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A Vanishing Landscape: Current Trends for the Glaciers at Mount Rainier National Park, Washington, USA

I. Introduction

Mount Rainier is the most glaciated volcano in the Cascade Range of the western United States and has more glacial ice on its edifice than all other volcanoes in the Cascade Range combined. Accurate measurements of rates of glacial ice loss during warming climates are critical to understanding the future impacts to riparian areas downslope of the glaciers, sediment production to braided rivers, aquatic impacts due to increasing stream temperatures, and many other important areas for park resource management. Glacial area has been delineated many times in the last 125 years; most importantly in 1896, 1913, 1971, 1994, 2009, and, most recently, in 2015. Each of these extents represents a snapshot of the surface area of the volcano occupied by glacial ice during those years and provides an opportunity to visualize the health of the glaciers in the park over time.

Using aerially derived Structure from Motion (SfM) data acquired in September 2021, as well as other satellite and aerial imagery, glacier area for each of the 29 named glacial features is updated for Mount Rainier and presented here. From these source data, we have mapped not only the extent of ice but estimate the volume of ice from methods developed by other researchers. Overall, our data shows a continuation of gradual yet accelerating loss of glacial ice at Mount Rainier resulting in significant changes in regional ice volume over the last century. Regional climate change is affecting all glacial features at Mount Rainier, but mostly smaller cirque glaciers and discontinuous glaciers on the south aspect of the volcano.

II. Methods

Mapping of the 2021 glacial extents in this study was completed by hand digitizing features from aerial imagery at a 1:1,000 scale. Several image products were used to successfully map all glacial features in the park: (1) a park-wide fixed-wing Structure from Motion image dataset acquired between 21-24 September 2021; (2) USDA Forest Service's National Agriculture Imagery Program images, acquired between 23-24 July 2021; and (3) Planet Labs satellite imagery from 1 September 2021. Manually digitizing glacial boundaries inherently introduces error into final measurements. For the purposes of this study, the horizontal accuracy of a point at 1:1,000 scale is 0.847 m (2.778 ft). To account for all other potential errors, a relatively high 5% value was used for potential variability error. Glacial extents delineated in 2021 were compared to previous extents and volumes measured in 2015 (Beason, 2017; George & Beason, 2017). These studies highlighted changes in 1896, 1913, 1971, 1994 and 2015 and are included here to show overall change over the last 125 years.

Glacial volume estimations have been recalculated using the following equations developed in previous studies of glacial volume and surface area at Mount Rainier and other Cascade volcanoes:

