Comments on “Dam type and topological position govern ice-marginal lake area change in Alaska and NW Canada between 1984 and 2019”

The authors have completed the first comprehensive inventory of Alaskan glacier marginal lakes, sub-dividig them both by dam type, topological relationship to the glacier, and size. This is a useful approach and as a baseline the number of lakes in each category and their respective area changes is useful. At present the paper does not provide the reader with sufficient context to understand the unique nature of many of the ice marginal lakes in Alaska, particularly the largest. There is a lack of referencing of previous studies that have explored specific areas identifying the relationship of the lakes and glaciers in away that would lend much better context to the inventory. An over reliance on references to the Himalayan and Peruvian Andes, which are not the best or in most cases even useful analogs underscores this issue. For Alaska it is indicated that large glacier lakes have an area greater than 10 km^2, whereas inventories of both Cordillera Blanca and High Mountain Asia often use 0.1 km^2, a two order of magnitude difference in scale (Emmer et al 2016; Chen et al 2021). The combination of these issues limits the value of the inventory data.

There are several common features of the Alaskan lakes that are unusual leading to different behavior than for most glaciated alpine regions. I will review another of examples that illustrate this with referencing where appropriate. These illustrations are meant as examples, and not specific ones the authors may choose to use or need to specifically address.

An examination of Figure 5 illustrates how context is vital. The frequency of lakes is broken down by actual area in 2016-2019 in panel A, with the largest four groups greater than 2 km^2 in area representing few of the total, but dominating the spatial area change noted in panel B. There are a significant number of Alaskan glacier lakes with an area greater than 20 km^2. There are some specific unique characteristics of these larger lakes.

Most of the largest Alaskan glacier lakes are found in a coastal plain environment and are impounded by a coastal shoreline systems and/or proglacial deltas formed when the glacier terminated at the lake margin and outwash plains more than by moraine. They can be categorized as moraine dammed. But there is no potential for a dam failure to cause issues at near coastal lakes such at Mendenhall Glacier, Yakutat Glacier, Excelsior Glacier or Bear Glacier. All of these lakes are less than 20 m in elevation. Johnstone Lake the proglacial lake of Excelsior Glacier it is less than 1 km from the ocean with the highest elevation between tidewater and the lake being ~10 m (Figure 1). This lake has expanded from 9-18 km^2 from 1994-2018, but still poses no GLOF risk. At Bear Glacier terminates in expanding Bear Glacier Lake, which is 0.5 km from the ocean with a maximum elevation of ~7 m between the ocean and the lake. Malaspina Lake (~85 km^2) is the proglacial lake at the southeast margin of Malaspina Glacier. It is 2 km from the ocean with a maximum elevation of about ~10 m. Grand Plateau Glacier Lake (~45 km^2 Figure 2) is in a similar position.

Many of these lakes have filled basins developed by the loss of the piedmont lobe terminus formed when the glacier exited the mountains onto low slope forelands/coastal zones. Giffen et al (2014) examined retreat and expanding lakes of glaciers in the Kenai and Katmai regions. ie. Bear, Fourpeaked, Spotted (Figure 3), Hallo Glaciers are examples of glacier lakes filling former piedmont lobe depressions. Mendenhall, Grand Plateau are examples from southeast Alaska. This is not a proglacial lake type seen in High Mountain Asia or the Andes north of Patagonia. Should you separate out this group of moraine dammed proglacial lakes terminating in a coastal environment? Loriaux and Casassa (2013) found a total lake area of the Northern Patagonia Icefield of 167.5± 8.4 km^2 for 2011, an increase of 64.9% from 1945 (101.6±19.1 km2). They noted an 18 km^2 expansion of San Quintin Lake accounting for 27% of the total expansion. This also is a coastal environment piedmont lobe terminus depression filled proglacial lake.

The size of the lakes combined when depth also allows for the production of large tabular icebergs, such as seen at Excelsior, Ellsworth, Field and Yakutat in recent years. Trussel et al (2013) examined the rapid retreat of Yakutat Glacier in Harlequin Lake (in 2020 ~70 km^2), with sections going afloat (Figure 4 and 5). They note this ability the ability to calve large tabular icebergs is largely due to the limited subaqueous melt compared to tidewater glaciers. The buoyancy also requires substantial water depth. The other unique element to these lakes given the large glaciers that feed them and the coastal setting, is they can be much deeper than examples from the Himalaya or Peruvian Andes. Trussel et al (2013) reported a depth of 325 m at the 2010 calving front of Yakutat Glacier. Loso et al (2021) note water depths of 330 m in Alsek Lake. For ths inventory when do you draw the line between a glacial lake and one that is sufficiently tidally fed to not be a lake? Is Vitus Lake in front of Bering Glacier a part of the inventory?

