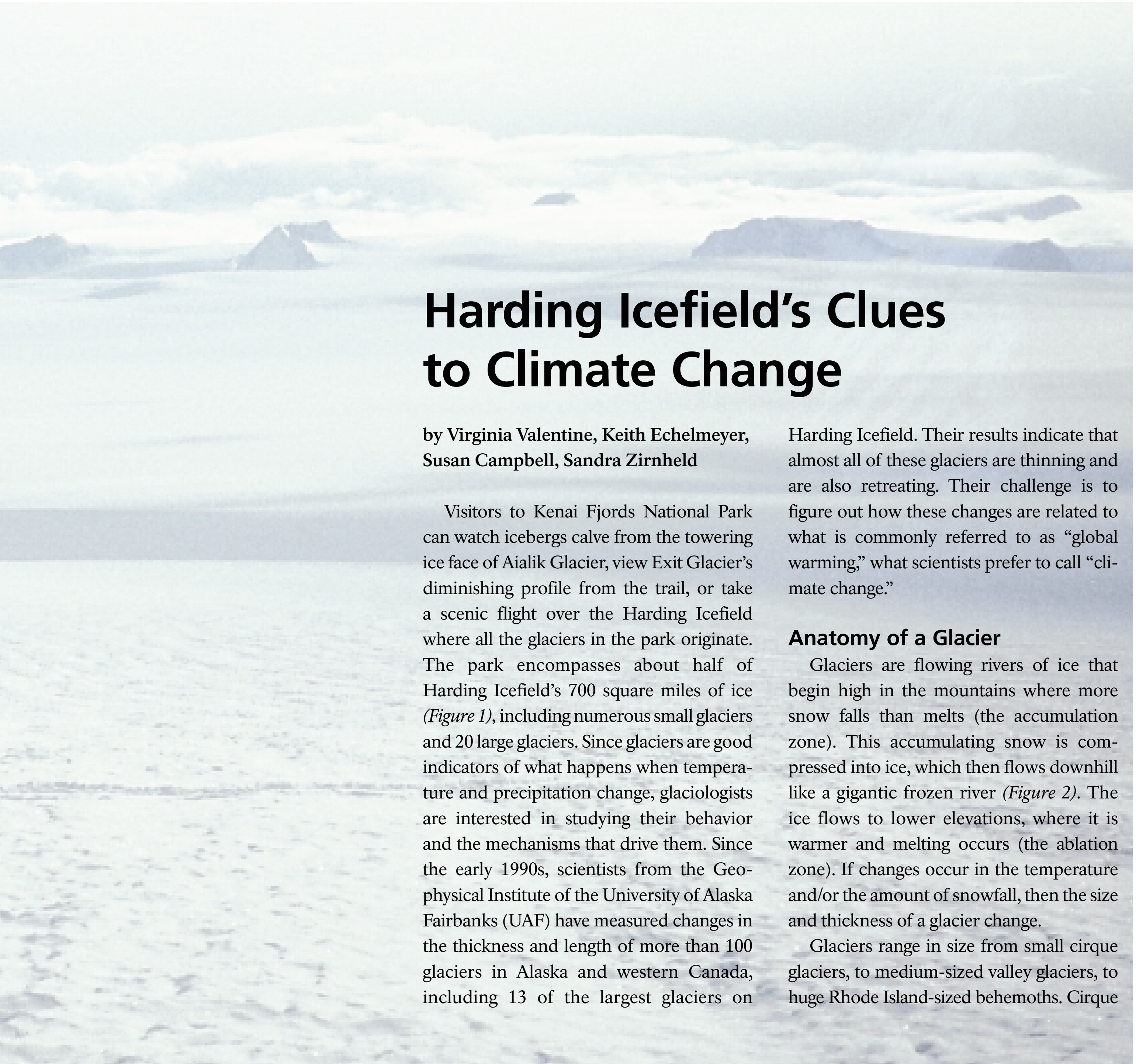
Physical Science in Kenai Fjords



Harding Icefield's Clues to Climate Change

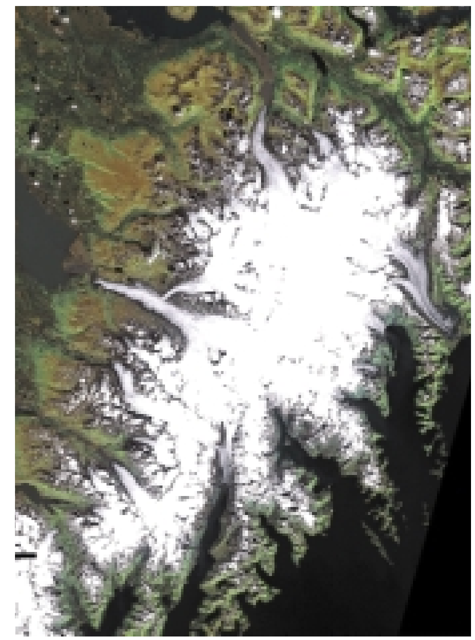
by Virginia Valentine, Keith Echelmeyer, Susan Campbell, Sandra Zirnheld

Visitors to Kenai Fjords National Park can watch icebergs calve from the towering ice face of Aialik Glacier, view Exit Glacier's diminishing profile from the trail, or take a scenic flight over the Harding Icefield where all the glaciers in the park originate. The park encompasses about half of Harding Icefield's 700 square miles of ice *(Figure 1),* including numerous small glaciers and 20 large glaciers. Since glaciers are good indicators of what happens when temperature and precipitation change, glaciologists are interested in studying their behavior and the mechanisms that drive them. Since the early 1990s, scientists from the Geophysical Institute of the University of Alaska Fairbanks (UAF) have measured changes in the thickness and length of more than 100 glaciers in Alaska and western Canada, including 13 of the largest glaciers on Harding Icefield. Their results indicate that almost all of these glaciers are thinning and are also retreating. Their challenge is to figure out how these changes are related to what is commonly referred to as "global warming," what scientists prefer to call "climate change."

Anatomy of a Glacier

Glaciers are flowing rivers of ice that begin high in the mountains where more snow falls than melts (the accumulation zone). This accumulating snow is compressed into ice, which then flows downhill like a gigantic frozen river *(Figure 2).* The ice flows to lower elevations, where it is warmer and melting occurs (the ablation zone). If changes occur in the temperature and/or the amount of snowfall, then the size and thickness of a glacier change.

Glaciers range in size from small cirque glaciers, to medium-sized valley glaciers, to huge Rhode Island-sized behemoths. Cirque



Landsat TM 7 satellite imagery of Harding Icefield, August 9, 2000.

(Left) Figure 1. An icefield is a great expanse of very thick glacier ice, with individual glaciers draining ice down adjacent valleys. Mountains buried beneath the ice sometimes emerge as isolated peaks, called nunataks, as seen here behind the plane.

Photograph ©Geophysical Institute

Photograph ©Geophysical Institute

Crevasses on the lower McCarty Glacier. Animal tracks enter from the lower left corner, cross the crevasse field, and exit from the upper right corner. You can imagine how some prehistoric animals became entrapped in glaciers. The wolverine who made these tracks escaped such a fate—this time.

