



Glaciers, Perennial Snowfields, and Seasonal Snow



NPS /D. McGrath

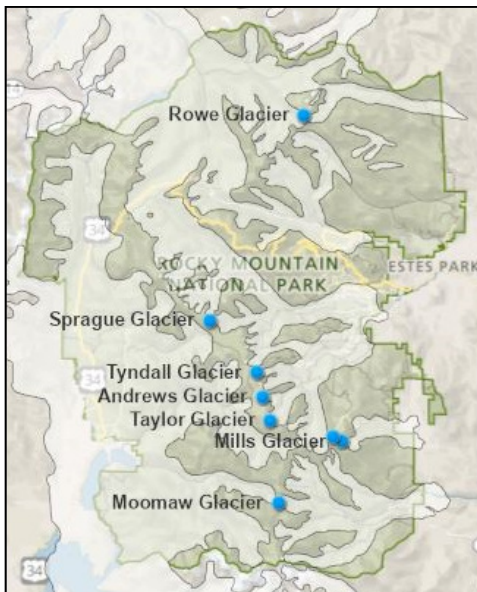
Brendan Hodge and John Knowles conducting a LiDAR (Light Detection and Ranging) scan at Tyndall Glacier. LiDAR uses pulses of light to measure distances to the earth. In this case, it was being used to measure seasonal glacier mass balance.

Each year, millions of visitors come to Rocky Mountain National Park (RMNP) to experience its scenic mountainous landscapes, abundant wildlife, and high elevation alpine tundra. Glaciers, perennial snowfields, and ice patches are an important part of these human experiences. Glaciers shaped this landscape, carving the dramatic alpine cirques and arêtes and filling valley floors (e.g., Moraine Park) with glacial deposits. Today, meltwater from snow and perennial ice fields/glaciers support the park's plants and wildlife, as well as human populations on both sides of the Continental Divide (Clow et al. 2016; Fassnacht et al. 2018; Ingersoll et al. 2007; Patterson 2016). The vast blanket of seasonal snow draws many visitors and supports a robust winter recreation economy (Fassnacht et al. 2018; Patterson 2016).

RMNP has been shaped by two glacial periods: the Bull Lake Glaciation (200,000-130,000 years ago) and the Pinedale Glaciation (30,000-11,700 years ago). On U.S. Geological Survey topographic maps, eight masses of snow and ice in RMNP were historically identified as glaciers: Andrews, Dove, Mills, Moomaw, Rowe, Sprague, Taylor, and Tyndall. Under a strict definition, however, Andrews may be the only "true" glacier because the others do not appear to flow. The park contains another 20+ perennial ice/snow patches. Glaciers, perennial snowfields, and ice patches are strongly influenced by climate, particularly air temperature and frozen precipitation. Past and current research has increased our understanding of past climate and air quality. Research is also shedding light on the long-term sustainability of our glaciers, threats to their continued existence, and how we can mitigate those threats.

Key Messages

- Major landforms in Rocky Mountain National Park (RMNP) were shaped by recent glacial periods (~130,000 and ~26,000 years before present). Today, there are eight small "named" glaciers and approximately 22 perennial snow and ice patches in the park.
- Glaciers are retreating globally in response to warming atmospheric temperatures. In recent decades, RMNP's glaciers have been less impacted, likely due to their high-elevation shaded locations and the abundant accumulation they receive from wind-blown snow and avalanches.
- On decadal timescales, snowmelt is occurring earlier and snowpack water content is decreasing.
- Concentrations of dust, ammonium, nitrates, and pesticides, deposited through atmospheric deposition, are increasing in snowpack.
- Andrews Glacier in RMNP is the thickest known glacier in Colorado, measuring up to 45 meters at its thickest section.
- Predicted atmospheric warming through the end of the century will lead to pronounced decreases in seasonal snow and the likely demise of glaciers in RMNP.



General locations of the eight glaciers in Rocky Mountain National Park, as well as glacial extent within the area 26,000 years ago (NPS 2019).