For Ice Dammed lakes it has to be emphasized that there are many that have had a long history of consistent GLOF events. Neal (2007) provides a detailed examination of glacier lake outbursts from beneath Tulsequah Glacier into the Taku River. They report on 41 GLOF's during the 1987-2004 period with the main source migrates from Tulsequah Lake to Lake No Lake, with little change in maximum outburst discharge. After 1984 a large proglacial lake has formed at the terminus of the glacier as well, which can help mitigate peak flows (Figure 6) (Pelto, 2017). Carrivick and Tweed (2016) list Tulsequah as the glacier lake with the most outburst floods. Wilcox et al (2014) report on the migration of Ice Lake which is ~17 km upglacier. This lake drains once or twice each year usually in late summer or early fall. This is another attribute worth noting that if a ice dammed lakes or supraglacial lakes drain into large proglacial lakes, there impact on discharge will be limited. Lake Linda on Lemon Creek Glacier is at the head of the glacier, and typically drains near mid-summer and does not refill.

Pelto et al (2013) examined the expansion of nine lakes at distributary termini of Brady Glacier that are a combination of ice-dammed and proglacial and expanded from 8.5 km^2 in 1948 to 18.2 km^2 in 2010 (Figure 7 and 8). How did you classify these lakes? Capps et al (2011) identified a depth of 200 m for Abyss Lake. Brady Glacier an exceptional case having so many proglacial calving terminus fronts.

Merging of lakes can also occur for these large lakes. Loso et al (2021) note that glacier thinning in the region can alter which lake a glacier feeds in this case Alsek Lake (~60 km^2) and Grand Plateau Lake (Figure 3). Another future merging of lakes will be at Fingers Glacier. The merging of lakes has been observed at Melbern Glacier (Clague and Evans, 1993) Gilkey Glacier (Figure 9) and Llewellyn Glacier (Pelto, 2017).

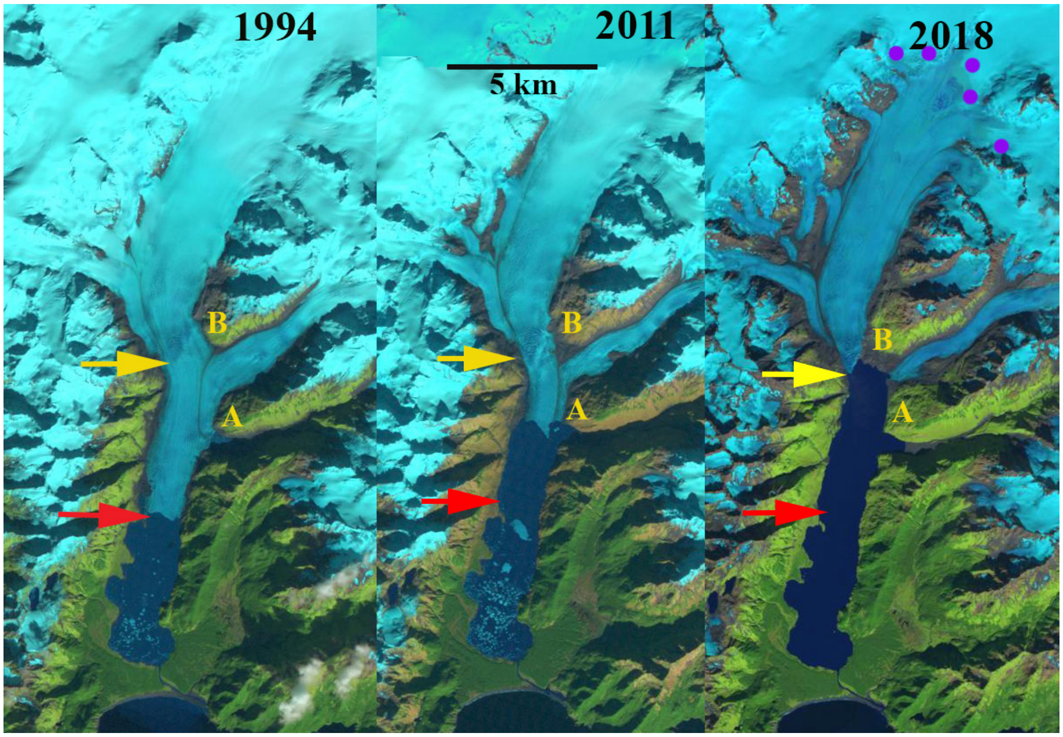

Figure 1. Excelsior Glacier retreat from 1994 to 2018 in Landsat images from 1994, 2011 and 2018. The red arrow is the 1994 terminus location and the yellow arrow is the 2018 terminus location. Point A and B are on the south and northwest side of the eastern tributary glacier (Roan Glacier). Johnstone Bay is at bottom of images.

