ABSTRACT: Thermography, using fully radiometric infrared imagers, is a still emerging field. Thermal imaging technology is continually improving and is easy to take into the field. New applications for thermography continue to be found.

This project explores the suitability of fully radiometric thermal imaging technology to examining temperature profiles in snowpack, and to presenting the information in an intuitive, visual format that is scientifically useful. The non-contact, non-destructive and data rich (commonly there are 19,000-300,000 pixels per image, each with an associated temperature measurement) nature of IR imaging technology holds interesting possibilities for snow scientists measuring temperatures in snow. From a palette, each pixel is assigned a color based on the temperature it “sees”.

During weekly field sessions to Turnagain Pass in the Kenai Mountains of Southcentral Alaska, we made full snowpit measurements and took thermal images of standardized snow study walls with a Fluke Ti25 imager. We compare snowpit measurements to thermal images and the temperature data embedded in those images. We refined methodologies in an effort to improve the images captured.

Understanding the limitations of a tool or technology is an important part of applying it well. For this reason, we paid special attention to those characteristics of thermography as well as the IR imager itself that may limit their use in the snow science fields. We present and discuss thermal images that are useful to our original purpose and others that show the limitations of the technology, equipment and methods we are currently using.

KEYWORDS: infrared thermography spot size, emissivity, snow temperature

1. INTRODUCTION

Temperature gradient is the driver of vapor movement and changes to snow grains within the snowpack. Understanding this phenomenon is important to snow scientists and snow safety personnel, avalanche dog handlers and recreational snow enthusiasts. Standard snow pit methods of gathering data on temperatures within snow layers, is to measure temperatures every 10 cm vertically, with either thermometers or temperature probes. The data points are then plotted on a graph so as to describe the trends of temperature variation within the snow pack. This method may be difficult for some learners to understand fully.

We wanted to create a visual teaching aid that would make it easy to show the temperature differences in a snowpack that drive metamorphism and move vapor and buried human scent. Infrared thermal imagery or thermography was a logical place to start, as the technology has been designed to measure temperature and provide both visual and numeric output. This
project explores the suitability of using IR thermal imagers to providing visual illustrations of and accurate data about thermal conditions in snow.

We know that thermal imagers can provide precise and abundant data on temperature, instantaneously and without contact with a target medium. A few basic questions needed to be answered, however, before we proceeded to work on our visual aids.

How does it work and can we take it into the field?  
Do thermal imagers see anything in snow?  
Is it precise and accurate?  
What affects the image we see and its’ accuracy?  
Altogether, how suitable is infrared thermography to examining temperature profiles in snow?

2. BACKGROUND: HOW DOES INFRARED TECHNOLOGY WORK AND CAN WE TAKE IT INTO THE FIELD?

Historically, thermal imagers were large and cumbersome. The bolometer was cooled by liquid nitrogen and data processing required large computers. The evolution of the technology has brought us to non-cooled microbolometers, which have arrays of sensors (focal plane array or FPA) with pixel densities of 19,200 on the low end, to some 300,000 on the upper end of readily available hand-held units. These are fully radiometric, which means that each pixel (or sensor) records a temperature measurement. The cameras capture the data instantly and can refresh at rates that make it possible to collect video on upper end models. All the temperature data is taken from the surface of the target object or medium in non-contact and non-destructive fashion. IR images can be viewed in real time on the instruments’ LCD screens, are stored on data cards by the cameras and can be studied later on a personal computer, with appropriate software.

Infrared radiation fits between visible light and microwaves on the electromagnetic spectrum. The primary source of infrared radiation is heat, or thermal energy, from the motion of atoms within a substance. All objects or substances that have temperatures above 0 K (absolute zero) radiate infrared waves. This includes mediums that we commonly think of as being cold, such as snow. Infrared waves are categorized either short, mid- or long wavelength. Long-wavelength infrared is defined as wavelengths of 8-15 microns. This is the part of the spectrum that thermal imagers “see”. Generally, the warmer the object, the more infrared it will emit, depending on its emissivity. (Perazzo, 1999).