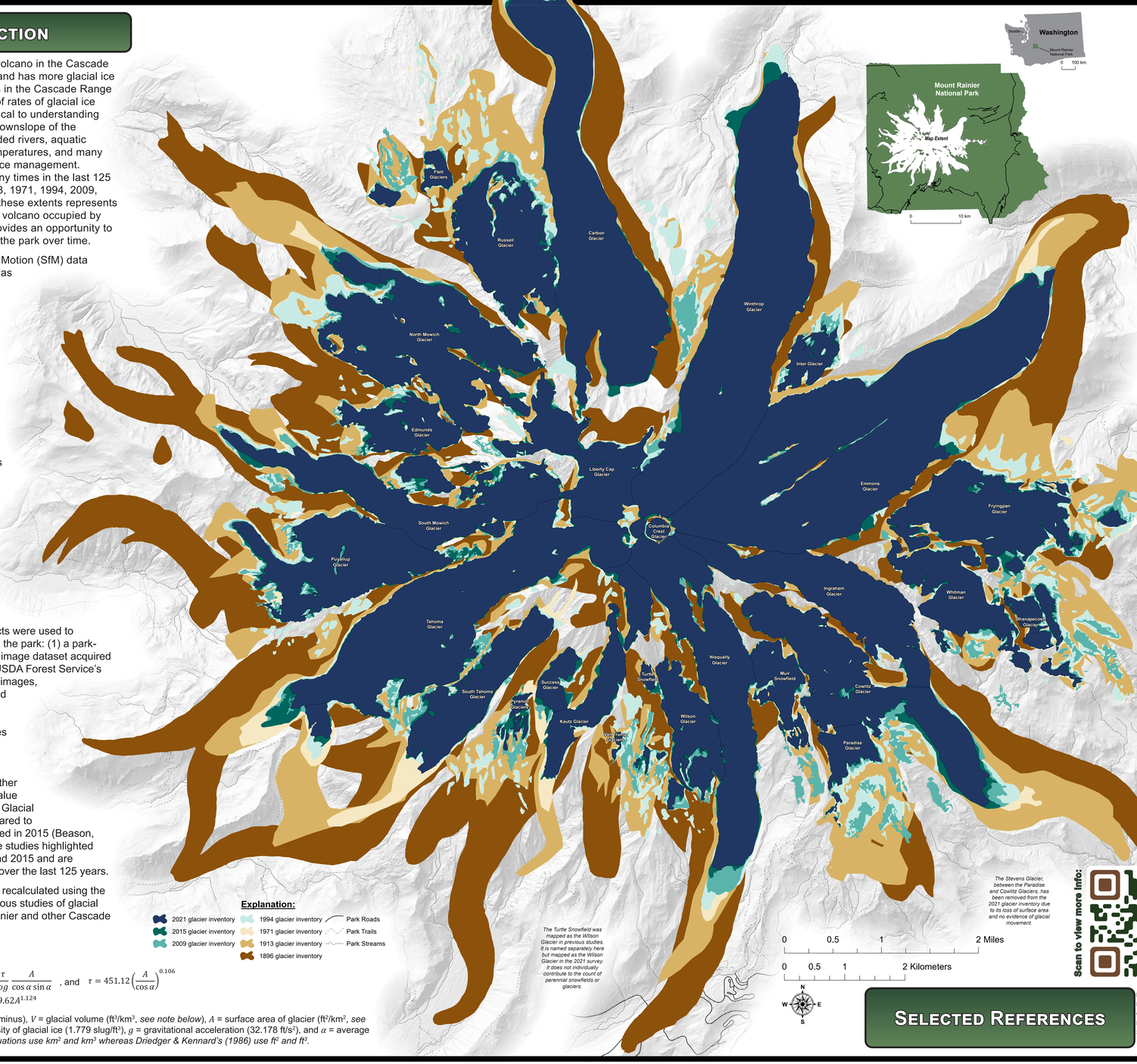
From Nylen (2001): $V = 0.0255A^{1.36}$

From Driedger & Kennard (1986):

Large glaciers ($L \geq 8{,}500$ ft): $V = \frac{\tau}{\rho g}\frac{A}{\cos\alpha \sin\alpha}$, and $\tau = 451.12\left(\frac{A}{\cos\alpha}\right)^{0.106}$

Small glaciers ($L < 8{,}500$ ft): $V = 9.62A^{1.124}$

Variables: L = length of glacier (source to terminus), V = glacial volume (ft³/km³, *see note below*), A = surface area of glacier (ft²/km², *see note below*), τ = basal shear stress, ρ = density of glacial ice (1.779 slug/ft³), g = gravitational acceleration (32.178 ft/s²), and α = average slope of the glacier. *Note: Nylen's (2001) equations use km² and km³ whereas Driedger & Kennard's (1986) use ft² and ft³.*



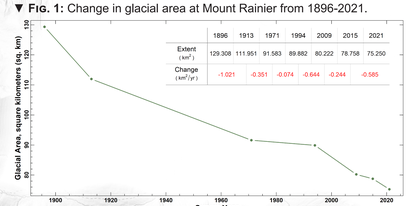
III. Results

Glacial Extent

- **MORA has 28 named glacial features in 2021.**
- **2021 glacier extent:**
  75.250 ± 1.076 km² (29.054 ± 0.415 mi²).
  - **Change from 2015 to 2021 (6 yrs; Fig. 1):**
    -3.51 km² (-1.35 mi²), a reduction of 4.45% in area. Rate: -0.585 km²/yr (-0.225 mi²/yr).
  - **Change from 1896 to 2015 (125 yrs; Fig. 1):**
    -54.06 km² (-20.87 mi²), a reduction of 41.8% in area. Rate: -0.432 km²/yr (-0.167 mi²/yr).

▼ **Fig. 1:** Change in glacial area at Mount Rainier from 1896-2021.