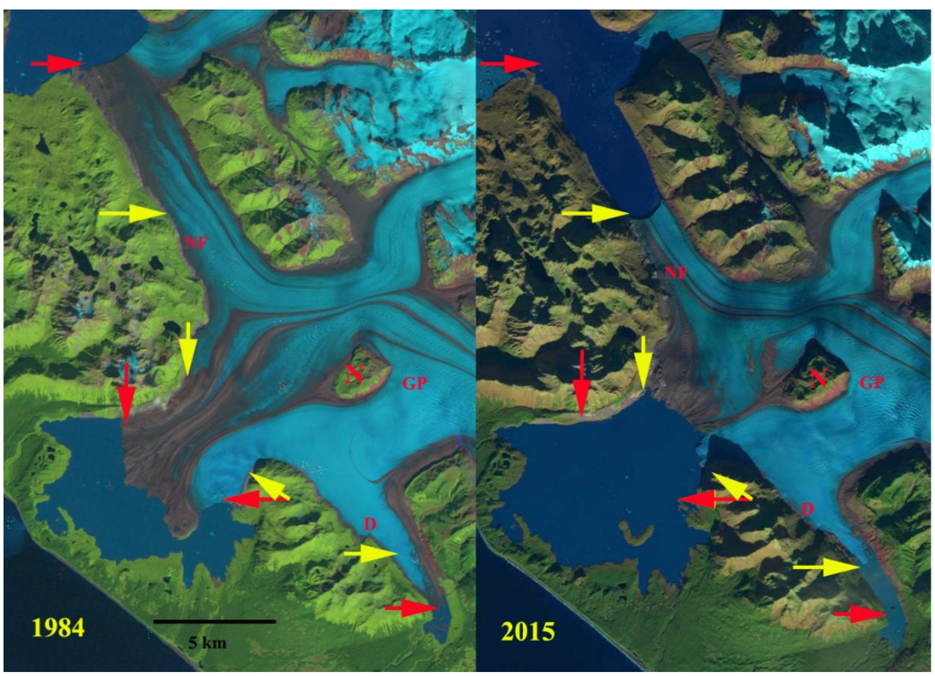

Figure 2. Grand Plateau Glacier in 1984 and 2015 Landsat images. Red arrow is the 1984 terminus location and yellow arrows the 2015 terminus locations. D=Distributary tongue, NF=North Fork, N=Nunatak, GP=Grand Plateau. Alsek Lake top left.

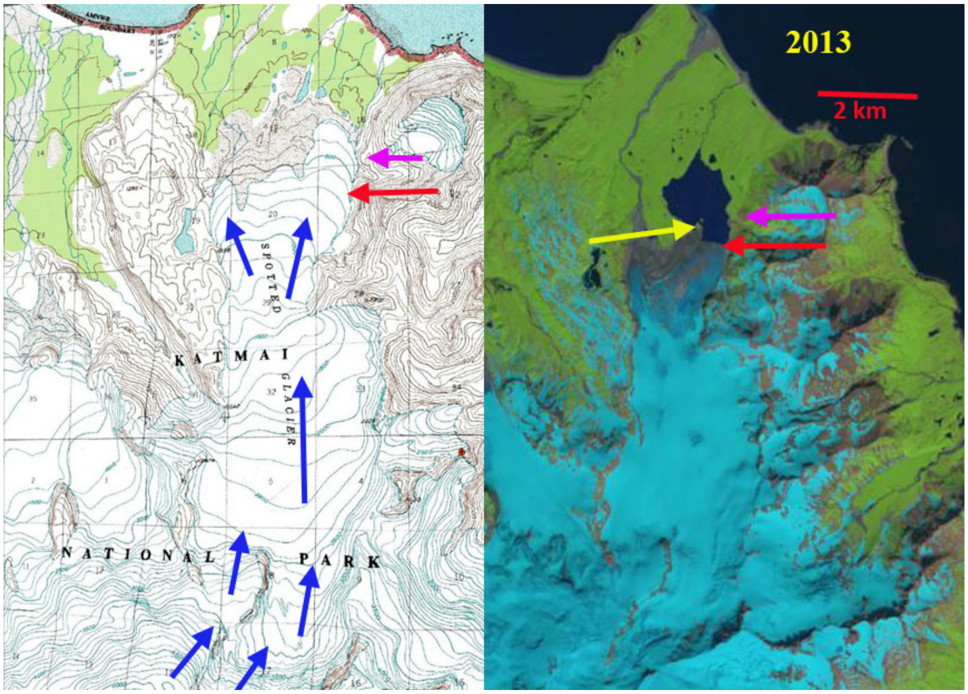

Figure 3. Spotted Glacier in USGS map before lake formation and in 2013 Landsat image. Red arrow indicates the 2013 east side of the terminus, the pink arrow a rock knob adjacent to the 1985 terminus, and the yellow arrow a peninsula that should become an island as the further retreat occurs.