The emissivity of a material (usually written ε or e) is the relative ability of its surface to emit energy by radiation (Liebmann 2009). Emissivity is a measure of the material’s ability to radiate absorbed energy and any real object has an e<1. Hori et al (2006) conducted research focused on spectral emissivity of five different snow grain types; fine new dendrites, medium granular snow, coarse grained snow and welded sun crust, as well as ice. The emissivity of these different snow types ranged from .709 for bare ice to .996 for fine new snow.

Overstreet (2010) states “emissivity must be properly accounted for in order to get an accurate temperature measurement. Emissivity is the most important variable in the measurement equation”. Most current IR imagers have field adjustable emissivity settings and indeed, most analysis software allows for readjusting emissivity settings in the office or lab. By measuring with the focal plane array (microbolometer), the amount of infrared energy emitted by the target and knowing its emissivity, the temperature of the target is determined.

All target temperature measurements are assigned a color by the imager. The assigned color is chosen from a palette selected by the user. On most imagers, there are several palettes to choose from. We selected the "Blue-Red" palette which, for us, seemed intuitive to the temperature variations seen in snowpack and would likely work well in our teaching aids. Red is warmer, blue is colder.
All palettes are a continuous scale of color. Therefore nearly infinite choices are available for assignment by the imager. Precision of color is enhanced by adjusting “level and span” settings of the palette. Span is the width of the palette on the temperature scale. A narrow span will assign color variations to very small temperature changes, as the entire palette is available to a narrow temperature range. A wide span requires more temperature variation to see a change in color. The level is the mid-point of the palette on the temperature scale. If a temperature reading is outside of the span of the palette, it will in our case, display white on the hot end and black on the cold end.

3. INITIAL IMAGES: CAN WE SEE ANYTHING IN SNOW?

Our initial images showed us enough that we determined to keep going. We exposed a couple of trial study walls. One was in a shallow somewhat faceted snowpack, the other in a much deeper, wind-loaded area with lots of layering. We looked at these with two imagers, a Fluke Ti25 and an older though higher resolution camera. The older camera was unable to provide usable data or images when exposed to even moderate cold (−4 −8°C). Neither keeping this instrument warm, nor acclimatizing it to the cold improved its results. The Ti25 easily provided images and the data that was in these, corresponded roughly, to some contact temperature measurements that we made of the same trial study wall. A trial image of the faceted snowpack, taken on a day when ambient air temperature was -5°C, showed strong color patterns as seen in Figure 2. In the deeper trial area, we saw mostly subtle green/blue color variations but were still able to see layering. Snow is cold but, as we know, there is a lot of temperature variation in a snow pack.

Most common snow pack temperatures fall within the range of capability of modern IR imagers (−40°C - +500°C). So, measuring the temperatures is not problematic. The Ti25, which is a fully radiometric infrared camera, worked well during our field days. This instrument is typically used in industrial settings for testing performance and functionality of machinery and electrical components. The imagers themselves have an operating temperature range that may or may not be adequate for use in the winter/snow environment and a serious consideration of operating temperature range must be made when choosing an imager for a snow project.
4. RESULTS: IS THIS METHOD PRECISE AND ACCURATE?

In order to answer this key question, we decided to do a simple comparison of measurements in snow by a thermal imager to measurements made by more traditional contact methods.

We collected data on five field days in February and March 2010 in a high latitude maritime snow climate in Turnagain Pass, Alaska, with the help of an undergraduate snow science research class from Alaska Pacific University. We used a Fluke Ti25 thermal imager and we adjusted our methods as needed to achieve the best technique for a thermal image capture. A vertical snow study wall was exposed with a shovel. We set the study wall width at 90 cm, and backed the camera away until the field-of-view (FOV) width exactly filled the 90 cm. This distance was 225 cm. A FOV calculation based on the particular lens of this camera supports this as correct.

At each site, we made an IR image of a part of the snow column and made temperature readings with contact thermometers, every 10 cm, from bottom to top of the same snow column. The data from the image was extracted and graphed using Smartview 2.1 software. The contact thermometer data was plotted in Excel. The data points produced by two methods were compared in a combined Excel chart to see the correlation.

The data from both methods generally correlated with each other, as can be seen by similarly shaped graphs in figure 4. There are however, definite differences in temperature measurements taken with these two methods.

Figure 4. IR to thermometer comparisons on three study walls.
5. DISCUSSION: BUT, IS IT ACCURATE?

