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Interactive comment on "Rapid retreat of permafrost coastline observed with aerial drone photogrammetry" *by* Andrew M. Cunliffe et al.

Anonymous Referee #1

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General comments The manuscript presents investigations of short-term coastal dynamics at a very rapidly retreating coastline using UAVs (drones) combined with data on long-term coastal dynamics of the same section according to satellite and aerial images. Although using multitemporal imagery analysis for coastal retreat measurements is common practice, and Herschel Island is a relatively well studied area in terms of coastal dynamics, the authors made the first attempt to provide very high temporal resolution observations of coastal erosion, including intra-seasonal dynamics presented by short-term periods (3-7 days during the summer of 2017). This is the principal novelty of the study, which gave new insights into mechanisms and rate variability of coastal erosion and proved again its episodic nature, when a coastal segments can retreat by several meters in a few days during one storm. In this way, the investigated

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coastal segment gave a unique opportunity for such detailed analysis, as the rates of retreat in 2017 were unprecedented. Another strong point of the manuscript is the well-described methodology, giving an example of using drones for coastal dynamics monitoring, which is already popular and will surely become one of the main tools in coastal investigations in the years to come. We would advise to reduce some general comments about the evident benefits of using drones and focus on giving more technical details that can be further used for elaboration of technologic standards (flight heights, required number of ground control markers, etc. - see in Specific comments below). Overall, the manuscript is a high quality study, with valid and appropriate methods, new trustful results supporting the discussion, fluent and precise language, well-readable figures and abundant supplementary material. The discussion can be re-grouped and some sections of it shortened (see below), however, this does not hinder the general good impression of the paper.

Specific comments Abstract The abstract might be shortened, omitting information on the Kuvluraq – Simpson Point gravel spit, which is mentioned in the text shortly. The objectives can be shortened. The phrases: Lines 28-30 ("We found drone surveys analysed with image-based modelling yield fine-grain and accurately geolocated observations that are highly suitable to observe intra-seasonal erosion dynamics") and Lines 33 Page 1 - 2 Page 2 (We conclude that the data available from drones is an effective tool to understand better the mechanistic short-term controls on coastal erosion dynamics and thus long-term coastline change, and has strong potential to support local management decisions regarding coastal settlements in rapidly changing Arctic landscapes") are somewhat repetitive, and one of them can be omitted Introduction Page 2, Line 8 - "Coastal erosion is prevalent along the Western North American Arctic coastline and Eastern Siberia" - what about significant erosion rates in Western Siberia and in Western Russia along the Pechora Sea coasts? (Vasiliev et al., 2005, Kritsuk et al., 2014, Ogorodov et al., 2016, Novikova et al., 2018) Kritsuk, L.N.; Dubrovin, V.A.; Yastreba, N.V. Some results of integrated study of the Kara Sea coastal dynamics in the Marre-Sale meteorological station area, with the use of GIS technolo-

gies. Earth's Cryosphere, 2014, 4, 59–69. http://www.izdatgeo.ru/pdf/earth_cryo/2014-4/52_eng.pdf Vasiliev, A.; Kanevskiy, M.; Cherkashov, G.; Vanshtein, B. Coastal dynamics at the Barents and Kara Sea key sites. Geo-Mar. Lett. 2005, 25, 110–120. https://link.springer.com/article/10.1007%2Fs00367-004-0192-z Ogorodov, S., Baranskaya, A., Belova, N., Kamalov, A., Kuznetsov, D., Overduin, P., Shabanova, N., and Vergun, A. (2016). Coastal dynamics of the Pechora and Kara seas under changing climatic conditions and human disturbances. GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY, 9(3):53–73. Novikova A., Belova N., Baranskaya A., Aleksyutina D., Maslakov A., Zelenin E., Shabanova N., and Ogorodov S., Dynamics of permafrost coasts of Baydaratskaya bay (Kara sea) based on multi-temporal remote sensing data, Remote Sensing 10 (2018), no. 1481 Is there direct evidence that coastal erosion prevails over accumulation in the mentioned regions? Is the sum of erosional segments overall longer than the sum of accumulative segments? If not, would be better to rephrase, e.g., "rates of coastal erosion are considerable", or "the fastest coastal erosion was documented..." or "coastal erosion has high rates" Methods Section 3.1. Page 4, Line 32 Artificial ground control markers were deployed along the shoreline and precisely geolocated to an absolute accuracy of centimetres using global navigation satellite system (GNSS) equipment (Leica Geosystems). If it is possible it would be interesting to mention how the used number of markers was chosen, and how many markers are sufficient, depending on the study site characteristics? Page 6, Lines 19-20: Total shoreline uncertainties were calculated as the sum of georeferencing, pixel and digitising errors (Radosavljevic et al., 20 2016; Río and Gracia, 2013), and survey parameters and shoreline errors are given in Table 1. Why aren't the total uncertainties calculated as the root mean square error (square root of the sum of the squares of independent errors)? Page 6, Lines 13-14 "Shoreline digitising errors were derived from the estimated accuracy of operator vegetation edge detection, informed by reference to finer grain aerial imagery" - not sure I understood well from this fragment how exactly the digitising errors were calculated. Was it by comparison of digitising by different operators? Why are they the same for all drone images from 2017? Page