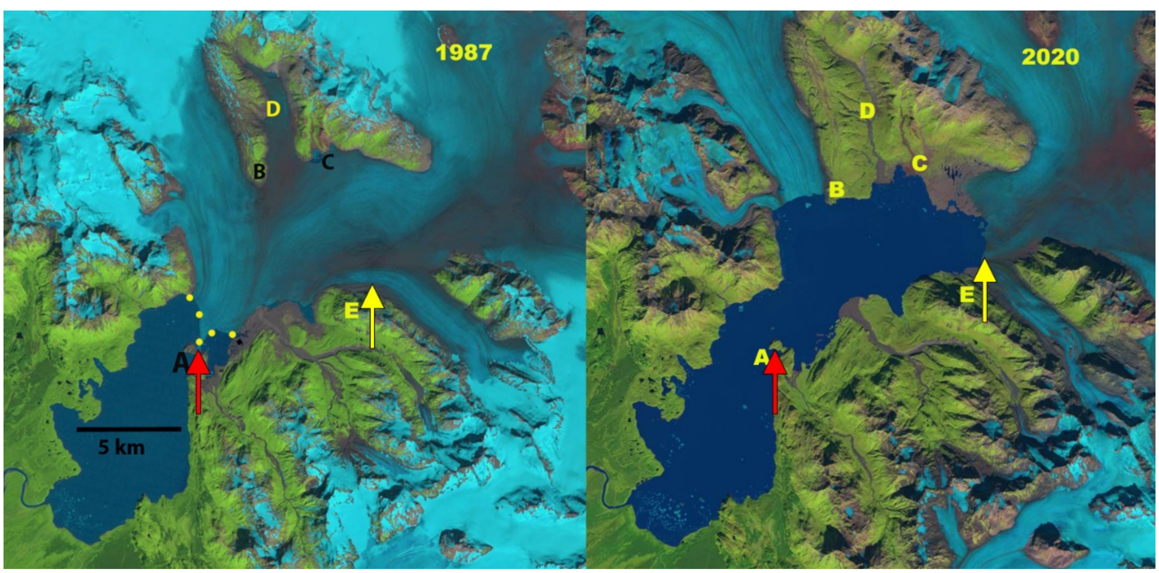

Figure 4. Yakutat Glacier, Alaska in 1999 and 2020 Landsat image illustrating expansion of Harlequin Lake by 40.5 km². Yellow line is the 1999 margin, orange line is the 2020 margin, and yellow dots indicate the margin of the lake shoreline. Point A indicates the 1987 terminus location, Point X and Y the 1999 terminus location. Main terminus now extends south near Point C. Northern terminus extends west from Point B.

