Surface Elevation Change on debris-covered Emmons Glacier, Mount Rainier, WA

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Abstract:

Emmons Glacier is located on Mount Rainier, one of the Cascade Volcanoes in Washington State. Much of the ablation area of Emmons Glacier is blanketed by a thick debris cover, which reduces ablation rates and has led to relative ice thickening in past decades, even as the terminus position retreated. To measure how glacier surface elevation has changed in time, we use elevation transects collected from the glacier surface between 2016 and 2021, and compare these field measurements to a digital elevation model based on a 2007 and 2008 LiDAR survey. Elevation change appears to be dependent on the thickness of the debris cover, which we have estimated from digging 43 pits to the depth of glacial ice, or until an obstruction was met or the walls of the pit failed and digging was no longer possible. The thickest debris cover occurs at the margins of the glacier, where pits reached depths of 53 to 85 cm, but did not reach the buried ice surface. The debris cover is thinnest near the centerline of the glacier where the ice surface was located beneath 2 to 22 cm of debris. A 2018 elevation transect, perpendicular to ice flow, showed lower surface elevations near the centerline of the glacier, where the debris is thinnest, including a 32 m deep supraglacial drainage channel. When compared to the 2007/2008 digital elevation model, the 2018 transect shows 35 m of surface lowering at the bottom of this drainage feature, and significant thinning of ~ 20 to 30 m across the transect, even in areas of thick debris cover. Our results suggest multiple influences on the evolution of the surface of Emmons Glacier, including supraglacial meltwater stream development, as well as spatial and temporal variations in the thickness of the debris cover including redistribution of debris on the surface.

Research Question:

How does variability in debris-cover thickness on Emmons Glacier impact glacial morphology?

Study Area/Introduction:

Mount Rainier: Mount Rainier is a 14,410 ft active stratovolcano located in the Cascade Range of the Pacific Northwest (Figure 1; Beason, 2017); the peak is covered by 28 glaciers and snowfields; most of the glaciers have experienced volume loss between 1970-2007/2008 (Sisson et al., 2011).

Emmons Glacier: Emmons Glacier occupies the northeast flank of Mount Rainier, and has the greatest surface area of Mount Rainier glaciers. 17% of Emmons Glacier's surface is blanketed by debris cover (Moore et al., 2019). Debris accumulates on the glacier surface via rockfall, ice flow and ablation. Debris thickness varies, with a mean thickness of 9.0 cm (Moore et al., 2019). Emmons Glacier may retreat at a slower rate due to its terminus thickening in areas of thicker debris cover (Sisson et al., 2011). Emmons Glacial debris cover may be partially attributed to the 1963 Little Tahoma Peak rockfall (Crandell and Fahnestock, 1965; Little Tahoma Peak is visible in Figure 2).

