SURFACE HOAR MORPHOLOGY AND ASSOCIATION WITH SNOW SURFACE SUBSTRATE

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ABSTRACT: Field observations of surface hoar crystal formation onto the snow surface raised the question of the potential influence which the surface snow grains (i.e. the nucleating substrate) may play in the crystal habit of developing surface hoar. Observations made during three seasons in Mount Shasta, CA, USA showed an association of classic planar "feathery" surface hoar with new snow, whereas, observed cup shaped striated surface hoar was associated with weathered snow surfaces. While detailed meteorological data was not available, parameters such as snow surface temperature and humidity likely play a role. Photomacrography was used to show both the surface hoar crystal and the substrate snow grains. These results encourage continued observation and further studies to better understand processes on and within the snowpack. This project continues to suggest that the snow substrate may have an influence on surface hoar morphology.

KEYWORDS: Snow crystals; snowpack; surface hoar; macrophotography

1. INTRODUCTION

Surface hoar crystals, when buried, can persist and become a common weak layer, producing fractures and avalanches when disturbed (McClung & Schaerer, 2006; Birkeland et al. 1996 & 1998; Schweizer and Lutsch, 2001; Schweizer and Jamieson, 2000; Jamieson and Langevin, 2004). The shape and structure of surface hoar can be found in many forms, however, the one most frequently associated with surface hoar is a planar "feathery" habit.

During numerous field observations in the Mount Shasta area of northern California, USA from 1996 to 2007, two distinct surface hoar crystal habits were seen. The first was the planar "feathery" habit, while the second type was a striated, cup shape similar to depth hoar but growing upward. Additionally, these two different habits were observed on different snow surface substrates. The planar habit was found on recent snowfall where the precipitation particles were present. The cup shaped crystals were found on wet grains or rounded grains.

In the study of ice crystal habits forming from vapor in the atmosphere, temperature and supersaturation are thought to be the primary habit determining factors (Hallett & Mason, 1958; Bailey & Hallett 2003). Some studies of crystal habit have taken place on or in the snowpack (Seligman, 1936; Lang, et al. 1984, Colbeck, 1988, McClung & Schaerer, 2006; Hachikubo & Akitaya, 1998, McCabe, et al. 2008; Cooperstein et al. 2004). While temperature and supersaturation remain important in crystal habit on or in the snowpack, it has been suggested that the substrate may be a factor in crystallographic orientation (Adams & Miller, 2002 and 2003).

However, several differences can be found when comparing the atmospheric and snow surface conditions where crystal growth occurs. Temperature gradients of 100-300 C/m on the snow surface can exist during surface hoar formation (Lang, et al., 1984; McClung & Schaerer, 2006). Additionally, a difference exists when the size of nucleating substrates are compared. Freezing nuclei in the atmosphere are around 1µ (Battan, 1984; Mason, 2010), while grains on the snow surface can vary from approximately 0.2mm to 5.0mm (Fierz et al. 2009), or a difference of around 10^3.

While snow surface temperature and humidity are likely a strong component in the morphology of surface hoar crystals, field observations raise a curiosity with the possible influence that the

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snow surface substrate could have. Depending on environmental conditions there may be a preferential orientation for substrate crystals in the development of surface hoar morphology. To begin delving into this theory, photographs showing both the substrate grain and the surface hoar crystal were needed, becoming the primary goal of this research project.

2. METHODS

Field observations and photographs all took place in the general vicinity of Mount Shasta, California, USA. Many areas were selected for their historical occurrence of surface hoar and included open slopes and fields near Castle Lake and non-forested areas on Mount Shasta near Sand Flat, Bunny Flat, Old Ski Bowl, and above tree line. The latitude and longitude of this general area is approximately 41ºN and 122ºW.

Weather conditions were monitored to choose field days when surface hoar formation would be more likely. Mesoscale factors reviewed to determine this included air temperature, relative humidity, sky conditions (cloud coverage) and wind speed. General climate conditions in the area studied are considered maritime (Tremper, 2008).

Field observation days occurred between December, 2007 and April of 2010. In general, climate conditions during fall 2007 to spring 2009 showed near normal temperatures and below normal precipitation, while fall 2009 to spring 2010 showed near normal to warm temperatures and above normal precipitation (MSAC).

Photomacrography was used to obtain images. Equipment and methods for photomacrography were adapted from LaChapelle (1969), and Elder (2008).

A Nikon N80 camera with a Nikkor 60mm macro lens and 12, 20 and 36mm Kenko extension tubes, was used. Additionally, a Gitzo tripod and Elder stand supported the camera (Fig. 1).

Figure 1: Photomacrography being used in the field.

A variety of crystal cards were used to obtain samples showing both surface hoar crystals and the snow surface substrate, and then photographed immediately.