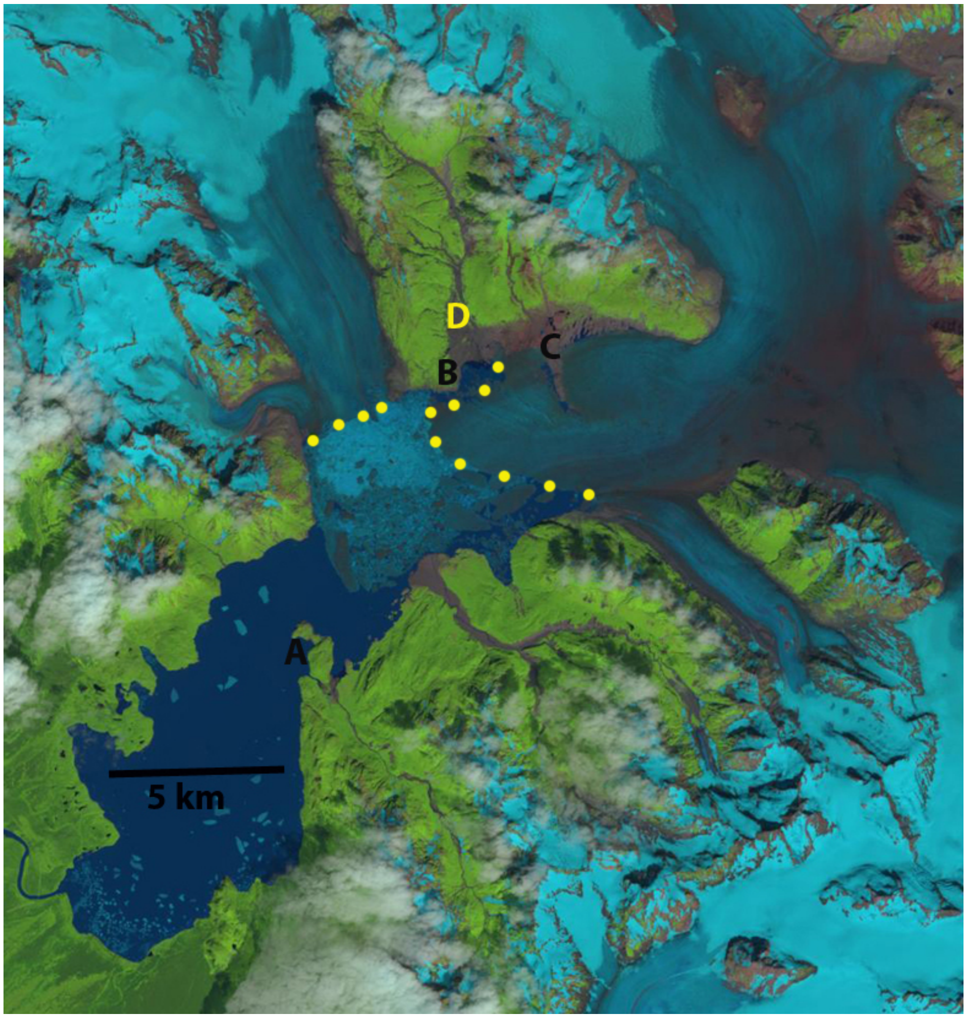

Figure 5. Landsat images from 2013 with terminus indicated by yellow dots. Point A indicates the 1987 terminus location. Note large area of melange and icebergs from the rapid disintegration during the 2010-2013 period.

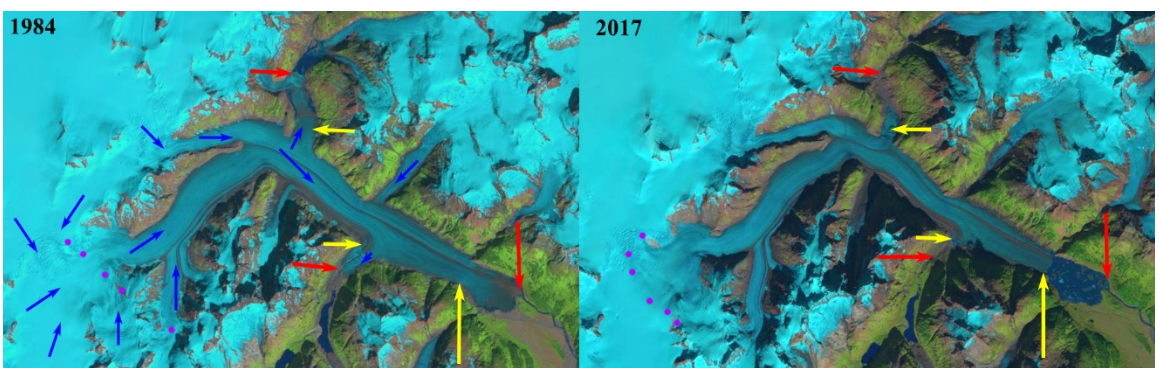

Figure 6. Tulsequah Glacier in 1984 and 2017 Landsat images. The 1984 terminus location is noted with red arrows for the main terminus, northern distributary tongue which also dams Lake No Lake, southern distributary red arrow indicates ice dammed Tulsequah Lake margin. The yellow arrows

indicate the 2017 glacier terminus locations. The retreat of 2900 m since 1984 led to a lake of the same size forming. Purple dots indicate the snowline.