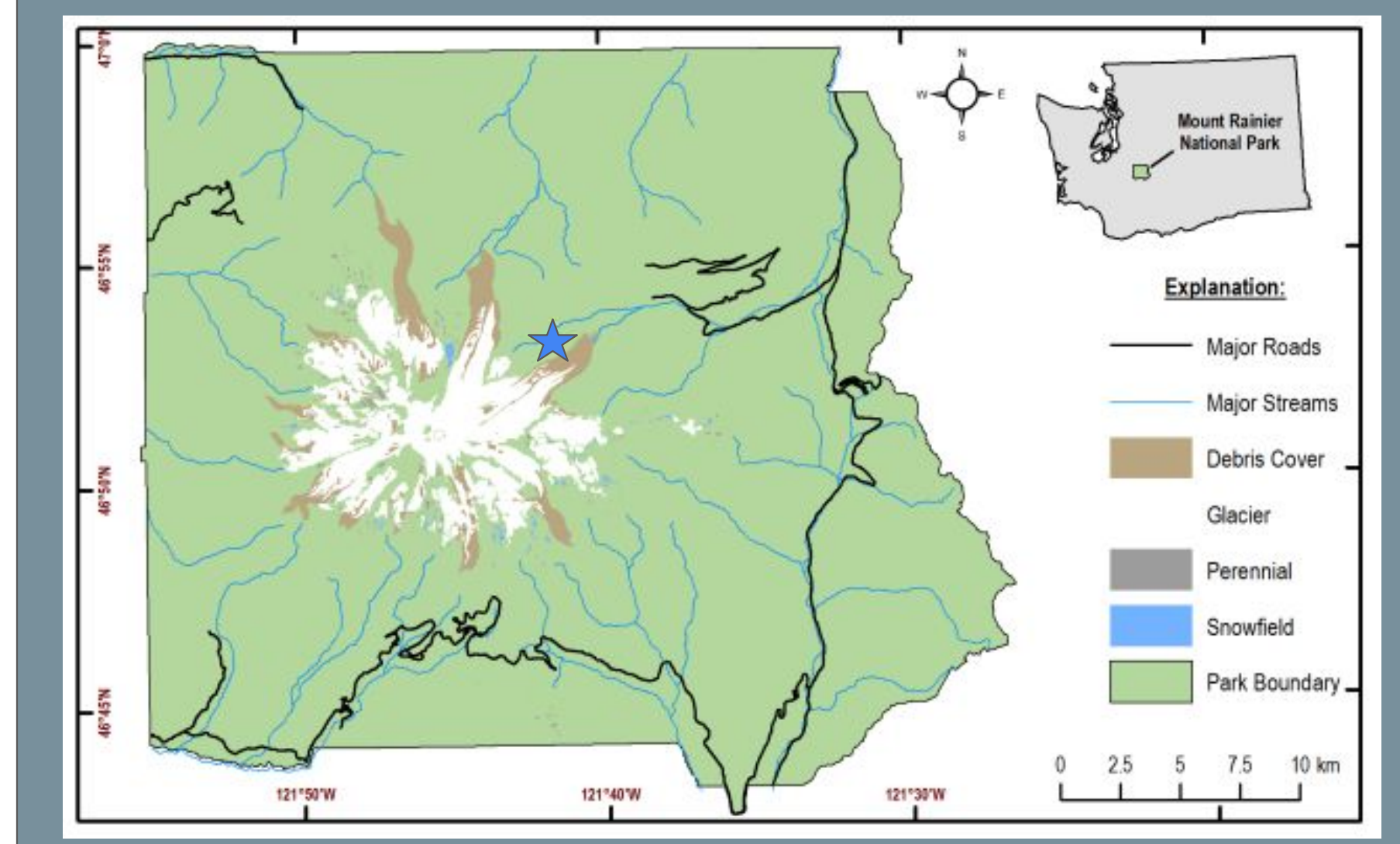

Figure 1: From Beason (2017). Mount Rainier National Park. Emmons Glacier is marked by a blue star.

Figure 2: Debris-covered terminus of Emmons Glacier. Little Tahoma Peak is visible in the center of the image. Mount Rainier's summit is visible at the right edge.

Debris Cover and Glacial Morphology: Glaciers respond differently to supraglacial debris based on varying debris thickness and extent. Thin debris cover causes greater ablation rates than open ice faces due to increased shortwave radiation absorption; thick debris cover slows ablation by insulating ice from shortwave radiation (Moore et al., 2019). The impact of supraglacial debris on surface mass balance thus influences the morphology of the glacier surface (Moore, 2018).

Methods:

- We selected pit locations based on sediment units apparent in satellite imagery and safe access.
- We dug pits to the ice surface where possible. In areas of thick debris cover, large clasts or pit wall failure limited pit depth and a minimum debris thickness was noted (Figure 3).
- Pit depth was measured using a plumb bob suspended from a meter stick placed across the pit opening.
- We also measured debris thickness atop glacial ice face exposures (Figure 4).
- Surface elevations were collected along transects perpendicular to glacier flow using a Trimble GeoExplorer 7x (Figure 5).
- We compared our surface elevation profiles to a LiDAR survey collected at Mount Rainier in September 2007 and October 2008 (Robinson et al., 2010) using the 3D Analyst Tool in ArcGIS.

Figure 3: Digging a pit in the debris cover on Emmons Glacier.