A number of things affect the apparent accuracy of our comparison. For contact temperature measurements, we used a single Backcountry Access brand, calibratable digital thermometer. It was calibrated periodically during the project. The accuracy of this economical thermister thermometer is +/- 2°C. We followed the standard procedure from Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States (SWAG) for temperature measurements (Greene et al 2004). While we did not concentrate on the shortcomings of manual temperature readings, it is important to remember that these take a long time as compared to the instant capture of the imager. Also, the Ti25 claims accuracy of +/- 2°C or 2%, whichever is greater (Fluke 2009).

With thermal imaging, focus, spot size (or projected pixel size) and emissivity settings are very important to accuracy. Reflected background temperatures as well as imager temperature relative to the target, also affect results. Each makes a contribution to the accuracy or inaccuracy of the data collected and therefore the image quality and usefulness.

Poor focus is a major system error that WILL result in poor images and poor, even unusable, data. Achieving good focus when viewing our snow study walls was challenging. The picture-in-picture feature of the imager helped, but placing FOV guide cords 90 cm apart on the walls helped the most. These allowed us to focus clearly and to assure that the imager was perpendicular to the wall. The cords were 3 mm nylon strung with 10 cm lengths of colored plastic air tubing.

Spot size is determined by the pixel size, lens configuration and distance from the target. A reasonable pairing of spot size to target size is necessary for good results. The spot size in our field set-ups was 5.65 mm x 5.65 mm. This is reasonable for gathering temperature data about snowpack layers, but not for measuring individual snow crystals. By moving closer in this case, we could achieve smaller spot size and measure temperatures on smaller targets.

Figure 5. Large spot size (left) measures more than the target. Small spot size (right) is more precise.

As stated earlier emissivity is the most important variable in the measurement equation. Fairly precise measurements may be taken, but the accuracy will be off, if incorrect emissivity settings are used. We need to learn more about the emissivity of snow and snowpack layers. We used an emissivity setting of .90 in our field sessions.

Figure 6. Digging to expose temperature profile – the digger does, however affect background temperature. Image: Tanner Revoir 02/28/2010

Reflected and background temperature are influenced primarily by the ambient air temperature, but also by the camera itself, the operator or nearby objects (figure 6). Ambient temperature compensation setting is available on some imagers, including the Ti25. Cameras that are taken from warm to cold will suffer inaccuracy,
if not allowed to acclimatize, and if not compensated to ambient temperature.

6. CONCLUSION

The question of suitability is not easily answered. When an application for a technology is not yet well defined, industry will not have designed instrumentation to meet the particular criterion of the application. The user must choose the instrument most suited to their purpose. We chose an imager because of its availability, that had shortcomings for looking at snow.

We were able to get interesting thermographic images, so we know that IR imagers are able to see and record temperature variations in the snow. We did discover however a number of limiters to the quality of image that is possible, given a specific imager and looking at snow. As we continue our project, we will address these limiters in several ways. We will move away from an imager designed for industrial inspections to one designed for research, with higher resolution (640 x 480), smaller pixel size and greater pixel density. The imager will have an eye-piece type of viewfinder, since the LCD we had in the field was difficult to see. On bright days, we did not know the quality of the image we had captured until we viewed it on the computer screen. Video capability may be useful. The Ti25 uses a proprietary file format for storing and analyzing images. A more sharable format, if available, will help when working with teammates and when integrating data with other programs. As we begin to learn more about the emissivity of different snow grain types, it may be helpful to be able to adjust emissivity settings of areas within an image.

The contact measurements in our comparisons can be improved and we will try a data logging temperature probe, such as SM4 Sensor (Ingolfsson & Grimsdottir 2008) to continuously monitor temperatures in the study wall.

We still want to create our teaching aids and so will target different snow types and distinct layers, e.g. crusts and depth hoar. We are intrigued by the ability of IR thermography to capture thousands of measurements in an instant and will try to use IR imaging to monitor how dynamic events effect snow pack temperature profiles. This may lead to a better understanding of the movements of buried human scent, a rarely studied topic.

Good thermography is really not a point-and-shoot activity. It requires good and appropriate equipment, a strong understanding of the technology and the medium and good technique. With them, interesting and accurate images should be possible.

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REFERENCES

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