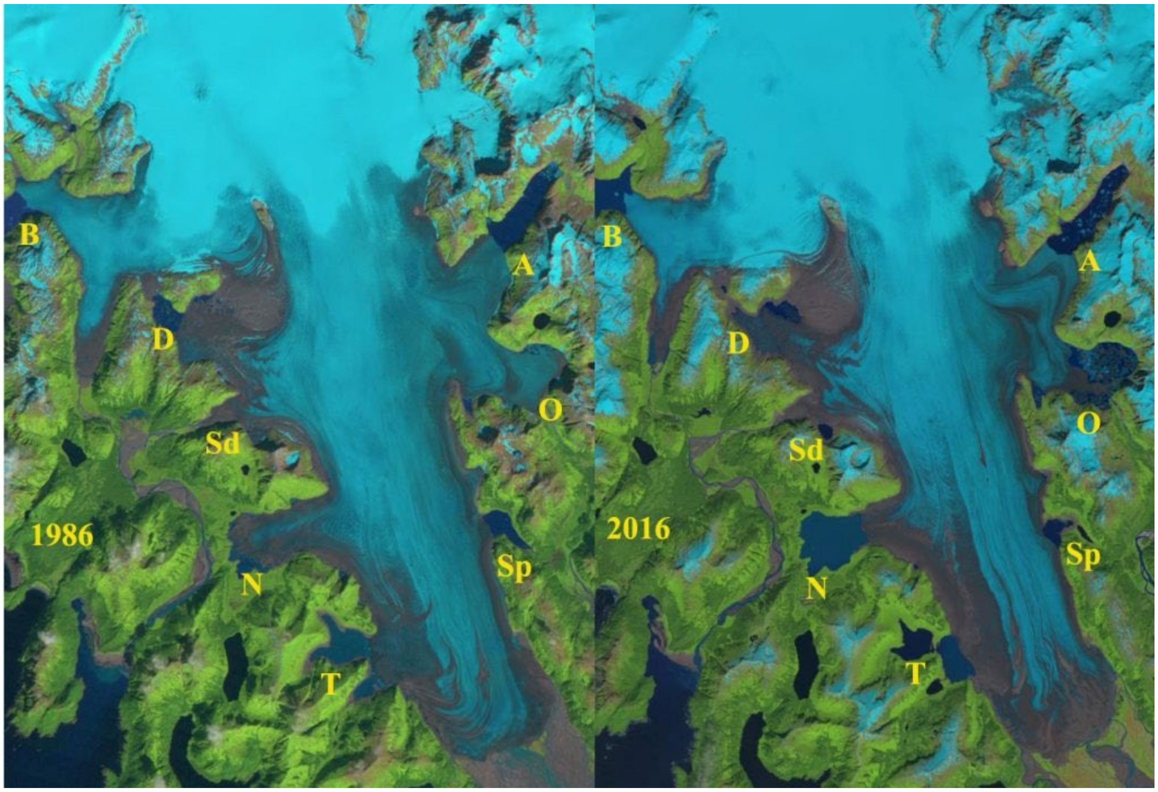

Figure 7. Comparison of Brady Glacier in 1986 and 2016 Landsat images. The snowline is similar in May 2016 and August 1986. Lakes noted are: A=Abyss, B=Bearhole, D=Dixon, N=North Deception, O=Oscar, Sd=South Dixon, Sp=Spur, T=Trick.

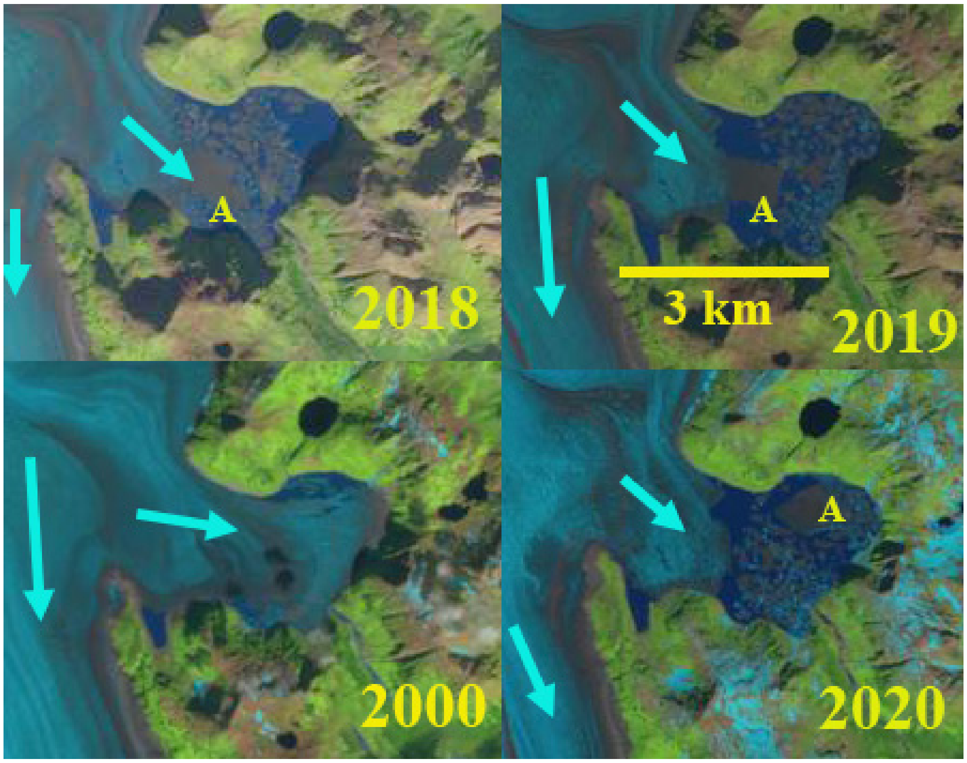

Figure 8. Oscar Lake growth on the east margin of Brady Glacier in Landsat images from 2000-2020. Point A indicates glacier tongue that becomes iceberg. Blue arrows indicate flow direction.