Analysis of the photographic data took place via computer enlargement. The subject and quality of images were reviewed.

3. RESULTS AND DISCUSSION

Over 1000 photographs were taken in the field. The majority of images show cup shaped surface hoar crystals which formed on melt/freeze grains on the snow surface (Figs. 2 & 3).

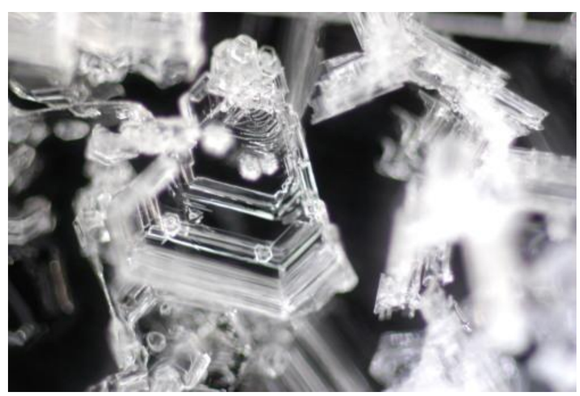

Figure2: A cup shaped, striated surface hoar crystal which formed on a melt/freeze snow surface in December of 2008.

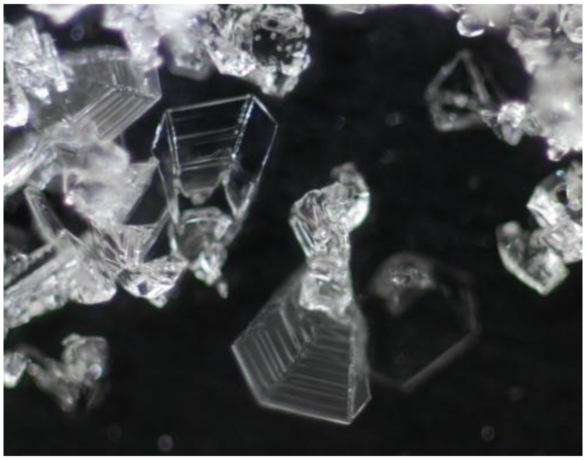

Figure 3: Cup shaped surface hoar crystals formed on melt/freeze grains in February of 2009

The melt/freeze grains in both Figs. 1 and 2 are around 1 mm in diameter, while the surface hoar crystals were around 3 mm in diameter and 3-4 mm in length.

No planar surface hoar crystals were observed or photographed on melt/freeze grains in the snow surface substrate. A few images were taken with a standard lens to show the general appearance (Fig. 4).

Figure 4: A melt/freeze crust with cup shaped surface hoar in January of 2009.

There were, however, several occurrences of planar surface hoar crystals growing on recent snowfall. The most common type of precipitation particles observed were planar stellar dendrites. From these, planar (flattened) surface hoar crystals were observed (Figs. 5, 6 & 7). It is noted by the authors that during sampling for photography, these planar surface hoar crystals were growing in the same orientation as the parent stellar precipitation particles which were oriented vertically (perpendicular to the snow surface). The orientation of the melt/freeze grains was not observed.

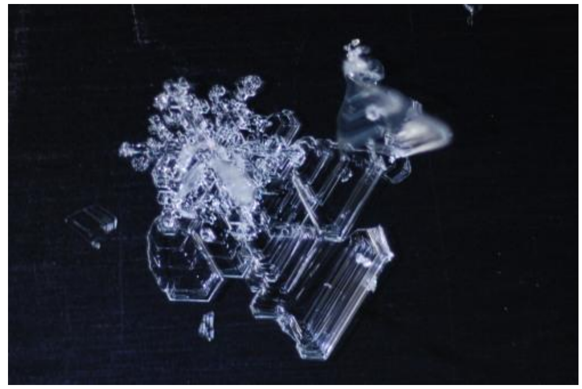

Figure 5: Planar surface hoar crystal growing on a stellar dendrite precipitation particle. January 2009. The planar surface hoar crystals are flattened and follow the same orientation as the stellar parent crystal.

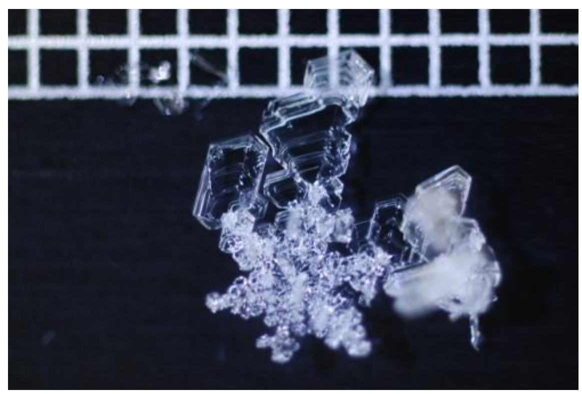

Figure 6: Flattened, planar surface hoar crystals growing from a stellar dendrite with similar orientation. December 2008.