	1896	1913	1971	1994	2009	2015	2021
Extent (km²)	129.308	111.951	91.583	89.882	80.222	78.758	75.250
Change (km²/yr)		-1.021	-0.351	-0.074	-0.644	-0.244	-0.585



Glacial Volume

- **1896 volume:**
  5.90 ± 1.11 km³ (1.42 ± 0.27 mi³).
- **2021 volume:**
  3.07 ± 0.27 km³ (0.74 ± 0.06 mi³).
- **Change from 2015 to 2021 (6 yrs; Fig. 2):**
  -0.146 km³ (-0.035 mi³), a reduction of 4.54% in volume. Rate: -0.024 km³/yr (-0.006 mi³/yr).
- **Change from 1896 to 2021 (125 yrs; Fig. 2):**
  -2.826 km³ (-0.678 mi³), a reduction of 47.9% in volume. Rate: -0.023 km³/yr (-0.005 mi³/yr).

Previously Published MORA Glacier Volumes:

Beason & George (2017):
2015: 3.22 km³

Riedel (Unpublished):
2003: 3.94 km³
2009: 3.22 km³

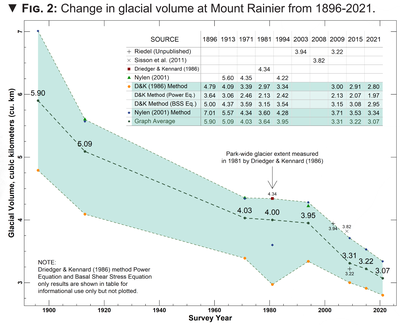
Sisson et al. (2011):
2008: 3.82 km³

Nylen (2001):
1913: 5.60 km³
1971: 4.35 km³
1994: 4.22 km³

Driedger & Kennard (1986):
1981: 4.34 km³

▼ **Fig. 2:** Change in glacial volume at Mount Rainier from 1896-2021.

SOURCE	1896	1913	1971	1981	1994	2003	2008	2009	2015	2021
Riedel (Unpublished)					3.94		3.22			
Sisson et al. (2011)						3.82				
Driedger & Kennard (1986)				4.34						
Nylen (2001)		5.60	4.35		4.22					
D&K (1986) Method	4.79	4.09	3.39	2.97	3.34		3.00	2.91	2.80	
D&K Method (Power Eq.)	3.64	3.06	2.46	2.13	2.42		2.13	2.07	1.97	
D&K Method (BSS Eq.)	5.00	4.37	3.59	3.15	3.54		3.15	3.08	2.95	
Nylen (2001) Method	7.01	5.57	4.34	3.60	4.28		3.71	3.53	3.34	
Graph Average	5.90	5.09	4.03	3.64	3.95		3.31	3.22	3.07	



IV. Conclusions

- As of 2021, Mount Rainier has 28 named glacial and perennial snow features (-1 from 2015).
- Analysis of changes in glacier extent and volume at Mount Rainier continues to show an overall loss of glacial ice and perennial snowfields over the last 125 years:
  Extent: -54.058 km² (-20.872 mi²), a reduction of 41.81% in area between 1896 and 2021.
  Volume: -2.826 km³ (-0.678 mi³), a reduction of 47.90% in volume between 1896 and 2021.
- Despite a relatively gradual decrease in glacial area, glacial volume loss is accelerating as glaciers not only retreat but also thin from the top down.
  Average rates of area loss:
  -0.432 km²/yr (-0.167 mi²/yr) between 1896 and 2021 (125 years).
  -0.585 km²/yr (-0.226 mi²/yr) between 2015 and 2021 (6 years).
  Average rates of volume loss:
  -0.023 km³/yr (-0.005 mi³/yr) between 1896 and 2021 (125 years).
  -0.024 km³/yr (-0.006 mi³/yr) between 2015 and 2021 (6 years).
- Unabated regional climate warming will continue to result in loss of glacial area and volume.
- Several smaller, lower-elevation (cirque) glaciers have been lost in the last few decades. This survey has officially removed the Stevens Glacier from the park's inventory. Several features including the Flett, Inter, Pyramid, Sarvent, and Van Trump Glaciers are in a critical state.
- The loss of glacial ice at Mount Rainier will have severe negative implications for the health of aquatic organisms, freshwater usage, dam operations, and geologic hazards in the region.

Scan to view more info:

Selected References

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Driedger, C. L. and P. M. Kennard, 1986, Ice volumes on Cascade Volcanoes: Mount Rainier, Mount Hood, Three Sisters, and Mount Shasta: United States Geological Survey Professional Paper 1365, 28 p.
George, J.L. and S.R. Beason, 2017, Dramatic changes to glacial volumes and extent since the late 19th century at Mount Rainier National Park, Washington, USA: Poster #158-6, Geological Society of America Abstracts with Programs, Vol. 49, No. 6.
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