7, Lines 8-9 "To inform qualitative interpretation of the erosion dynamics at this location, a time-lapse camera was installed at the location indicated on Figure 1 between 2017-07-29 and 2017-08-03." - this goes to section 3.1 (it can be called "Fieldwork and UAV image acquisition") or to section 3.2. Anyway, it's neither meteorological nor oceanographic data Results After the drone surveys, DEMs were built, from which profiles are provided in Figure 4. Why are there no calculations of volumes of the material eroded in 2016-2017? Would be good to provide pictures in 3D. The authors faced some problems with the destroyed ground control markers; however, there could be some conclusions on the volume with smaller accuracy, and/or for the periods between surveys with good quality referencing only Page 7, Lines 12-15. Are you speaking about average values of retreat for the 500-m coastal segment? What was the spatial variability of coastal erosion? If 14.5 $\pm$ 3.2 m was an average distance of retreat in 2017, were there locations with greater or smaller retreat, and what were the extremes? You are showing that coastal retreat was episodic in time, and saying it was also episodic in space - could you highlight examples in the text? Page 8, Lines 23-25 "A timelapse video illustrating the erosion at this coastline over five days from the location marked in Figure 1 is presented in video 25 S1" - could you please describe here very briefly what exactly the video shows? Discussion The grouping of the Discussion is not always logical and needs to be revised. One of the suggestions is to move Section 5.1 to the end of the discussion. Otherwise, the introductory paragraph (page 8, Lines 27-31, Page 9 Lines 1-2) should be put after it. According to our opinion, Section 5.1 is too long and contains much obvious information that can be omitted without harm to the general content. Part of this is somewhat repetitive to the Introduction, other information can be moved to the Introduction. Lines 10-15 belong to other sections of the Discussion, e.g., Section 5.3. Page 10, Lines 9-10 "Fine spatial grain measurements from drone products are especially useful for isolating the drivers of coastal erosion events" - would be good to provide exact examples from the study site where you could isolate the drivers of separate coastal erosion events you are describing Section 5.2 There is no discussion on spatial variability of coastal erosion

rates during short periods (e.g., 2017) and its reasons. Would be good to add it. Could you state precisely, what is the main short-term driver, according to your findings? Is it the wind speed? Might be a good idea to try to build a quantitative correlation between the wind speed and the erosion rates during the investigated period? Page 11, Lines 9-10. Is there any quantitative data on sea-level fluctuations during the observations? Section 5.3. Would be good to provide some brief information on hydrometeorological conditions of the past years and discuss why 2017 was characterized by such dramatic retreat rates compared with previous years . You are speaking about the ice-free period increase, temperature growth, increased wave height, war water discharge, but all of these factors were already present in 2016, 2015, etc. - what is your opinion of why coastal erosion accelerated so much namely in 2017? The name of Section 5.4 does not match its content. This section describes coastal erosion at Herschel Island in the context of long-term erosion rates at different locations around the Arctic, rather than short-term coastal erosion in the context of long-term observations