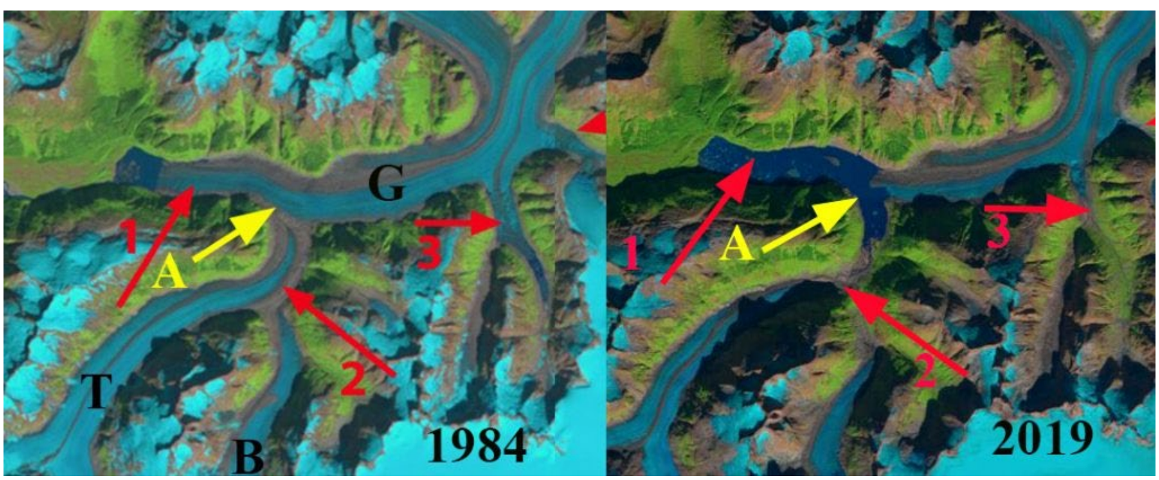

Figure 9. Gilkey Glacier in 1984 and 2019 Landsat images indicating retreat of 4300m, tributary separation and 5 km^2 lake expansion. A=Terminus tongue, B=Battle Glacier, G=Gilkey Glacier and T=Thiel Glacier. #3 is the location of an ice dammed lake that still forms and empties each year but is reduced in size. There had been two lakes near Point A that merged in 2019.

Specific Comments:

43: In fact large area change is dominated by large lakes, does this suggest you need a separate categorization for them?

45: I would avoid the ecological consequences discussion until later. There is a complexity that is not examined here particularly in this region. For example the pro-glacial lakes in front of Excelsior Glacier as it has expanded has hosted numerous harbor seals, which will diminish as the glacier retreats form the lake. Loso et al (2021) further examine the issue of river capture changes impact on fisheries.

50-65: This section references numerous examples from the Himalayan and Peru Andes region. The majority of references here should be specific to the study region Alaska. Glacier lake inventories from the Northern and Southern Patagonia icefield are probably more relevant as a comparison than the Himalayan or Peruvian Andes (Warren et al 2001; Loriaux and Casassa, 2013). Is there value in indicating that the best analog regions varies depending on which range you are examining? Emmer et al (2016) notes that only 7.3% of the 8882 Cordillera Blanca lakes have an area greater than 0.1 km2, which is a different magnitude of size than the Alaska glacier lakes.

150: Why are unconnected lakes used in this study, since they are neither fed by or connected to glaciers? I understand if it is just a validation tool, but then they should not be included in most of the analysis.

187: Given the ephemeral nature, which will make an accurate inventory impossible, and there limited importance base on extent, is this study stronger with or without supraglacial lakes? I would suggest the data set is more robust without. I offer this as a suggestion, but leave it to the authors to determine and will trust that answer.

213: "…decreasing by 9 lakes", you indicate that 22 lakes were lost later in this section.

310: This is where a reference to Brady Glacier would be useful given the number of ice dammed lakes, and that this a large low slope glacier (Capps et al, 2011; Pelto et al., 2013).

315: Neal (2007) is a good reference here as well for changing drainage from different ice dammed lakes of Tulsequah Glacier.

349: Should note the trends observed both at Tulsequah Glacier (Neal, 2007) and Bear Glacier (Wilcox et al 2014).

358: What is the importance of knowing normalized lake area variation by region?

387: Yes this is true but here is where a closer look at the main area changing lakes will define the key topological elements.

388: I do not see specific evidence supporting this assertion. You have identified that supraglacial lakes are limited to a few large debris covered glaciers and have a small area. This does not suggest the range or role is expanding.

397: What are the similarities and just as importantly what are the differences? Many of the debris covered glaciers in Alaska are not confined glacier tongues, but instead have an expanding terminus lobe either in a wide river valley (Battle, Donjek, Kaskawulsh, Lowell etc.) while others terminate on a coastal plain (Fingers, La Perrouse, Bering, Malaspina etc.). In terms of debris cover change and proglacial lake changes how does this compare to the data from the Northern Patagoina Icefield from (Glasser et al 2016). "North Patagonian Icefield (NPI) in southern South America between 1987 and 2015 shows that the total amount of debris cover has increased over time, from 168 km^2 in 1987 to 307 km^2 in 2015. The area occupied by proglacial and ice-proximal lakes also increased from 112 to 198 km^2"

415: I do not see the close correlation in the nature of the glaciers. They differ in their climate setting, size, thickness, velocity, slope and elevation range. The trend in lake dam type that is similar is relevant. It must be emphasized that the size of the lakes between the two regions is vastly different.