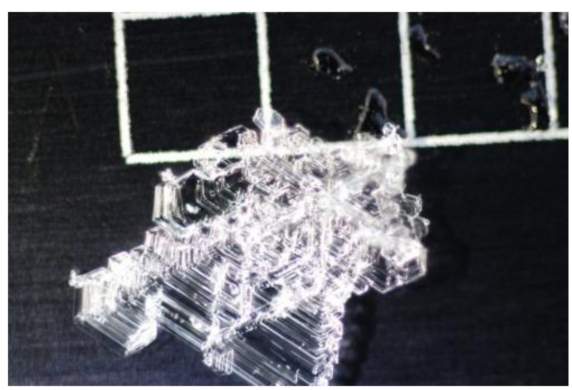

Figure 7: Flattened, planar surface hoar crystal growing from a broken stellar dendrite. February 2009.

Another type of crystal habit was observed on melt/freeze snow surface substrates which began with columns and later developed into cups (Fig. 8).

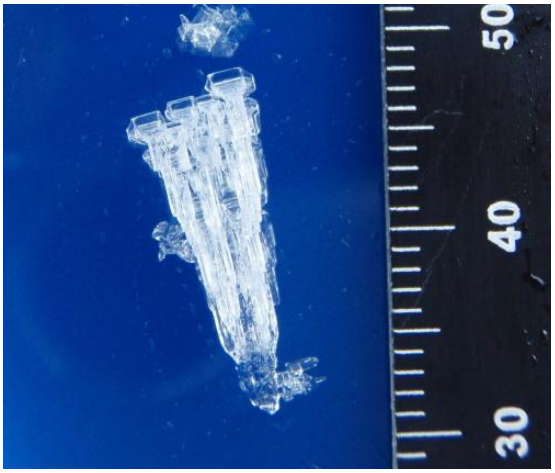

Figure 8: Long columns with developed cups. Melt/freeze clusters were approximately 3mm while the surface hoar crystal extended for 12-14mm. These were termed “chandelier” crystals.

While these results correlate with the authors’ previous field observations of distinct crystal habits associated with distinct snow surface substrates, several things must be considered. First, a thousand photographs over 3 winters where a nearly infinite number of surface hoar crystals were available, may represent a very limited observation and data set. Secondly, these results were from a specific locality which may have climatic influences favoring specific results. Observations in other climatic regions may show different results.

Some specific factors which were not measured include snow surface temperatures and humidity during crystal growth, looking for correlations with surface hoar morphology.

Additionally, climatic conditions during this 3 year period of observation limit the overall data set. An extended period of observation along with a broader geographic and climatic data set will likely provide more significant results.

4. CONCLUSIONS

The photographic results of this study correlate with previous field observations by the authors (unpublished) showing an association of surface hoar morphology with specific snow surface substrates in the area of study (northern California, USA). Planar surface hoar crystals were associated with recent precipitation particles, specifically, stellar dendrites, while cup shaped and striated surface hoar crystals were found in association with melt/freeze snow surface substrates.

Whether this association is a result of snow surface and air temperatures, or the size and shape of the snow surface substrate, was outside of the scope of this study. However, the observed association continues to raise questions about the possible influence which the substrate could have on surface hoar morphology.

Another observation of this study was that flattened, planar surface hoar crystals held the same orientation as the parent stellar precipitation particles in the snow surface substrate. Other studies in the laboratory have found new crystal growth from the vapor phase adopting the same orientation as the parent crystal in lake ice (Adams & Miller, 2003).

A similar concept has long been in use in crystallography where commercial crystal development uses seed crystals and substrates to develop specific crystal morphologies. These include pharmaceutical manufacturing (Lahav et al. 1987) and semiconductor manufacturing (Roulston, 1998). Additionally, in mineralogy, one of the crystal growth parameters studied is the shape of the substrate (Rodriguez-Navarro & Garcia-Ruiz, 2000)

Surface hoar crystals are a significant weak layer in snowpack. The purpose of this study is to provide photographic observations which improve our understanding of morphological changes on and in the snowpack. Results support an association between snow surface substrate and surface hoar morphology, suggesting the need for further study of influences on crystal habit.

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6. REFERENCES

Adams, E.E. 2002: Microstructural studies on bonds and crystal growth in a snowpack. *American Geophysical Union*, Fall Meeting, abstract C11B-0997

Adams, E.E. and D.A. Miller 2003: Ice crystals grown from vapor onto an orientated substrate: application to snow depth hoar development and gas inclusions in lake ice. *Journal of glaciology*, vol 49, #164, pp8-12.