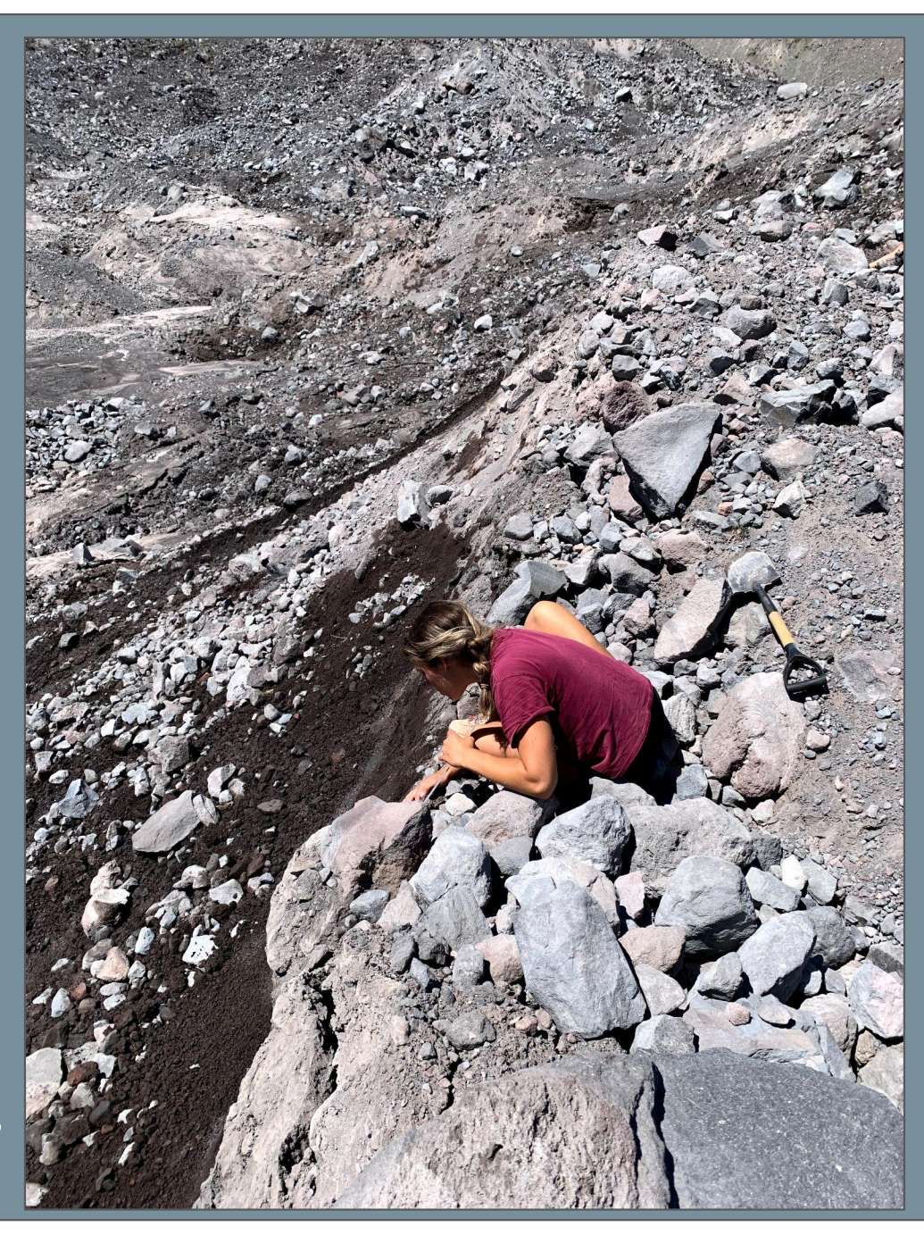

Figure 4: Measuring debris thickness above an exposed ice face.

Figure 5: Recording the location of a completed pit.