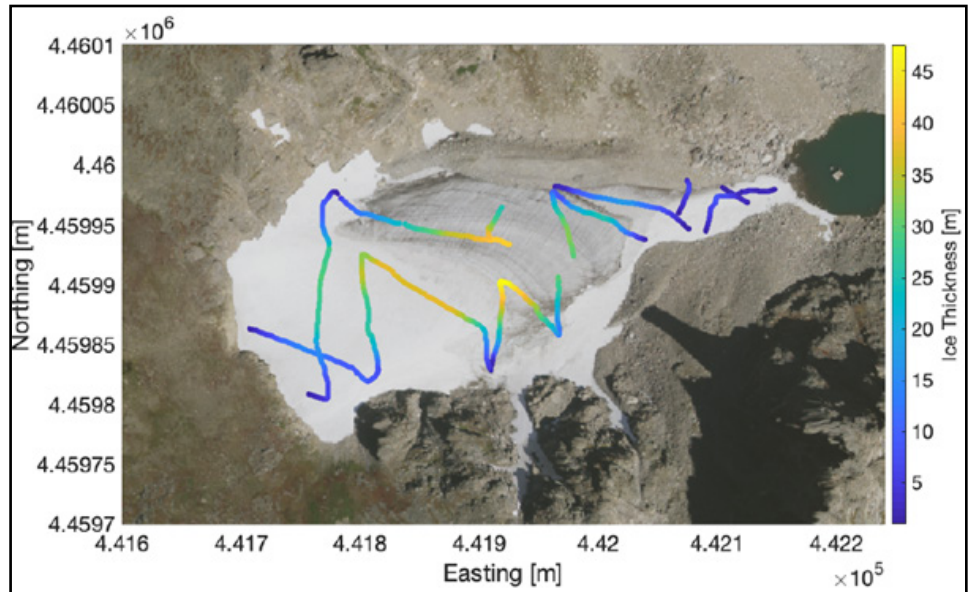


Figure 1. Ground-penetrating radar survey measured ice thickness of Andrews Glacier in May 2017. The thickest part of the glacier was approximately 45 meters deep, making it most likely the thickest glacier in Colorado. Figure courtesy of D. McGrath.

Research

Early research on glaciers in and around RMNP focused on historic glacier extent and the timing of glacial retreat. During the Last Glacial Maximum, glaciers filled many major valleys in RMNP and along the Front Range but did not reach Estes Park and Tahosa Valley (Jones and Quam 1944). Research on the history of glaciers also includes the timing of glacial advances and retreats, and climate variations in the Holocene (Benedict 1973; Benedict 1968; Madole 1980; Madole 1976). Benedict et al. (2008) used radiocarbon dates on timber emerging from a melting ice patch to suggest treeline was ~175 m higher during the mid-Holocene and that ice patches are at a minimum extent today relative to the past 4,200 years. Previous work documented at least four periods of Holocene glacier growth, with the most recent during the Arapaho Peak advance (300-100 BP); regional climate change was the primary mechanism behind Holocene glacial change (Benedict 1973). Given their unique topographic setting and outsized role of wind redistribution of snow, the mass balance of glaciers in RMNP today is relatively insensitive to winter accumulation but does respond to spring precipitation and summer temperatures (Hoffman et al. 2007; Outcalt 1965; Olyphant 1985).

Recent research has focused on both modern and long-term changes in snowpack, ice patches, and glaciers. Hoffman et al. (2007) found that glacier extent fluctuated throughout the 20th century, with significant recession between 1999 and ~2005. More recent work by McGrath (2019) found the glaciers exhibited marked interannual variability, but limited net change in area between 2001 and 2018. McGrath used historical topographic maps and modern digital elevation models to calculate glacier volume change over 50-year intervals and found that

Andrews and Tyndall were in near balance, whereas Moomaw Glacier had thinned by 3.2 m between 1964 and 2016. Elsewhere along the Front Range, Arapaho Glacier thinned by approximately 23 m over this same interval, suggesting that these glaciers do not respond equally to climate forcings. Topography, aspect, and wind redistribution clearly play an important role in the observed variability. McGrath used ground-penetrating radar to measure the ice thickness of Andrews Glacier along transects and found one section to be over 45 meters thick, making it most likely the thickest glacier in Colorado (Figure 1).