435: No need to speculate given the glacier by glacier thinning data from Juneau Icefield and Stikine Icefield for example that illustrate variations Melkonian et al (2014 and 2016).

451: Why use the Cordillera Blanca as an analog instead of the Northern Patagonia Icefield?

456: What do the observations from Tulsequah, Brady and Bear Glacier suggest as to diminishing number of ice dammed lakes?

References

Boyce, E., Motyka, R., and Truffer, M. Flotation and retreat of a lake-calving terminus, Mendenhall Glacier, southeast Alaska, USA. Journal of Glaciology, 53, 211–224, 2007.

Capps DM, Wiles GC, Clague JJ, Luckman BH. Tree-ring dating of the nineteenth-century advance of Brady Glacier and the evolution of two ice-marginal lakes, Alaska. The Holocene 21(4): 641–649. 2011.

Chen, F., Zhang, M., Guo, H., Allen, S., Kargel, J., Haritashya, U., and Watson, C. S.: Annual 30-meter Dataset for Glacial Lakes in High Mountain Asia from 2008 to 2017, Earth Syst. Sci. Data Discuss., 4275164, 1–29, https://doi.org/10.5194/essd-500 2020-57, 2021.

Clague, J., & Evans, S. Historic retreat of Grand Pacific and Melbern Glaciers Saint Elias Mountains, Canada: An analogue for decay of the Cordilleran ice sheet at the end of the Pleistocene? Journal of Glaciology, 39(133), 619-624. doi:10.3189/S0022143000016518, 1993.

Emmer, A. Klimeš, J. Mergili, M. Vilímek, V. Cochachin. A. 882 lakes of the Cordillera Blanca: an inventory, classification, evolution and assessment of susceptibility to outburst floods Catena, 147, 269-279, 2016.

Giffen B.A., Hall D.K., Chien J.Y. Alaska: Glaciers of Kenai Fjords National Park and Katmai National Park and Preserve. In: Kargel J., Leonard G., Bishop M., Kääb A., Raup B. (eds) Global Land Ice Measurements from Space. Springer Praxis Books. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-79818-7_11, 2014.

Glasser, N. F., Holt, T. O., Evans, Z. D., Davies, B. J., Pelto, M., and Harrison, S. Recent Spatial and Temporal Variations in Debris Cover on Patagonian Glaciers. Geomorphology 273, 202–216, 2016.

Loriaux, T. and Casassa, G. Evolution of glacial lakes from the Northern Patagonia Icefield and terrestrial water storage in a sea-level rise context. Global and Planetary Change, 102, 33–40, 2013.

Loso, M. G., C. F. Larsen, B. S. Tober, M. Christoffersen, M. Fahnestock, J. W. Holt, and M. Truffer. 2021. Quo vadis, Alsek? Climate-driven glacier retreat may change the course of a major river outlet in southern Alaska. Geomorphology 384: 107701, 2021.

Melkonian, A. K., Willis, M. J., and Pritchard, M. E. Satellite-derived volume loss rates and glacier speeds for the Juneau Icefield, Alaska. *J. Glaciol.* 60, 743–760. doi: 10.3189/2014JoG13J181, 2014.

Melkonian, A. K., Willis, M. J., and Pritchard, M. E.: Stikine Icefield Mass Loss between 2000 and 2013/2014, Front. Earth Sci., 4, 89, https://doi.org/10.3389/feart.2016.00089, 2016.

Neal, E.G. Hydrology and glacier-lake-outburst floods (1987–2004) and water quality (1998–2003) of the Taku River near Juneau, Alaska: U.S. Geological Survey Scientific Investigations Report 2007–5027, 28 p, 2007.

Pelto, M., Capps, D., Clague, J.J. and Pelto, B. Rising ELA and expanding proglacial lakes indicate impending rapid retreat of Brady Glacier, Alaska. Hydrol. Process., 27: 3075-3082. https://doi.org/10.1002/hyp.9913, 2013.

Pelto, M. Recent Climate Change impacts on Mountain Glaciers. Wiley-The Cryosphere Science Series, ISBN: 978-1-119-06811-2, 2017.

Trüssel, B., Motyka, R., Truffer, M., & Larsen, C. Rapid thinning of lake-calving Yakutat Glacier and the collapse of the Yakutat Icefield, southeast Alaska, USA. Journal of Glaciology, 59(213), 149-161. doi:10.3189/2013J0G12J081, 2013.

Warren, C., Benn, D., Winchester, V., & Harrison, S. Buoyancy-driven lacustrine calving, Glaciar Nef, Chilean Patagonia. Journal of Glaciology, 47(156), 135-146. doi:10.3189/172756501781832403, 2001.

Wilcox, A., Wade, A and Evans, E. Drainage events from a glacier-dammed lake, Bear Glacier, Alaska: Remote sensing and field observations. Geomorphology 220: 41-49, 2014.