Manuscript Submitted to *Nature Clim. Change*

Updated: Sat 29th Sept, 2012, 14:10

Snowfall brightens Antarctic future

Charles S. Zender

Department of Earth System Science

University of California, Irvine

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Charles S. Zender (Corresponding author)

Department of Earth System Science zender@uci.edu

University of California, Irvine Voice: (949) 824-2987

Irvine, CA 92697-3100 Fax: (949) 824-3256

Abstract

Snowpacks absorb more sunlight as they warm. The Antarctic Plateau may buck this trend over the 21st century since increased snowfall there inhibits the snowpack from dimming.

1 Introduction

The color of snow tells a remarkable story. Of course snow appears white because its reflectance to 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 that reflects up to 85% of sunlight and traps only the remainder as heat[1,3,4]. That is why almost imperceptible reductions in snow reflectance due to warming and pollution[3,5] have become a great concern. Increased heat trapping by darker snow triggers a vicious cycle which amplifies the greying of snow[5–7]. With temperatures rising globally what, if anything, will oppose the self-reinforced darkening of snow and keep it from melting even faster? On page fxm of this issue, Picard et al.[8] deduce from snow color measurements 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 of Antarctic snowfall expected with 21st century warming may be enough to prevent the surface from further darkening.

Antarctica's reprieve from darker snow would be 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 and reflects less sunlight[1,5,9]. Snow reflectance also changes during wind events (which shatter and sublimate crystals), and due to surface crusts and ripples. Findings reported here suggest these secondary contributors explain less than a third of summer snow reflectance changes 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 behavior 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 microwaves traveling from the surface through the atmosphere best matches the measured signal when the snowpack is modeled as smaller, younger surface grains atop larger, inactive snow grains deposited in previous seasons.

To confirm the findings deduced from the satellite imagery required “ground truth” measurements of grain sizes in Antarctic snow. For this the authors built an optical probe that operates at infrared wavelengths selected for sensitivity to snow grain size and brought it to Dome C, high atop the 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 do the deeper snow grains which are insulated from the relatively warm daily maximum surface temperatures of summer.

The 10-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 that 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 percent. How exactly does snowfall reduce the reflectance? Not simply by 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 to 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 Plateau will increase with 21st century warming. If that snowfall inhibits surface dimming at present rates, the findings here 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 Picard *et al.* hint at many important questions regarding snow/climate interactions. For instance, climate models inadequately represent the snow grain size and shape distributions that determine not only the reflectance studied here, but also snow thermal, hydraulic, and mechanical behavior. 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 coastal regions of Antarctica and Greenland where snow is much nearer the freezing point and is subject to strong katabatic winds? What about in tundra, alpine, and sub-alpine 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.

[Figure 1 about here.]

Acknowledgments

C.S.Z. acknowledges support from NASA ACCESS-NNX12AF48A. Download this manuscript from http://dust.ess.uci.edu/ppr/ppr_Zen12.pdf.

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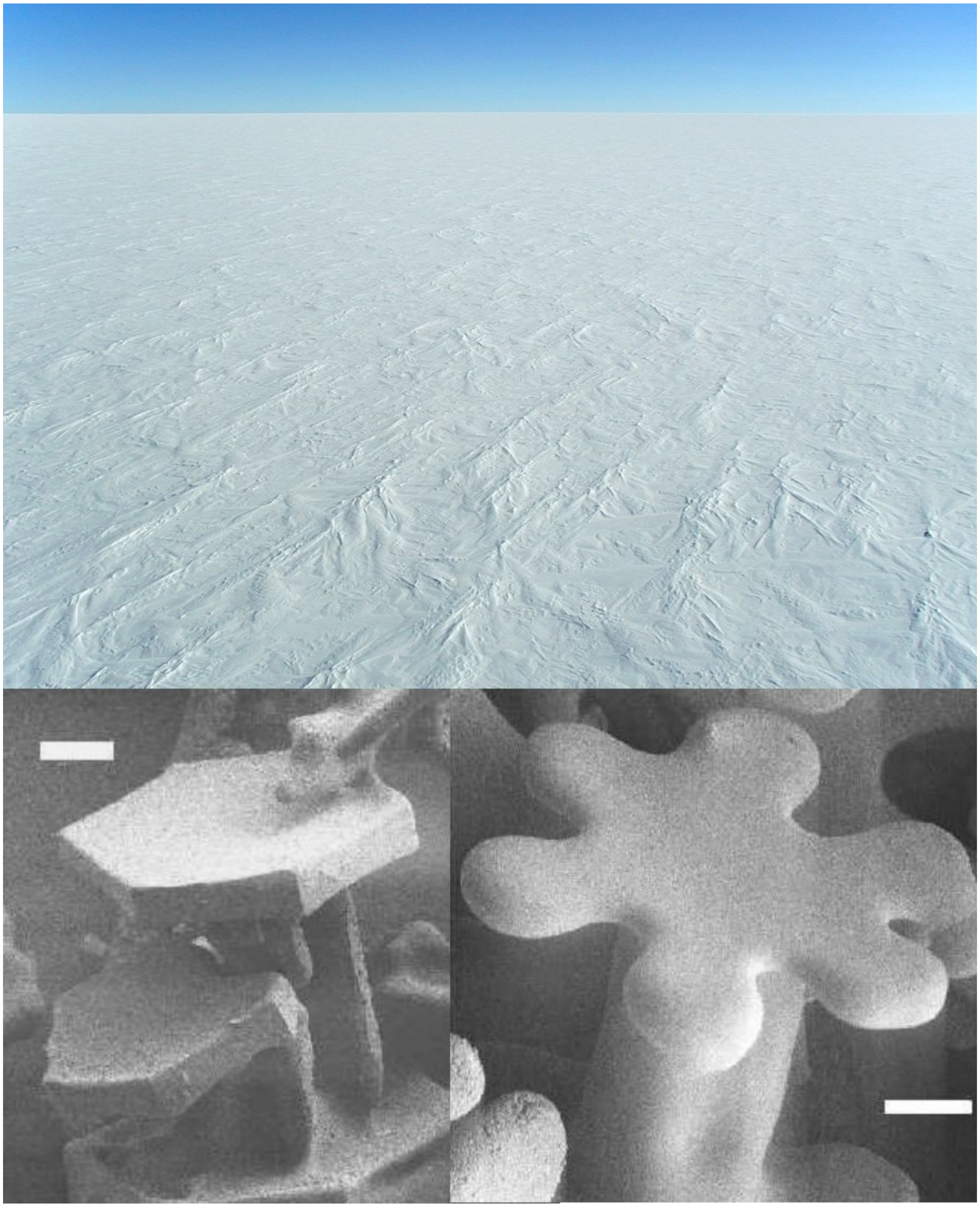

Figure 1: Picard et al.[8] used near-infrared optics to probe surface snow grain sizes over a summer campaign at **a,** Dome C in Antarctica[2]. The daily *in situ* measurements match changes in grain size retrieved from microwave remote sensing across the high Antarctic Plateau. The warmer temperatures during summer tend to change ice crystals from **b,** the pristine, sharply faceted shapes of fresh snowfall to **c,** the larger, rounder shapes of aged snow which absorbs more and reflects less sunlight[5,9]. SEM images show metamorphism of Alpine snowpack crystals (scale bars are 100 μm). 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 through the 21st century. This will offset the darkening of the Plateau expected from rounder snow grains in the warmer climate.