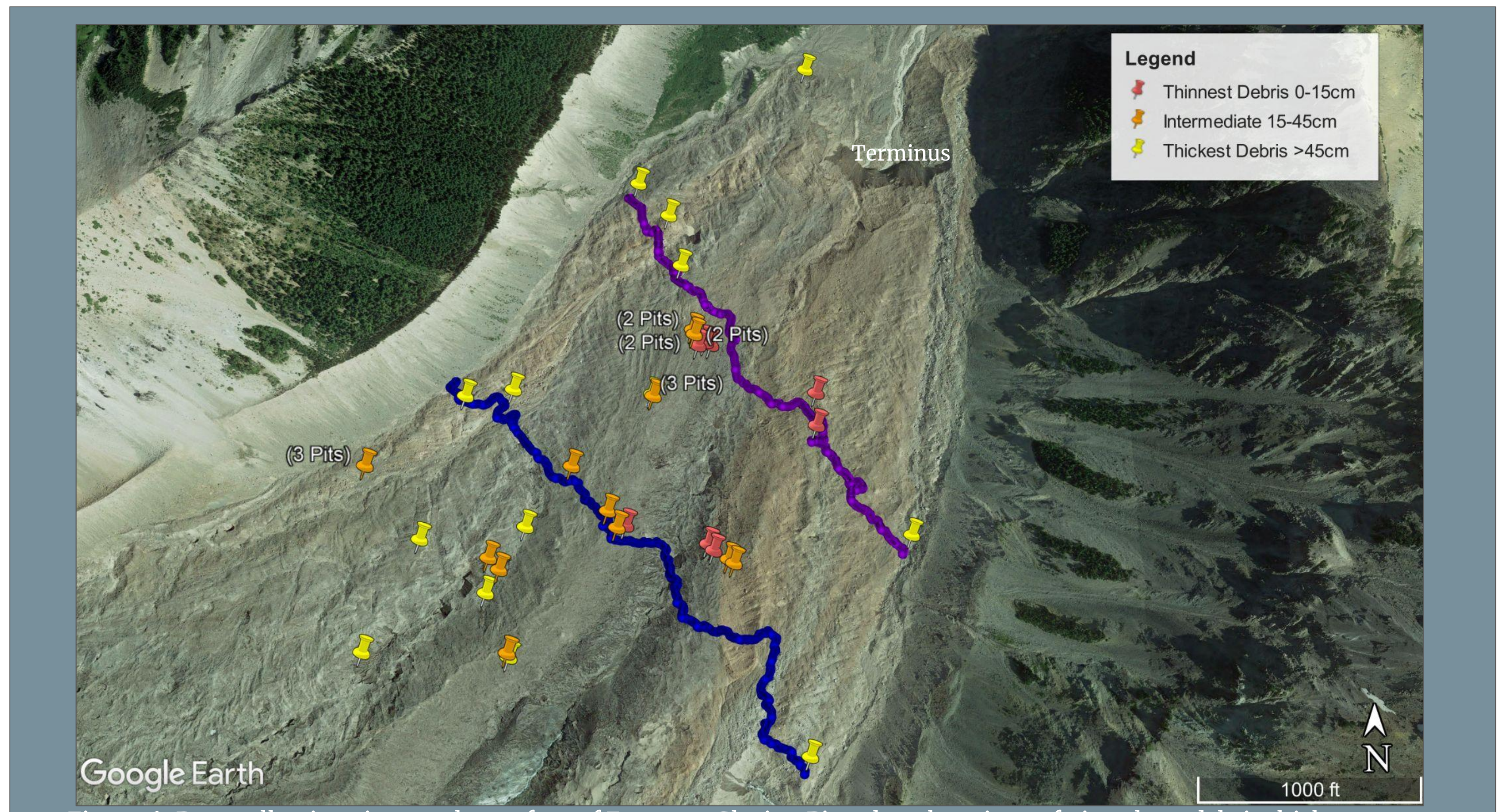

Figure 6: Data collection sites on the surface of Emmons Glacier. Pins show locations of pits where debris thickness was measured. Purple and blue lines show locations of elevation transects plotted in Figures 7 and 8.