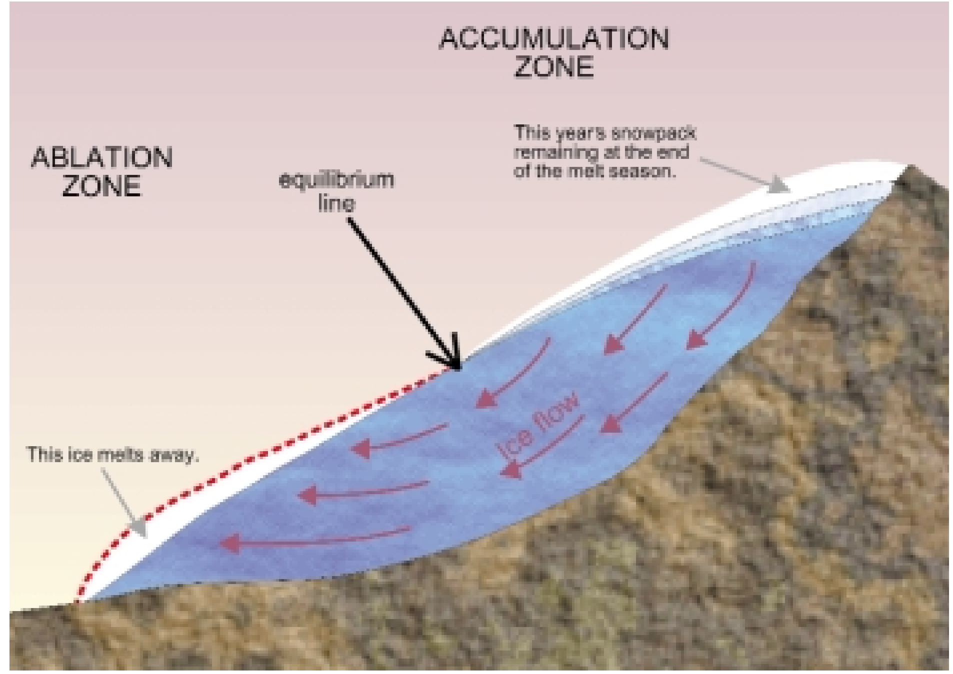


Figure 2. Anatomy of a Glacier. At the end of the melt season, there is still snow left high on the glacier (in the accumulation zone). The equilibrium line is the divide between the accumulation and melting (ablation) zones. As each year's snowpack is buried, the snow is compressed into ice, which begins to flow downhill. Ice that melts on the lower end of the glacier tends to be replaced by ice flowing from above.

glaciers fill bowl-shaped hollows and are typically a half mile wide and long. There are many cirque glaciers in Kenai Fjords National Park, but most of them are unnamed because they are so small. Valley glaciers are what most people picture when they think of glaciers. All of the glaciers that drain the Harding Icefield are valley glaciers. Examples of typical, medium-sized valley glaciers in the icefield are Skilak and McCarty. They are each about 15 miles (24 km) long and two miles (3 km) wide. On the far end of the spectrum are the largest glaciers in Alaska, Malaspina and Bering in Wrangell-St. Elias National Park and Preserve. These glaciers are up to 100 miles (160 km) long and 50 miles (80 km) wide.

Two basic categories of valley glaciers emanate from Harding Icefield: terrestrial and tidewater. Of Harding's 20 large glaciers, 13 are terrestrial glaciers, such as Exit and Little Dinglestadt *(Figure 3)*, and are entirely on land. There are seven large tidewater glaciers, including Aialik *(Figure 3)* and McCarty. They start on land and flow to the ocean, but do not float; instead the terminus (the lowest end) rests on the sea floor. Bear Glacier was once a tidewater glacier, but its terminus has retreated onto land, making it a terrestrial glacier now.

Glacier Changes

Terrestrial and tidewater glaciers respond differently to climate change. Terrestrial glaciers become thinner if less snow falls or if temperatures rise, causing more melting. Evidence of such thinning are trimlines, which resemble bathtub rings, high on valley walls where a glacier once scraped the surrounding mountainsides. Visitors can see these trimlines on Tustumena and Skilak Glaciers on the western side of Harding Icefield *(Figure 4)*. Terrestrial glaciers become thicker if snowfall increases and/or temperatures decrease and prevent melting.