Adams, E.E., L. McKittrick, A. Slaughter, P. Staron, R. Shertzer, D. Miller, T. Leonard, D. McCabe, I. Henninger, D. Catherine, M. Cooperstein and K. Laveck 2009: Modeling variation of surface hoar and radiation recrystallization across a slope, *Proceedings of the 2009 International Snow Science Workshop*, Davos, Switzerland

Bailey, M. and J. Hallett 2003: Growth rates and habits of ice crystals between -20º and -70ºC. *Journal of the Atmospheric Sciences*, vol. 61, pp 514-544

Battan, L.J. 1984: *Fundamentals in Meteorology,* Prentice-Hall, pp 91-109

Birkeland,K.W., Johnson, R.F. and Schmidt, D.S., 1996: Near-surface faceted crystals: Conditions necessary for growth and contribution to avalanche formation, southwest Montana, USA, *Proceedings of the 1996 International Snow Science Workshop*, pp 75-79, Banff, Canada

Birkeland, K.W., Johnson, R.F., and Schmidt, D.S., 1998: Near-surface faceted crystals formed by diurnal recrystallization: A case study of weak layer formation in the mountain snowpack and its contribution to snow avalanches, *Arctic and Alpine Research*, vol. 30, no. 2, pp 200-204

Cooperstein, M.S., K.W. Birkeland and K.J. Hansen 2004: The effects of slope aspect on the formation of surface and diurnally recrystallized near-surface faceted crystals: Implications for avalanche forecasting, *Proceedings of the 2004 International Snow Science Workshop*, Jackson, WY, USA pp 83-93

Elder, K. 2008: Methods of photographing snow crystals, *Proceedings of the 2008 International Snow Science Workshop*, pp 963, Whistler, BC, Canada

Fierz, C. et al. 2009: *The International Classification for Seasonal Snow on the Ground*, International Association of Cryospheric Sciences, UNESCO, pp 5

Hachikubo, A. and Akitaya, E. 1997: Effect of wind on surface hoar growth on snow, *Journal of Geophysical Research*, 102(D4) pp 4367-4373

Hachikubo, A. and Akitaya, E. 1998: Daytime preservation of surface-hoar layer, *Annals of Glaciology*, 26: 22-26S

Hallett, J. and B.J. Mason 1958: The influence of temperature and supersaturation on the habit of ice crystals grown from the vapour. *Proceedings of the Royal Society*, A, vol. 247, pp 440-453

Jamieson, B.T. and P. Langevin 2004: Faceting above crusts and associated slab avalanching in the Columbia Mountains, *Proceedings of the 2004 International Snow Science Workshop*, Jackson Hole, WY, USA pp 112-120

LaChapelle, E.R. 1969: Field guide to Snow Crystals, *University of Washington Press*, pp 25-30

Lahav, M., et al. 1987: Chemistry at the surfaces of organic crystals, *Proceedings of the National Academy Science USA*, vol. 84, pp 4737-4738

Lang, R.M., B.R. Leo, and R.L. Brown 1984: Observations on the growth process and strength characteristics of surface hoar, *Proceedings of the 1984 International Snow Science Workshop*, Aspen, CO, USA

Mason, B.J. 2010: *The Physics of Clouds*, 2nd edition, Oxford University Press, pp 156-274

McCabe, D., H. Munter, D. Catherine, I. Henninger, M. Cooperstein, t. Leonard, E.E. Adams, A. E. Slaughter, and P. J. Staron

2008: Near-surface faceting on south aspects in southwest Montana, *Proceedings of the 2008 International Snow Science Workshop*, Whistler, BC, Canada pp 147-154

McClung, D. and P. Schaerer 2006: *The Avalanche Handbook*, 3rd Edition, pp 37-52, The Mountaineers Books

MSAC, Mount Shasta Avalanche Center, Weather Data Archives, 2007-2010

Rodriguez-Navarro, A. and J.M. Garcia-Ruiz 2000: Model of Textural development of layered crystal aggregates, *European Journal of Mineralogy*, vol. 12, no.3, pp 609-614

Roulston, D.J. 1998: *An Introduction to the Physics of Semiconductor Devices*, Oxford Univ. Press

Schweizer, J. and J.B. Jamieson, 2000: Field observations of skier-triggered avalanches, *Proceedings of the 2000 International Snow Science Workshop*, Big Sky, MT, USA

Schweizer, J. and M. Lutsch, 2001: Characteristics of human-triggered avalanches, *Cold Regions Science and Technology,* 33: 147-162

Seligman, G., 1936: *Snow Structure and Ski Fields*, MacMillan and Co., Ltd., pp 52-55, 94-100

Tremper, B. 2008: *Staying Alive in Avalanche Terrain*, 2nd edition, The Mountaineers Books, pp 35-38