Technical corrections Page 1 Line 31 change to " Over a single four-day period" Line 32 " exceeded 1 ± 0.1 m d -1" - Please be consistent with number formats, and the number of decimals. If you previously reported the number of "2.2 ± 0.2 m a-1", you should provide this number as "1.0 ± 0.1 m d -1" Page 2 Line 11 - and affect? Line 20 - "improved understanding is required" Page 3 Line 6 - "repeated drone surveys" Lines 5-11. I would advice to use the present tense, rather than the past tense (e.g., "In this study, we use...") Lines 10-12 "We demonstrated that lightweight drones and aerial photogrammetry can be cost effective tools to capture short-term coastal erosion dynamics and related shoreline changes along discrete sections of permafrost coasts." - This goes to the conclusions Figure 1c - remove "Text" from the top right side of the map? Line 17 - please add a reference for Figure 1a Line 20 - "the mean annual air temperature is..."; "the mean annual precipitation is..." Line 22 - "between 2000 and 2011" or "in 2000-2011" Line 24 - delete "in this region" Line 28 - northwesterly and easterly winds; "they exert..." "and with easterly winds facilitating the transport of warm water from the Mackenzie River to Qikiqtaruk Herschel Island" - unfinished

phrase? Facilitate? Page 4 Line 1 - sea-level Page 5 Line 14 - Processing parameters are reported... Page 6 Line 20 " Río and Gracia, 2013), and survey parameters" - replace by " Río and Gracia, 2013); survey parameters" "and survey parameters and shoreline errors are given in Table 1" - this reference goes to section 3.1 (regarding the survey parameters); the reference to Table 1 in the context of shoreline position errors is repetitive with Lines 15-17 Line 25 - delete "calculated" Page 7 Line 5 - Figure 5 should be mentioned after the reference in the text to Figures 2, 3 and 4 Line 12: " by a net total of 143.7 $\pm$ 28.4 m" - is it an average value for the whole segment? Line 16 "shoreline retreat was 14.5 $\pm$ 3.2 m, an average rate of 36 cm per day." - replace by "the shoreline retreated by 14.5 $\pm$ 3.2, with an average rate of" Line 17 - the shoreline positionS Line 18 - meant that THE shorelines Lines 19-20 "Coastline retreat was highly episodic in time and space, occurring primarily over two periods" - repetitive, replace by "Coastline retreat primarily occurred over two periods" Line 21: " There was minimal change in coastline position DURING SIX DAYS between August 5th and August 11th Line 25: " a 13-month period" Line 26: " in Figure 4, sampled across the A-B-transect indicated on Figure 3." - replace " in Figure 4; they were sampled across the A-B-transect indicated in Figure 3" Page 8 Line 3 - from three to ten days Line 4 - and their speed reached up to... Line 5 "For zero to three days prior to the 1st 5 2017 survey (on 2017-07-06)" replace by " For zero to three days prior to the same survey" Line 11 - of very strong winds Line 16 - and facilitate further undercutting Line 18 - and the wind speed was low Lines 20-21 These meteorological conditions resulted in large waves and undercutting - sounds more logically Line 29 - where retreat rates typically range Line 30 - between 0 and 2 m Page 9 Lines 13-14 - "In this case, however, for the total 17.4 m of shoreline retreat between 2016 and 2017 reported here to remain consistent with the long-term average of 2.2 m a -1 , no further erosion of this reach would need to occur 15 for more than seven years" - rephrase: In this case, however, to remain consistent with the long-term average of 2.2 m a -1 , no further erosion of this reach would need to occur for more than seven years after the retreat of 17.4 m in 2016-2017. Page 11 Lines 2-3 " Further factors facilitating rapid erosion at this coastal

reach ARE the high ice content (ca. 40% Obu et al., 2016) and the low relief" Line 10 - Although this region is microtidal - "although the studied region is microtidal" Page 11, Lines 13-14 - "Winds exert substantial control over local sea levels, with north-westerly winds driving a positive storm surge and easterly winds driving a negative storm surge (Héquette et al., 1995; Héquette and Barnes, 1990)." - repetitive; already appeared in the Introduction Page 12 Line 11 - on Bykovsky Peninsula? Figures: Figure 1c - remove "Text" from the top right side of the map? Figure 2. What is the image at the background? Figures 2, 3 and 4. Would be better readable if you used different colours for coastlines of different time periods instead of shades of grey and black

Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2018-234/tc-2018-234-RC1-supplement.pdf

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