The thickening or thinning of a terrestrial glacier can happen relatively quickly—in a year or two. It takes more time for the length of a glacier to show a measurable change, and so terminus advance or retreat is not a sensitive indicator of recent climate change. Glaciers do not thin or thicken evenly over their whole length *(Figure 5a)*. Small changes tend to occur at the highest elevations (in the accumulation zone), while the surface can change by several feet per year near the terminus (in the ablation zone). Usually when glaciers are thinning drastically at their terminus, they are also retreating. For example, Exit Glacier retreated about one quarter of a mile from 1950-1994. In the same time period, the glacier thinned by 300 feet (90 m) near its terminus, but less than a foot at higher elevations. This distribution of thickness change led to an average glacier-wide rate of thinning of seven inches per year.

Tidewater glaciers have a mind of their own. In contrast to terrestrial glaciers, they advance slowly, maintaining a submarine shoal at their terminus. If the terminus moves back from the shoal, calving increases in the deeper water behind the shoal and the glacier retreats quickly. Northwestern Glacier is a good example of a retreating tidewater glacier in the park.

Measuring Glacier Changes

Even 100 years ago, people noticed that many glaciers around the world seemed to be shrinking. Scientists at UAF set out to determine whether this was true by building a laser altimetry system to measure thickness changes of glaciers throughout Alaska and western Canada *(Echelmeyer et al. 1996)*. This system is designed to fit in the back of a Piper PA-12, a two-passenger airplane nimble enough to navigate the steep, narrow terrain of small valley glaciers.

The altimetry system consists of a highly accurate Global Positioning System (GPS) receiver, a laser, and a gyroscope *(Figure 6)*. The GPS records the position of the plane every second as it flies down a glacier, the laser continually measures the distance between the plane and the glacier surface, and the gyroscope measures the direction in which the laser is pointing. Combining data from these instruments, elevation profiles of the surface of the glacier are created that are accurate to within a few inches.

These surface profiles are used to calculate long-term changes in glacier thickness by comparing them with U.S. Geological Survey (USGS) topographic maps made 50 years ago. Even after taking into account the inaccuracies of the old maps, the glaciolo-

Figure 3. There are two types of glaciers, those that terminate on land, and those that terminate in the water. The Little Dinglestadt Glacier (Left) is an example of a land-terminating or terrestrial glacier. Aialik Glacier (Right) is an example of a water-terminating or tidewater glacier. Tidewater glaciers do not float on the ocean surface, but rather rest on the sea floor.

Figure 4: The arrow points to trimlines of the Tustumena Glacier, which indicate areas that were scraped by the glacier when it was much thicker than it is today. Trimlines are often evidence of the dramatic thinning and/or retreat of a glacier.

gists have found that most glaciers have thinned hundreds of feet in the last five decades (up to eight ft/yr). The researchers have also followed the same flight lines after ten years. By comparing data from these repeated flights they are able to obtain short-term measures of glacier change that are much more accurate. In this ten-year period, they have seen substantial increases in the rate of thinning, up to 15 feet/year (2.7 m/yr), on many glaciers in Alaska and western Canada *(Figure 5b) (Arendt et al. 2002).*

Changes on the Harding Icefield

UAF researchers have flown altimetry profiles over 13 of the major glaciers in the Harding Icefield and have compared the profiles to USGS topographic maps *(Figure 7)*. From the 1950s to the early 1990s, they found that, on average, most glaciers flowing from the Harding Icefield were thinning *(Figure 5b) (Adalgeirsdottir et al. 1998)*. For example, Bear, Tustumena, and Northwestern Glaciers thinned about 2.5 feet/year (0.75 m/yr) in this long-term period. Northeastern Glacier was the big loser, with an average thinning of more than 7 feet/year (2.1 m/yr)! Two of the tidewater glaciers in the park did not thin: Aialik Glacier remained about the same, and McCarty Glacier actually thickened.