Rivers and streams throughout RMNP and all along the Front Range exhibit snowmelt driven hydrographs—the rate of flow (discharge) throughout the year is largely influenced by melting of snow, and to a lesser degree, ice. As such, there is significant interest in understanding the spatial distribution and magnitude of snow water equivalent (SWE), both today and in the future. Clow (2010) found that snowmelt is occurring an average of 4.8 days earlier per decade in Colorado and that the accumulated SWE on April 1 was declining. These decrease in accumulated SWE is especially prevalent at high elevations (Fassnacht et al. 2018). In general, the greatest decreases in accumulation and increases in melting have occurred at the start and end of the snow accumulation season (November and March, respectively), while increases in the snowpack were observed between December and February (Fassnacht et al. 2018; Patterson 2016).

RMNP's glaciers, snowpacks and perennial ice patches have also been a useful tool to investigate air quality—the

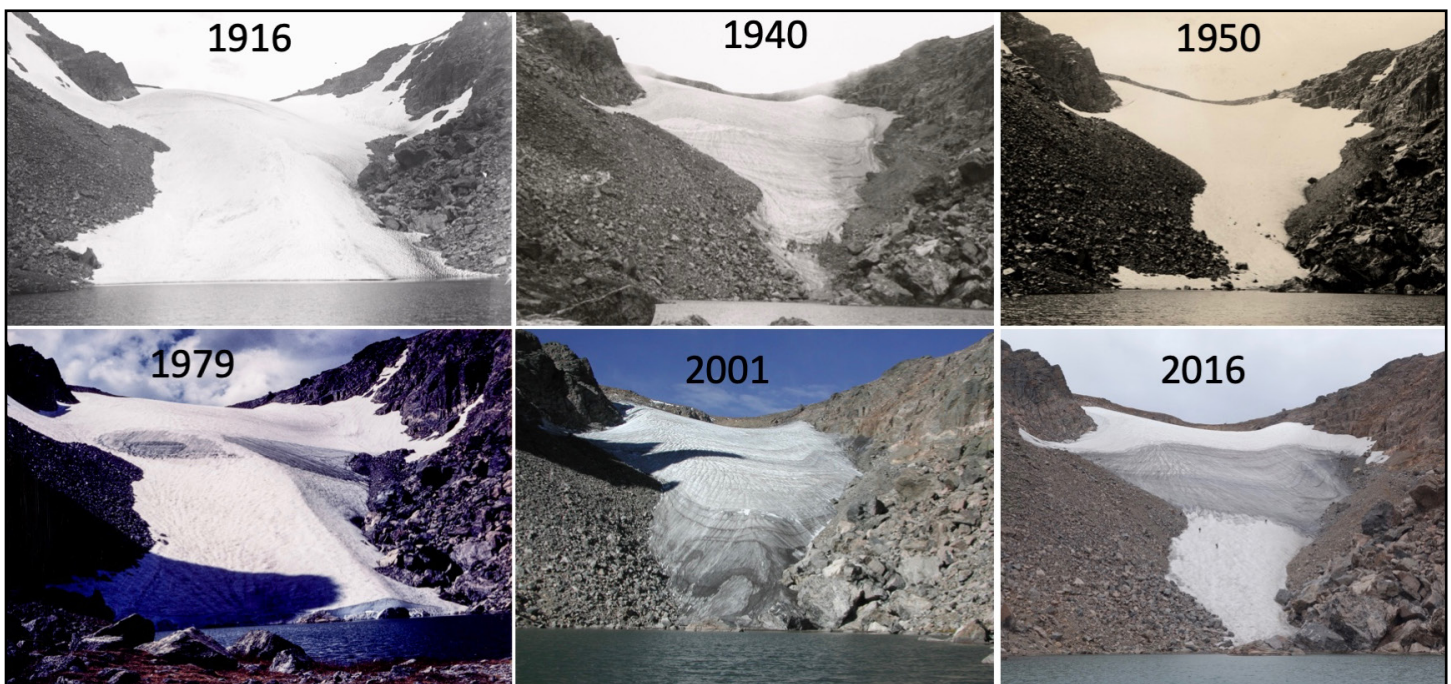
chemical properties of snowpack are changing, largely as a result of humans. Grazing, tilling, drought, and wind all influence dust concentrations in snowpack (Clow 2016). Thus, as these increased in the central and southern Rockies, so did dust concentrations. As of 2004, Ingersoll et al. (2007) found that, in National Parks and Forests near the Continental Divide, sulfate concentrations in snowpack had decreased overall, though more developed areas had relatively higher concentrations (Ingersoll et al. 2002). Additionally, development has resulted in increased ammonium and nitrate in snowpack, a trend that is evident in Colorado's relatively high concentrations (Ingersoll et al. 2007; Ingersoll et al. 2002). Chlorinated pesticides (endosulfan, dacthal, and chlorothalonil) have also been detected in snowpack (Mast et al 2006). Agricultural pesticides were higher in RMNP than in Glacier National Park, likely reflecting its proximity to agriculture. That being said, concentrations of DDE and DDD (both degradation products of DDT) were highest in sediments deposited in the 1970s, indicating that deposition has declined since the use of DDT was discontinued (Mast et al. 2006). Thus, through agriculture, carbon emissions, and development more generally, humans have changed and continue to change the chemical properties of snowpack, which could affect the health of both human and non-human populations that are dependent on snowpack quality.

