter, an icefoot or snowdrift can develop, protecting the shore platform and the lower parts of the coastal rock wall from denudational processes.*

L315 name the figure or chapter in the appendix you are referring to.

We added this information throughout the entire revised manuscript when referring to information in the appendix.

Line 462: *Topographically downscaled ERA5 climate data (Fiddes and Gruber, 2014; Hersbach et al., 2020; Renette et al., 2023) for Brøgger peninsula show that air temperature and longwave radiation increased over the past decades, while* *shortwave radiation decreased slightly (Appendix B).*

L358 where are those sites? Please include coordinates and a map.

We added the coordinates and a figure. As Stuphallet, Kongsfjordneset and Kjærsvika are already visualized in Fig. 1, we referred here to Fig. 1 and provided in addition a map for the three climate stations.

Line 522: *The terrain parameters were computed using a 30* m *resolution DEM of Svalbard (Norwegian Polar Institute, 2014a), focusing on 6 sites: the Ny-Ålesund climate station SN99910 (78°55'23" N, 11°55'55" E), the Ny-Ålesund BSRN station (78°55'22" N, 11°55'38" E), the Bayelva soil and climate station BCS (78°55'15" N, 11°50'0" E) (Fig. A1), Stuphallet (78°57'57" N, 11°35'57" E), Kongsfjordneset (78°58'21" N, 11°30'45" E), and Kjærsvika (78°55'17" N, 11°25'11" E) (Fig. 1).*

Figure A1. *(a) Orthoimage of the surroundings of Ny-Ålesund, where the climate stations are located, which were used for validation of the downscaled atmospheric data. Source: NP_Basiskart_Svalbard_WMTS_32633 © Norwegian Polar Institute.*

Figure 1 please indicate the photo positions of panel b and c in panel a.

We photos were both taken at Stuphallet. As this point is already marked, we added this information in the figure caption.

Caption of Fig. 01: *The (b) top and the (c) bluff face along the coastline of Brøgger peninsula show the rock cliffs covered with unconsolidated sediments. The green arrows and lines indicate the top of the cliff that is digitized. Both photos were taken at the location of the dGNSS survey at Stuphallet.*

Figure 4 the color scheme is not very intuitive. I would assume green is stable and yellow moderate retreat rates. For the highest rates of erosion, I would assume red colors.

We agree with the reviewer that a color ramp from green to red would be most intuitive. However, due to the guidelines for colorblindness, we cannot follow the suggestion of the reviewer. Therefore, we changed the color ramp, so that green indicates stable conditions (not yellow as before) and blue shows the highest retreat rates.