Data from the last ten years show that Harding Icefield glaciers continue to thin. Curiously, although these glaciers are still losing ice, they do not show the accelerated thinning rates measured elsewhere in Alaska and western Canada *(Figure 5b)*. Aialik Glacier is now thinning, while McCarty Glacier continues to thicken and advance. In the future, more of the tidewater glaciers in the park may become terrestrial like Bear Glacier.

Relevance to Sea Level Changes

Currently, global sea level is rising at a rate of 1.3 inches (3.25 cm) per decade *(Houghton et al. 2001)*. The largest component (~87%) of this current rise is due to the increasing temperature of the oceans, which causes the water to expand, filling the ocean basins to a higher level. Scientists estimate that the melting of glaciers around the world (excluding Greenland and Antarctica) makes the next largest contribution. In particular, glaciers in Alaska and western Canada account for ~9% of the measured sea level rise in the last 50 years. This amount is far out of proportion relative to the area these glaciers cover. Although Greenland ice is thinning *(Krabill et al. 2000)*, and although Greenland and Antarctica contain vast amounts of glacier ice, on a per-area basis these regions are not currently contributing to sea level rise as much as Alaska and western Canada.

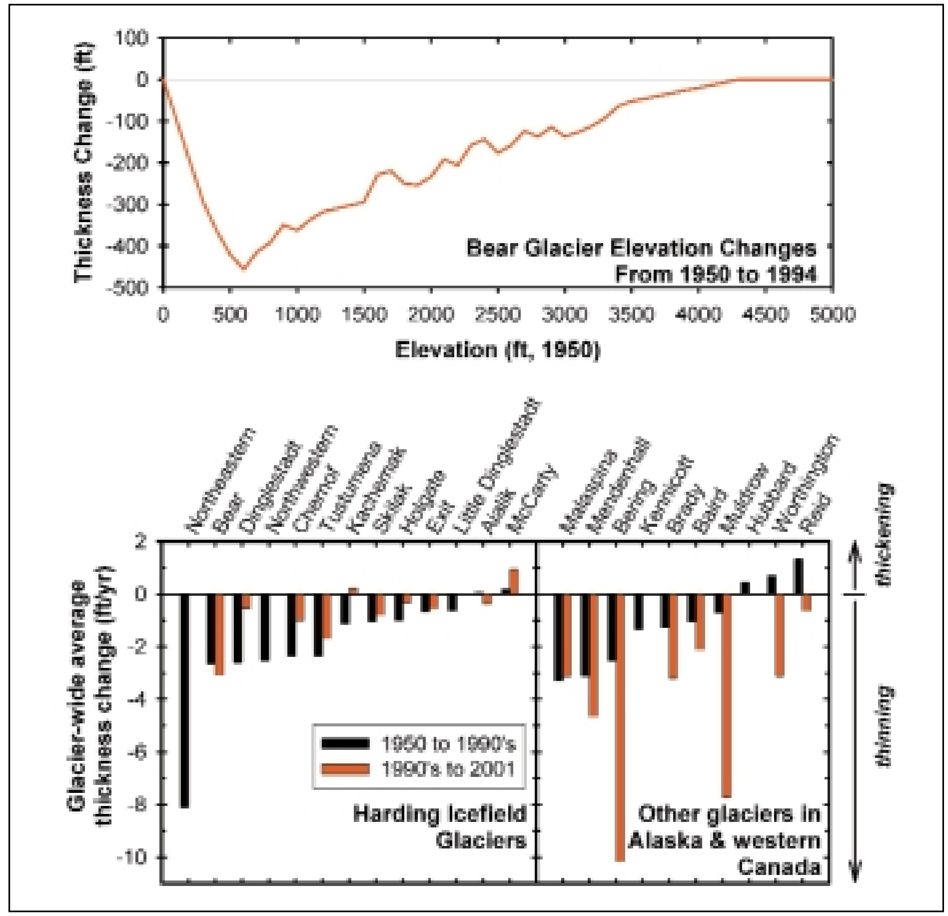


Figure 5a: (Top) Glacier Thickness Changes.
Ice thickness does not change uniformly over an entire glacier. Changes are small in the higher elevations, but often dramatic in the lower, warmer elevations where melting occurs. Bear Glacier exhibits the typical pattern of thickness change with elevation.