Predicted atmospheric warming and changes in precipitation will have a profound impact on the snow and glaciers of RMNP. Recent work has shown that for high-emission scenarios, snow water equivalent (SWE) for western US mountains could decrease by ~25% by 2040-2065 and by ~70% by 2075-2100 (Rhoades et al. 2018).

Although the projections for northern Colorado in the vicinity of RMNP are less severe, winter temperatures are still predicted to increase by +5°C, resulting in a major reduction in SWE (Rhoades et al. 2018). Detailed mountain-scale predictions of glacier mass balance do not exist for Colorado; however, a regional scale analysis predicts that glacier volumes throughout western Canada and the Rocky Mountains will decrease by >50% by 2030 and >80% by 2080 relative to 1980 volumes (Huss and Hock 2015).

Management

Research at RMNP has increased the understanding of why snowpack, ice patches, and glaciers are important, what is threatening their existence, and what can be done to mitigate those threats. Better agricultural practices (i.e. less grazing, tilling, and chlorinated pesticides) and significant global actions to reduce carbon emissions would mitigate glacier mass loss. Both RMNP and the National Park Service are working to reduce their own carbon footprints, largely by increasing their energy efficiency and encouraging visitors to do the same. The NPS Air Resources Division has also been leading the inter-agency Rocky Mountain National Park Nitrogen Deposition Reduction Plan (2007) and works closely with the park, partner agencies, and the Agricultural Subcommittee to address nitrogen emission from farms and ranches through the development of agricultural best management practices. RMNP encourages climate, glacier, and air quality research; supports long-term monitoring, including the SNOTEL sites within the park; and works with citizen scientists on a glacier repeat photography project.



Repeat photography series of Andrews Glacier from 1916 to 2016 (McGrath 2019). Similar efforts are being done through the Photopoint Citizen Science Project, started by park volunteers Jim Westfall and Kevin Zagorda, to collect repeat photos of glaciers throughout the park to monitor glacial change. Photo credits: 1916: Lee Willis/NSIDC; 1940: Paul Nesbit/NSIDC; 1950: ROMO Glacier Report/NSIDC; 1979: Russell Allen/NSIDC; 2001: unknown/RMNP library; 2016: Daniel McGrath. Series courtesy of D. McGrath.

*“Moving ice has a real magical quality to it,
it’s almost like being on the back of a dragon.”*

—Paul McLaughlin, RMNP Ecologist (retired)

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- *These and other reports and publications can be found in a collection created through the NPS Integrated Resource Management Applications (IRMA) data store: <https://irma.nps.gov/DataStore/Collection/Profile/7665>

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