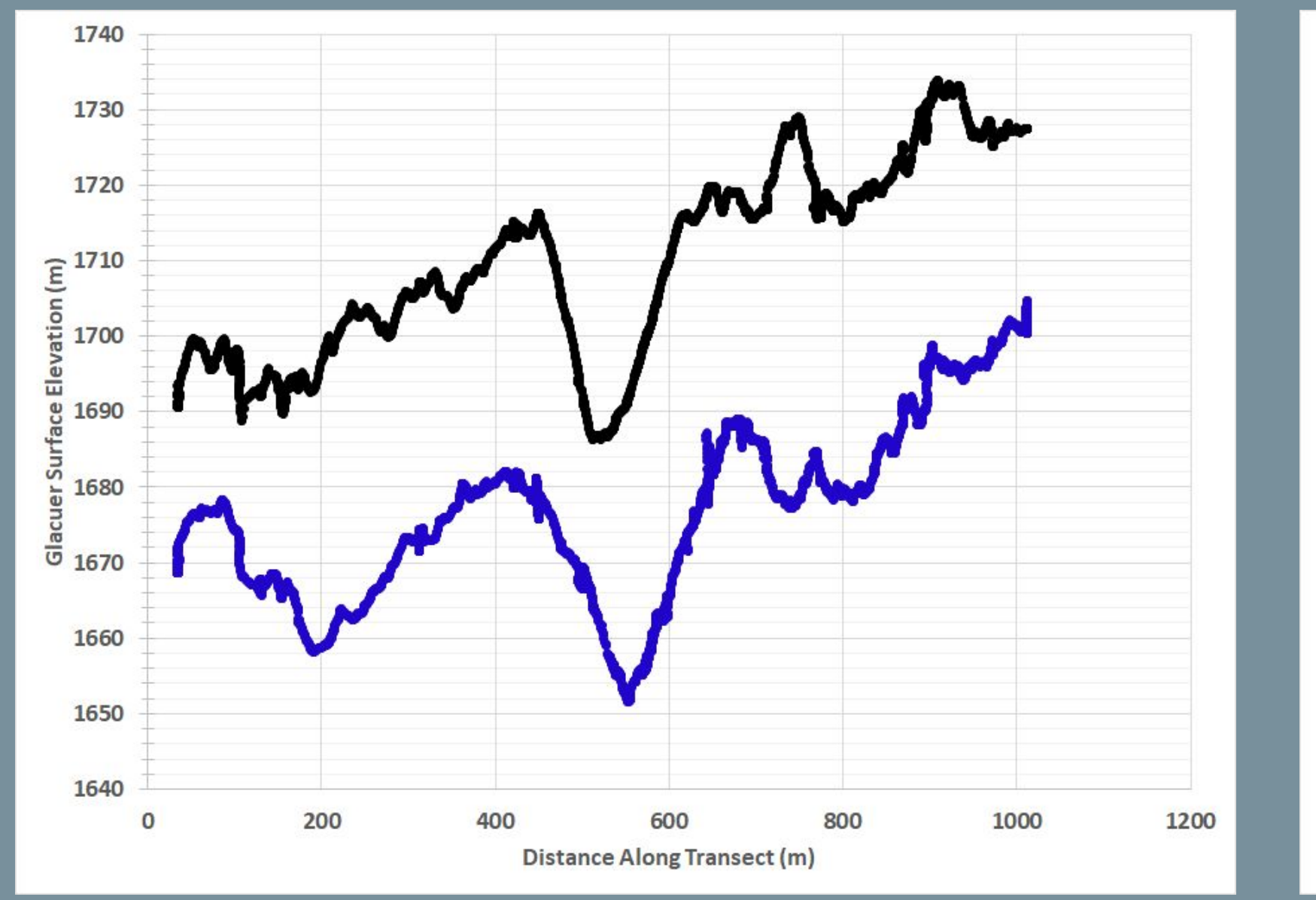

Figure 7. **2018 mid-debris cover glacier surface elevations: (blue)** compared to a **2007/2008 LiDAR DEM (black; Robinson et al., 2010)** along the same transect.

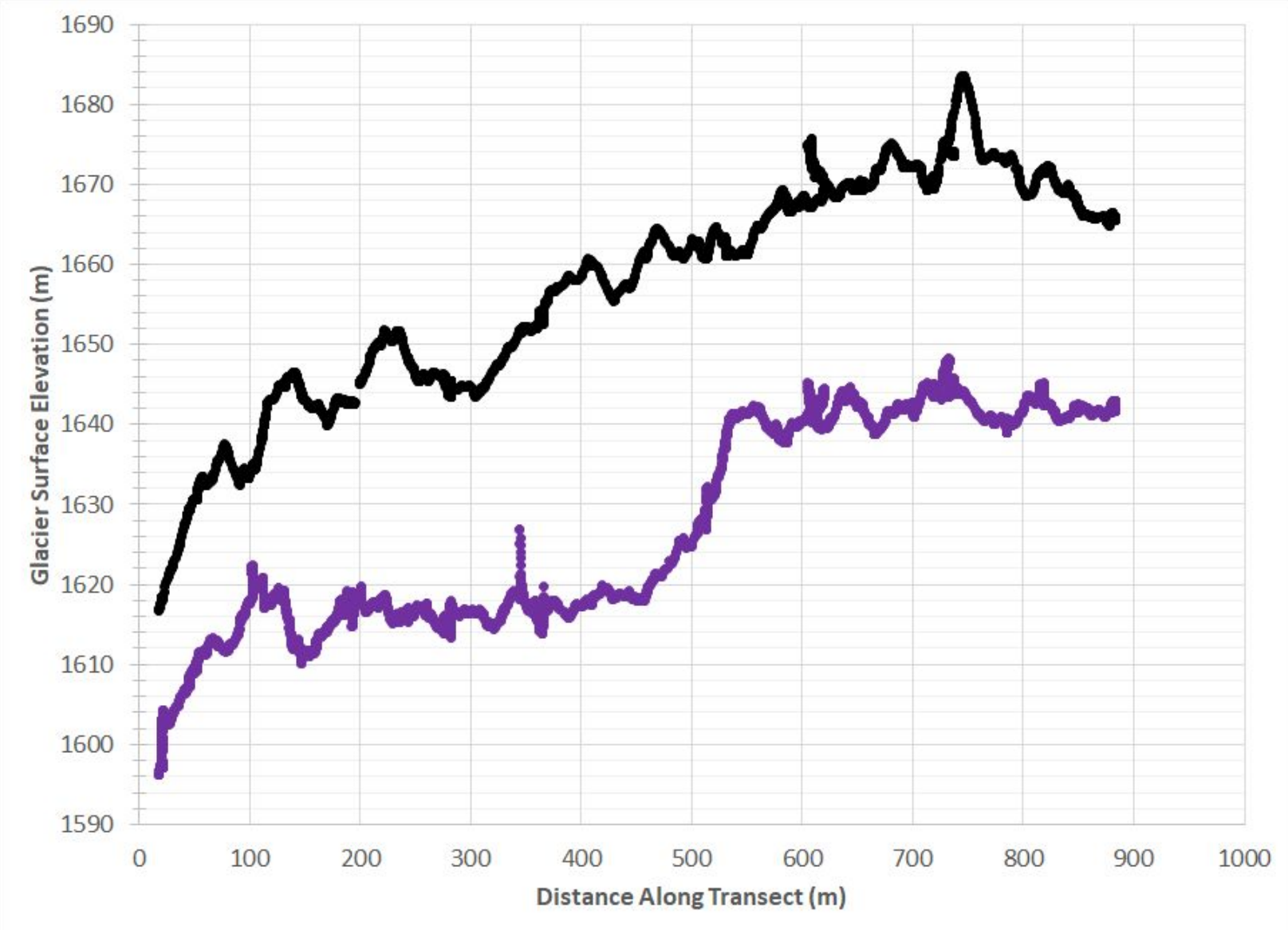

Figure 8. **2018 near-terminus glacier surface elevations (purple)** compared to a **2007/2008 LiDAR DEM (black; Robinson et al., 2010)** along the same transect.

