USING NIR REFLECTANCE FOR CHARACTERIZING STRATIGRAPHY AND LIQUID WATER IN SNOW

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ABSTRACT: Snow stratigraphy complicates the path liquid water takes through the snowpack, often disrupting vertical flow paths and concentrating liquid water at layer boundaries, and is therefore important for wet snow avalanches. Coincident NIR reflectance was measured with a modified SLR camera and an emitter/detector sensor pair on a probe, in addition to in-situ snow wetness, in a range of snow conditions. Near-infrared (NIR) photography provides a high resolution, two-dimensional view of snow stratigraphy and ice features, as NIR reflectance is sensitive to snow microstructure (i.e. grain size, shape) and liquid water content. The AvaTech SP Pro prototype device collects a single vertical hardness profile rapidly, but also includes a sensor that measures NIR reflectance with an emitter/detector pair. Comparison between the two independent reflectance measurements indicates valuable stratigraphic information is contained within the NIR signal from the probe, and will inform the exploration of new NIR probe sensors for better performance. In-situ liquid water content measured at 5 cm vertical resolution with a snowfork dielectric probe provides an evaluation of the sensitivity of NIR reflectance to water content in wet snow conditions during melt and rain on snow events.

KEYWORDS: Near-infrared, photography, wet snow, microstructure, liquid water, snow fork

1. INTRODUCTION

NIR photography is an extremely cost-effective way to measure high-resolution, two-dimensional reflectance of a surface. Measuring NIR reflectance of a cross-section through the snowpack provides useful information about layer stratigraphy down to the sub-millimeter microstructure scale.

Snow microstructure and its variability is a controlling factor of avalanche triggering, propagation, and stability on any given slope. Layers with smaller dominant snow grain sizes tend to retain water for longer periods of time than layers dominated by larger grains, as the water has less resistance to flow through the snowpack and capillary forces have less effect compared to gravitational forces. Layer boundaries that exhibit significant contrasts in grain size, and sometimes grain type, contrasts can provide an interface for liquid water transport. While NIR photography has traditionally been used to quantify properties on dry snow, the technique holds potential for characterizing liquid water pathways at high resolution along exposed snow pit walls [Wong et al., 2012]. By utilizing coincident profiles collected with the Snow Fork and manual snow pit measurements, we study changes in NIR reflectivity and compare the results with variations in grain size [e.g. Matzl and Schneebeli, 2006] and liquid water content.

2. STATISTICAL IMAGE ANALYSIS

CMOS sensors, like the one used in our NIR-modified DSLR, are composed of repetitive 2x2 Bayer arrays of color-filtered pixels in the pattern RGGB (top left to bottom right). By extracting RAW file intensities recorded at each respective pixel, avoiding interpolation, Dean et al. (2013) showed median and interquartile range (IQR) filters are a powerful way of displaying the reflectance changes within and between layers. Fig. 1 shows the lower and upper quartiles plotted in black bounding each of the RGB channels' median profiles.

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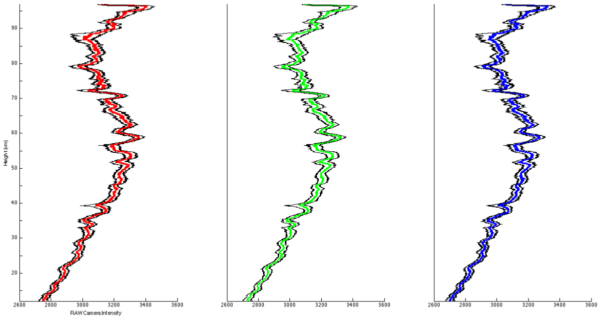

Fig. 1: Median (RGB) and IQR (black) of an NIR image from 30 April 2014 at Bogus Basin, Site 1, Boise, ID, USA.

Grain size-dominated NIR reflectance provides a formidable look at snow stratigraphy in this view. Abrupt changes in reflectance overall correspond to layer boundaries marking a change in grain size.

The data were collected on the south-east facing slope of CryoGARS research site 1 at Bogus Basin Ski Area, Boise, Idaho, USA.

3. DATA COMPARISON

The Snow Fork measures attenuation, frequency, and bandwidth of an electromagnetic pulse sent down a tuned waveguide [e.g. Sihvola and Tiuri, 1986]; measurements were taken every 5 cm up the pit wall. These signal properties can be used to invert for real and imaginary permittivity, and petrophysical models can be used to derive density, and wetness (as % volume or % weight). Fig. 2 shows these measurement outputs for the same pit as in Fig. 1.

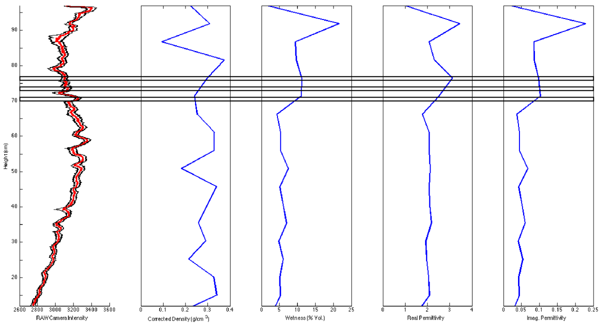

Fig. 2: NIR reflectance, density, wetness, and real and imaginary permittivity profiles from 29 April 2014.