Figure 5b. (Bottom) Thickness changes (ft/yr) for the two time periods: 1950s-1990s and 1990s-2001. During the earlier time period, Harding Icefield glaciers thinned like glaciers elsewhere, but do not show the accelerated thinning during the recent period that is seen in other areas throughout Alaska and western Canada. Wrangell-St.Elias NP: Malaspina, Bering, Hubbard, and Kennicott glaciers. Glacier Bay NP: Brady and Reid glaciers. Denali NP: Muldrow Glacier. Tongass National Forest: Mendenhall Glacier. Valdez: Worthington Glacier. SE Alaska: Baird.

Conclusions

Most of the glaciers in Kenai Fjords National Park are losing ice and becoming thinner, the same as other glaciers in Alaska and western Canada. Scientists believe that the loss of ice is due to increased temperatures and/or decreased snowfall, and that this glacier melting is contributing to sea level rise. The questions surrounding climate change are complex. The research being done on arctic glaciers continues, as scientists try to understand what glaciers are telling us about climate change.

Visitors to Kenai Fjords National Park can look forward to viewing the grandeur of some of Alaska's most beautiful glaciers for decades to come, but, as the years go by, the view will be changing.

Acknowledgments

The authors wish to acknowledge Anthony Arendt for his helpful comments and contributions to the creation of the figures. Research conducted in Kenai Fjords National Park was funded by the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, and the National Science Foundation-Office of Polar Programs.

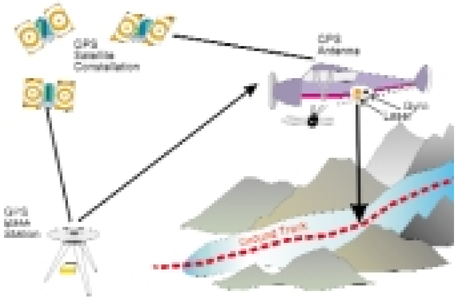


Figure 6. An airborne laser altimetry system allows Keith Echelmeyerís team to measure the elevation of the ice surface along a track down a glacier. These elevations can then be compared to map elevations dating from the 1950s, or to previously flown altimetry profiles, to determine the amount of thinning or thickening of a glacier during the intervening time period.

REFERENCES

Adalgeirsdottir, G., K. Echelmeyer, and W. Harrison. 1998. *Elevation and Volume Changes on the Harding Icefield, Alaska.* Journal of Glaciology, 44(148): 570-582.

Arendt, A., K. Echelmeyer, W. Harrison, C. Lingle, and V. Valentine. 2002. *Rapid Wastage of Alaska Glaciers and Their Contribution to Rising Sea Level.* Science, 297(5580): 382-386.

Echelmeyer, K., W.D. Harrison, C.F. Larsen, J. Sapiano, J. E. Mitchell, L. DeMallie, B. Rabus, G. Adalgeirsdottir, and L. Sombardier. 1996. *Airborne Surface Profiling of Glaciers: A Case Study in Alaska.* Journal of Glaciology, 42(142): 538-547.

Houghton, J., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, and D. Xiaosu (ed.). 2001. *Climate Change 2001: The Scientific Basis.* Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK.

Krabill, W., W. Abdalati, E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, W. Wright, and J. Yungel. 2000. *Greenland Ice Sheet: High-Elevation Balance and Peripheral Thinning.* Science, 289(5478): 428-430.