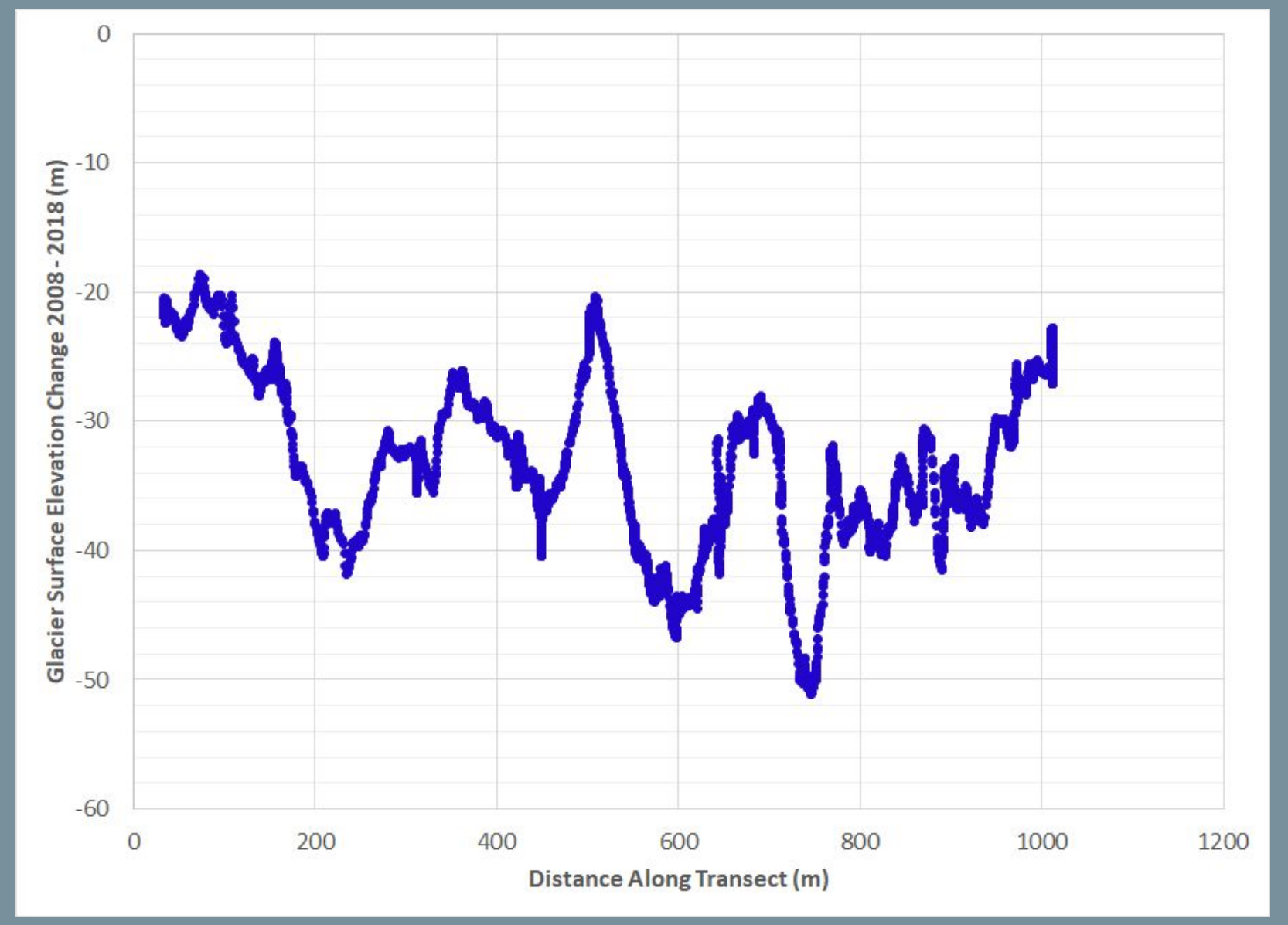

Figure 9. **Mid-debris cover glacier surface elevation change** between **2018** and the 2007/2008 LiDAR DEM (Robinson et al., 2010).

