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Snowfall brightens Antarctic future

Snowpacks absorb more sunlight as they warm. The Antarctic Plateau may buck this trend over the twenty-first century as increased snowfall there inhibits the snowpack from dimming.

Charles S. Zender

The colour of snow tells a remarkable story. To the human eye, snow appears white because its reflectance of visible light is uniformly high. However, its reflectance changes with astonishing abruptness at other wavelengths, and is a complex function of the exact ice crystal size and shape[1,2]. Pristine snow is a valuable shield against global warming as it reflects up to 85% of sunlight and traps only the remainder as heat[1,3,4]. This is why almost imperceptible reductions in snow reflectance owing to warming and pollution[3,5] have become a great concern. Increased heat trapping by darker snow triggers a vicious feedback cycle that speeds the greying of snow[5–7]. With temperatures increasing globally, what, if anything, will oppose the self-reinforced darkening of snow and keep it from melting even faster? Writing in *Nature Climate Change*, Picard *et al.*[8] use snow-colour measurements to deduce that fresh snowfall inhibits the seasonal greying of snow on the Antarctic Plateau by up to 3%, and reduces summertime temperatures there by up to 4 °C. On climate timescales, the increase in Antarctic snowfall expected with twenty-first-century warming may be enough to prevent the surface from further darkening.

Figure 1 | Snow surface and crystals. **a**, Study area at Dome C Station, Antarctica. **b**,**c**, Scanning electron microscopy images showing the metamorphism of Alpine snowpack crystals[9]. Picard *et al.*[8] used near-infrared optics to probe surface snow-grain size over a summer campaign at Dome C. The daily *in situ* measurements match changes in grain size retrieved from microwave remote sensing across the high Antarctic Plateau. The warmer temperatures during summer tend to change ice crystals from the pristine, sharply faceted shapes of fresh snowfall (**b**) to the larger, rounder shapes of aged snow (**c**) that absorbs more heat and reflects less sunlight[5,9]. Daily microwave imagery from 2000–2010 confirm that on seasonal timescales, fresh snow offsets much of the grain growth (and thus darkening) due to summer warming. On climate timescales, global warming is expected to increase Antarctic snowfall during the twenty-first century. This will offset the darkening of the Antarctic Plateau expected from rounder snow grains in the warmer climate. Images reproduced with permission from: **a**, Stephen Hudson; **b**,**c**, © 2008 Canadian Science Publishers.

Antarctica's reprieve from darker snow is a welcome surprise, because the enemies of snow reflectance are time and temperature, which is projected to rise by about 3 °C this century. Much like ice cubes in a home freezer, snow crystals lose their sharp facets to duller, rounder shapes as they age[1,9] (Fig. 1). Heat accelerates this metamorphism so that pristine, sharply faceted fresh crystals quickly grow during summer to become larger, rounder, aged snow, which absorbs more heat and reflects less sunlight[1,5,9]. Snow reflectance also changes during wind events (which shatter and sublimate crystals) and as a result of surface crusts and ripples. The findings reported by Picard and colleagues suggest that these secondary contributors explain less than one-third of changes in summer snow reflectance on the Antarctic Plateau. Temperature and snowfall are the main players.

The Antarctic Plateau endures long periods of polar night, during which its visible reflectance cannot be measured, so Picard and colleagues focused on the seasonal behaviour of a reflectance proxy — the snow grain size. First they teased grain-size information from the wavelength-dependent surface microwave emissions measured daily by meteorological satellites. A sophisticated model of the microwave signal travelling from the surface through the atmosphere best matches the measured signal when the snowpack is modelled as smaller, younger surface grains atop larger, inactive snow grains deposited in previous seasons.

Confirmation of the satellite imagery findings required ‘ground truth’ measurements of grain sizes in Antarctic snow. So Picard and colleagues constructed an optical probe that operates at infrared wavelengths selected for sensitivity to snow grain size and tested it at Dome C, high atop the Antarctic Plateau, one of the coldest places on Earth. Daily sampling showed that snow grains nearer the surface grow much faster through the brief summer season than the deeper snow grains that are insulated from the relatively warm daily maximum surface temperatures of summer.

The ten years of daily satellite measurements, calibrated with model and *in situ* results, show that surface snow on the Antarctic Plateau undergoes a remarkably consistent annual cycle. Snow crystals deposited in the polar night remain small (and therefore bright) because metamorphism is sluggish at winter temperatures, which can fall below −80 °C. Grains grow once temperatures begin to rise by December, and reach their maximum annual size by February at a balmy −25 °C. The stronger growth in years with weaker summer snowfall causes reflectance to drop by a few per cent. How exactly does snowfall affect the reflectance? It is not as simple as burying large, old crystals with small fresh ones, although that helps. Accumulated summer snowfall is usually less than 1 cm thick, but its reflectivity is high enough to chill the underlying crystals and short-circuit their temperature-driven growth (and greying).

Snowpack properties such as reflectance are notoriously heterogeneous[2,10], as comparison with other regions shows. For instance, Greenland’s summertime reflectivity has decreased significantly over the past decade[7]. Is summertime grain growth and rounding there already proceeding too rapidly to be fully compensated by increased snowfall? Snow accumulation gains partially offset the accelerating loss of Antarctic ice[11], and climate models project that snowfall in the interior Antarctic Plateau will increase with twenty-first-century warming. If that snowfall inhibits surface dimming at present rates, the findings of Picard and colleagues indicate that the Antarctic Plateau could (unlike Greenland) maintain its high reflectance.

Fresh snow is the brightest surface on Earth, outshining glaciers, sea ice, deserts and even the thickest clouds, and the authors hint at many important questions regarding snow–climate interactions. For instance, at present, climate models inadequately represent the snow grain size and shape distributions that determine not only the reflectance studied here, but also the thermal, hydraulic and mechanical behaviour of snow. What exciting effects might these connections have on surface temperature and hydrology? And, given that snow-crystal nucleation and metamorphism are poorly understood, how do they alter reflectance in the coastal regions of Antarctica and Greenland where snow is much nearer the freezing point and subject to strong katabatic winds? What about in tundra, alpine and subalpine regions? The authors combined lines of evidence from multi-channel satellite remote sensing, *in situ* monitoring, an active field campaign, and snowpack and radiative models. Their findings highlight needed improvements in snow–climate interactions in climate models, and shows Antarctica’s future is brighter than previously thought. ❐

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LIMNOLOGY

Lake warming mimics fertilization

Successful nutrient management has helped many lakes recover from the effects of phosphorus pollution. Now research suggests that climate warming can cause some of the same problems to return.

Monika Winder

Human activities are changing the chemistry of the Earth’s atmosphere and water at an unprecedented rate. Inputs of nitrogen and phosphorus from land run-off result in fertilization of many lakes that stimulates excessive plant growth and cause harmful algal blooms of cyanobacteria, fish kills and other related problems. The potentially toxic cyanobacterium *Planktothrix rubescens* (formerly *Oscillatoria rubescens*) is a widespread species of concern in polluted deep lakes that has detrimental impacts on drinking-water quality and causes surface scums that lower the recreation value of lakes. Work on lake fertilization and algal nutrition in the 1960s provided critical information that phosphorus is the major element causing algal blooms[1,2]. Effective nutrient management aimed at curbing phosphorus input has cleaned up many lakes in the western world and successfully controlled cyanobacterial blooms[3,4]. Writing in this issue, Posch *et al.*[5] report that lake warming can cause undesired symptoms similar to those of fertilization. However, the mechanisms under climate warming differ from those found under nutrient enrichment.

One of the major effects that climate warming has on deep lakes is that it changes the physical mixing dynamics.