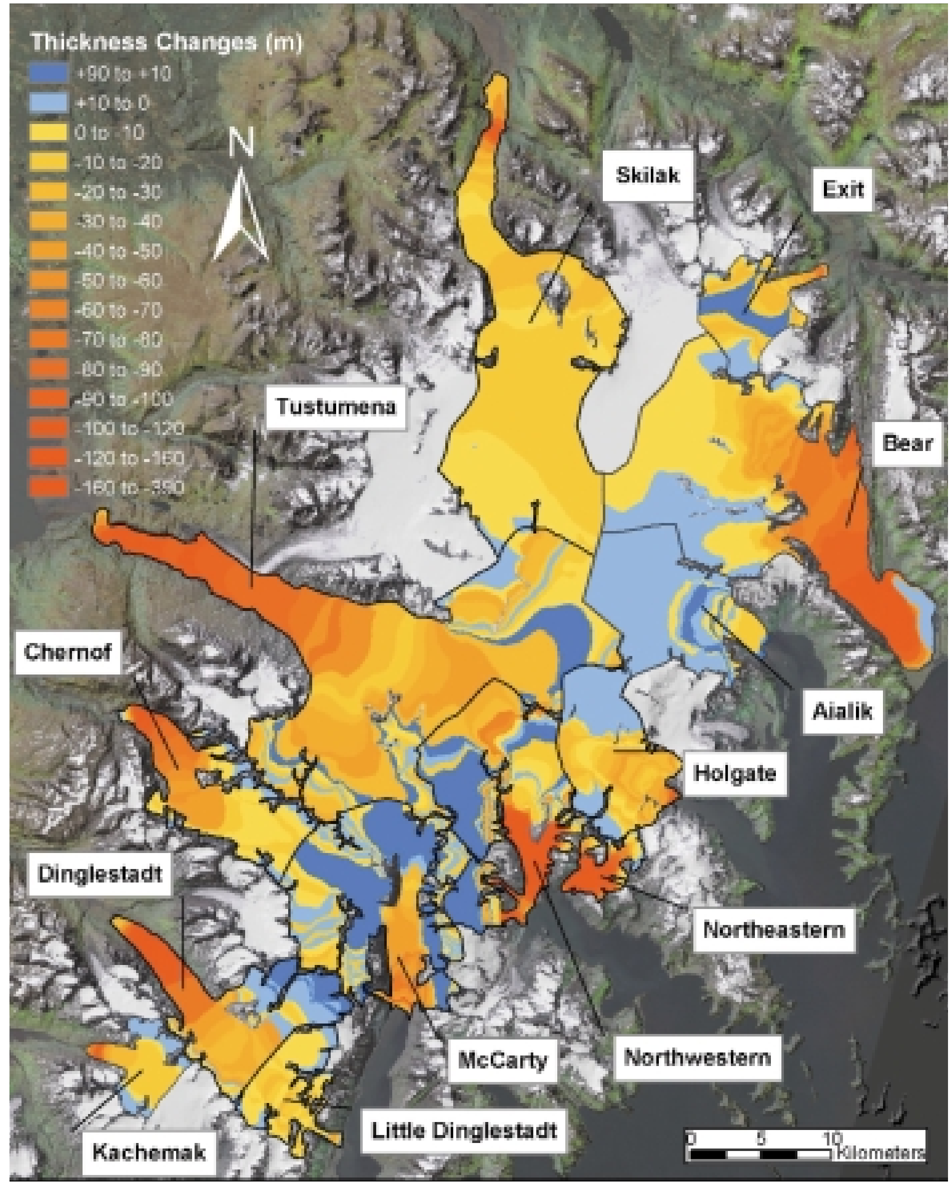


Figure 7. Harding Icefield glaciers monitored by researchers from the University of Alaska Fairbanks, Geophysical Institute. Glacier basins are outlined in black. Thickness changes from the 1950s to the 1990s are indicated by color, with blue indicating areas of thickening, yellow indicating areas of moderate thinning, and red indicating areas of dramatic thinning.