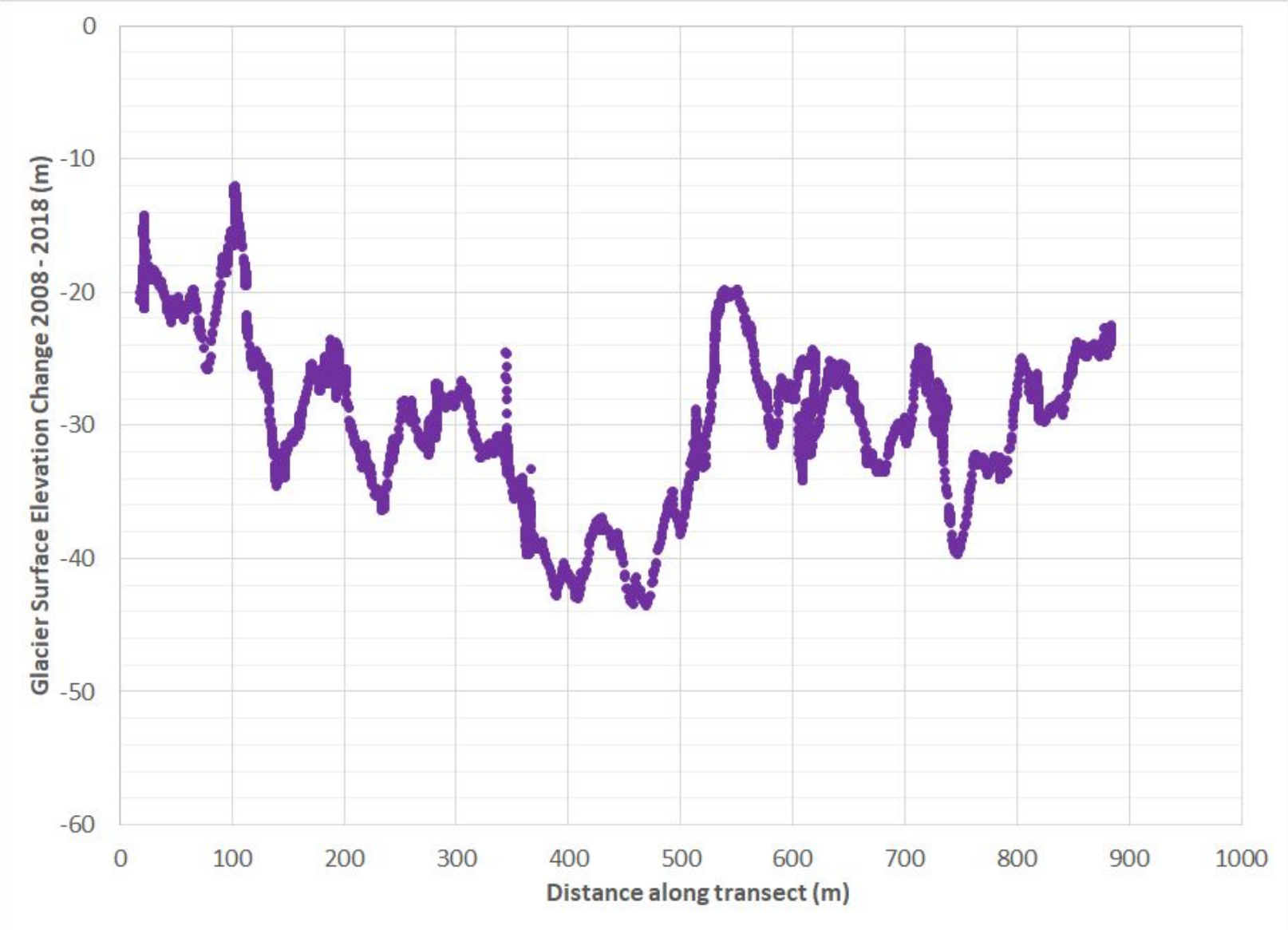

Figure 10. **Near-terminus glacier surface elevation change** between **2018** and the 2007/2008 LiDAR DEM (Robinson et al., 2010).

Results:

Debris cover thickness measurements range from 100 cm +/- 5 cm to 2 cm +/- 1 cm, with an average thickness of 25 cm. In 17 of 43 sites, pit walls failed or a large clast was encountered before reaching the ice surface beneath the debris cover. We observed the thickest debris cover near the glacier margins, and the thinnest debris cover close to the glacier centerline (Figure 6).

In the middle of the debris cover, the glacier surface is characterized by a 30-40 m deep supraglacial meltwater channel at the centerline of the glacier (Figures 7, 11, and 12). Near the terminus, surface elevations increase by approximately 50 m across the width of the glacier (Figure 8).

The glacier surface lowered by ~ 40 m in the center of the supraglacial meltwater channel (Figure 9). Average surface lowering along the mid-debris cover transect is 32 m +/- 7 m. Along the near-terminus transect, average surface lowering is 26 m +/- 7 m.

Figure 11: Emmons Glacier. Red arrow shows supraglacial meltwater channel in the center of the glacier.

Figure 12: Meltwater flowing in the supraglacial channel near the glacier centerline.

Interpretation:

Supraglacial debris on Emmons Glacier is thicker near the glacier margins, and thinner near the glacier centerline, consistent with patterns found on Himalayan debris-covered glaciers as summarized in Anderson and Anderson (2018), who attribute this pattern to convergent ice flow near glacier centerlines. Thicker debris cover near the margins of the glacier is likely due to proximity to sources of rockfall such as lateral moraines and valley walls.