Although many days of above freezing temperatures and rain-on-snow events had occurred, significant liquid water was confined to the upper 30 cm of this snowpack. Snow temperatures ranged from -2 to 0 degrees Celsius and although near isothermal, temperatures were still below zero overnight. Snow Fork observations confirmed wetness values below 30 cm were below the measureable value (<4%). However, a significantly higher volume of water existed in upper layers; significant stratigraphy that routed water downslope along near-surface crusts.

NIR reflectance in this upper 30 cm of the pit wall was relatively low in comparison to the reflectance values of underlying layers. A combination of the liquid water content (which is factored into the dry density measurements of the Snow Fork in Fig. 2) and the pathways shaped by prior melt/freeze events (i.e. the formation of ice layers) explain this unusually low reflectance measurement. Strong contrasts in wetness between Snow Fork measurements at 95, 90, and 85 cm above the ground (0, 5, and 10 cm down from snow surface) may suggest complex stratigraphy may be affecting how liquid water storage and movement occurs in the upper snowpack, but we do not have further data to confirm. Similar contrasts appear down to 65 cm above the ground, where below that the snow was moist to dry. Our suspicions of liquid water concentration around layer boundaries are supported by the NIR reflectance contrast at 90, 80, 70, and 65 cm and the wetness and permittivity spikes, as shown by Fig. 3. Spikes in the snow micropenetrometer (SMP) measurements further support these layer boundary locations and their concentration of liquid water (Fig. 3).

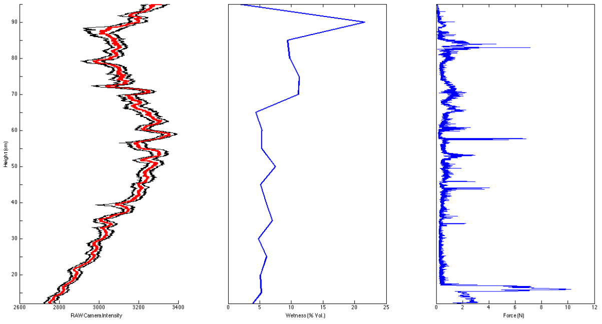

Fig. 3: R channel median and IQR (black), Snow Fork wetness (% volume), and SMP force profiles

In order to validate the Snow Fork density estimates, coincident manual snow pit data were collected.

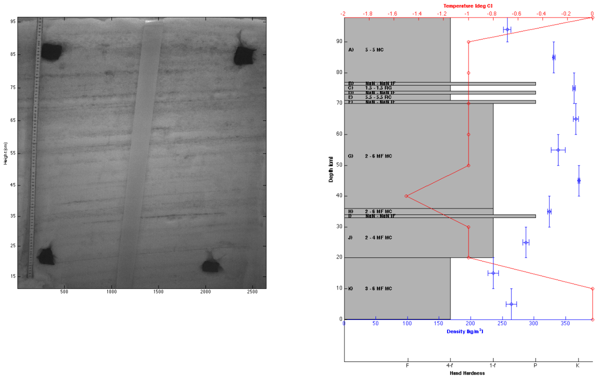

Fig. 4: NIR image and manual snow pit observations.

Ice layers described by the hand hardness profile correlate with density, wetness, and permittivity between 70-76 cm. These ice layers are outlined in Fig. 2 to show this correlation, as well.

The NIR image is not flat field corrected or calibrated with the targets. However, this does not affect comparisons between data, nor does it affect our interpretations. This is because even though the RAW camera intensities may not be the correct value, the changes between the values will remain the same. Also, even though the median/IQR profiles are not NIR bright spot corrected, the low frequency, bowed shape of the profile does not affect the high frequency, mm- to cm-scale changes between layers that appear in the reflectivity profile. Since we are, at the moment, comparing the NIR images and median/IQR curves qualitatively with the corrected density, wetness, Snow Fork, and SMP data, the fact that our NIR images are uncorrected does not affect the interpretations.

4. CONCLUSIONS

NIR photography is shown to be a powerful imaging tool when supported by Snow Fork, SMP, and manual snow pit observations. The high-resolution CMOS sensor captures subtle reflectance details with minimal noise and repeatable values.

Liquid water transport is of significant interest to those who study both small- and large-scale snowmelt, including water forecasters, which is especially important in the Boise area; snowmelt strongly dominates our annual water budget [Mote, 2006]. By using the NIR camera and supplemental snow pit data, we were able to show a correlation between NIR reflectance and wetness as % volume.

5. FUTURE WORK

The next step will be to acquire NIR reflectance data from the AvaTech SP Pro prototype device. We will compare this data with the NIR photographs of the pit wall we have. We will apply the Matzl and Schneebeli (2006) model for grain size from NIR reflectance and compare that to manual pit observations. We will determine if any difference between the two can be explained by liquid water content. We will compare NIR reflectance, liquid water content, density, and dielectric constant data and determine if there is any significant correlation. From the NIR imagery, we will analyze horizontal variability with depth. We will also look further into the relationship involving the hardness profile of the SMP and any correlation it has with the rest of our data.

6. REFERENCES

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