Surface lowering is taking place across the glacier surface, which appears to reverse Emmons Glacier thickening observed between 1970 and 2007/2008 by Sisson et al. (2011; Figure 13).

The margins of the glacier, where we observed the thickest debris cover, show less surface elevation lowering between the 2007/2008 LiDAR DEM (Robinson et al., 2010) and our 2018 surface elevation measurements than observed in areas with thin debris. This phenomenon is well documented on debris-covered glaciers (e.g., Østrem, 1959; Nicholson & Benn, 2006).

Other factors influence glacier surface morphology including supraglacial meltwater. We observed the most surface lowering at the bottom of and near a deep meltwater channel near the glacier centerline - where we also observed the thinnest debris cover.

We expect continued thinning of Emmons Glacier with higher surface lowering occurring near the centerline of the glacier.

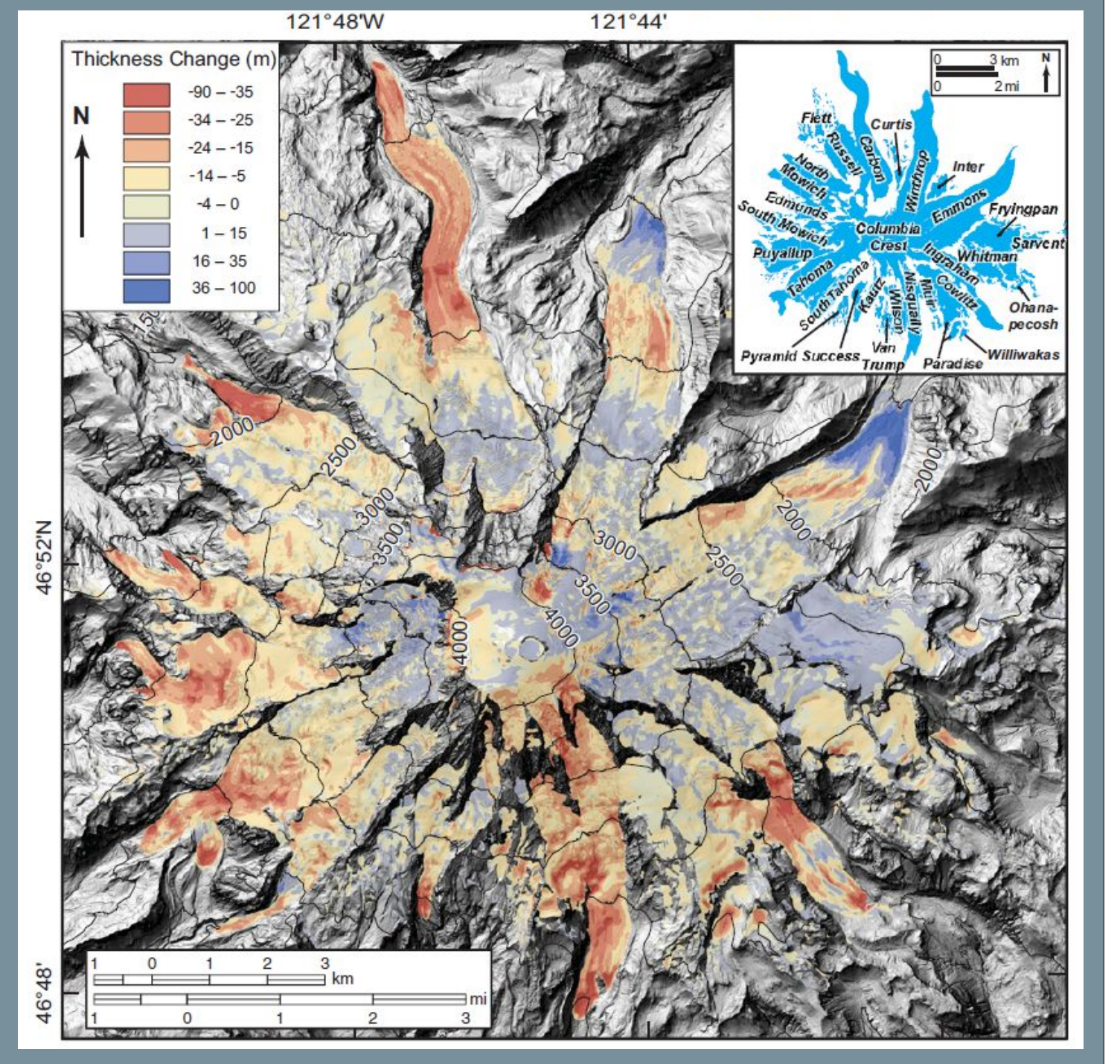

Figure 13: Surface elevation change on Mount Rainier Glaciers from 1970 to 2007/2008 (copied from Sisson et al.,2011; 2007/2008 LiDAR DEM from Robinson et al., 2010).

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