REMOTE GAME CAMERAS AS A COST-EFFECTIVE SOLUTION FOR MONITORING STORM TOTALS IN DATA-SPARSE AREAS

Zachary M. Guy[1]* and Evan Ross[1]

[1] *Crested Butte Avalanche Center, Crested Butte, CO, USA*

ABSTRACT: Ground truthing snowfall amounts during a storm is essential for weather forecast validation and predicting avalanche activity. Because of the prohibitive costs and maintenance of remote weather stations, most forecast centers rely on a small network of remote snow sensors and field observations to monitor snowfall amounts. During the winters of 2021-2022 and 2022-2023, the Crested Butte Avalanche Center deployed two game cameras in remote areas to supplement weather station data and weather forecasts. The camera setups cost about $300 plus a $10/month service plan to transmit images of snow stakes three times a day, including at night. For two seasons, the cameras successfully provided cost-effective storm monitoring resources. In this study, we describe the setup for the remote monitoring system. Furthermore, we present one of numerous examples in which the game cameras supported adjustments to the anticipated avalanche danger to improve forecast accuracy.

KEYWORDS: snowfall monitoring, remote instrumentation, game cameras.

1. INTRODUCTION

"Ground observation of precipitation over complex terrain is subject to large uncertainties due to inadequate sampling" (Ouyang et al., 2021). "Direct measurements of precipitation, particularly snowfall, in complex terrain are frequently scarce relative to the spatial heterogeneity they are expected to measure and may be unreliable" (Lundquist et al 2019). In mountainous terrain, radar signals are commonly blocked, and spatial details are too fine for satellites (Lundquist et al., 2019). Furthermore, winter precipitation gauges are prone to significant error (Rasmussen et al 2012).

Avalanche forecasters rely on forecasted and observed precipitation amounts to predict avalanche activity (McClung and Shaerer, 2006). Most remote stations use some combination of an ultrasonic snow depth sensor, precipitation bucket, and snow water equivalent pillow to quantify snowfall depth and precipitation amounts. The purchase and installation of such equipment typically costs tens of thousands of dollars, which makes it challenging for forecast centers to operate a robust network of snow monitoring stations. Permitting for these permanent fixtures can also present obstacles.

* *Corresponding author address:*
Zachary Guy, Crested Butte Avalanche Center, Crested Butte, CO 81224.
email: zach@cbavy.org

In addition to remote weather stations, avalanche centers utilize web cameras or "powder cams" typically hosted by ski resorts. Live images of regularly cleared snow stakes offer additional data points and verification for storm monitoring. These cameras generally require a power supply, internet connectivity, and daily site maintenance, making them challenging to deploy in backcountry settings.

In this study, we present a cost-effective supplement to existing storm monitoring resources: remote game cameras. Over the past two winters, the Crested Butte Avalanche Center (CBAC) has successfully deployed two game cameras in remote backcountry settings to improve storm monitoring and avalanche forecasting efforts.

2. METHODS

During the winters of 2021-2022 and 2022-2023, the CBAC installed and maintained two game cameras in data sparse backcountry locations in central Colorado. We used the Barn Owl RangeCam Mini bundled with a solar panel. The setup costs approximately $300 per camera and about $10/month for the cellular data plan. The cameras transmit photos using wireless signals, which can be boosted using supplementary antennas. We programmed the cameras to email three photos each day (06:00, 11:00, and 16:30), though users can adjust the frequency of photos as desired. The cameras have night vision which adequately captured the snow stakes during night hours (Figure 1). The cameras also send temperature readings and battery life indicators with each photo.

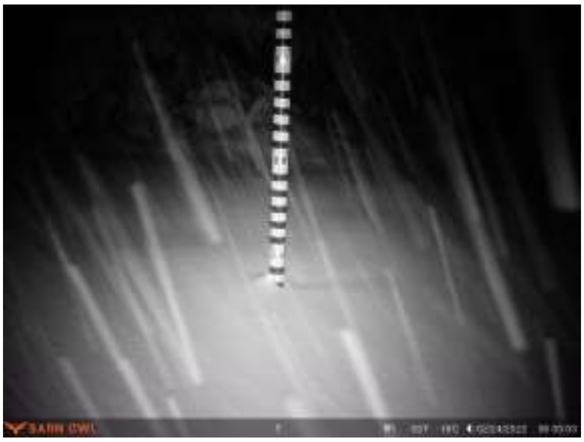

Figure 1: An example of a game camera image sent daily at 06:00, before daylight. The image also includes a time stamp, temperature reading, and battery indicator.

We chose relatively flat, wind protected terrain with sufficient cell phone signals for our monitoring sites (Figure 2). To install the snow stakes, we used a 3-meter PVC pipe with black electric tape and a permanent marker labeling snow depths by the inch. Then we strapped the game camera to an adjacent PVC and pointed it at the snow stake, ensuring that the stake was adequately framed within the field of vision of the camera. As snow depths increased throughout the season, we visited the sites several times to raise the PVC pipes up in the snowpack.

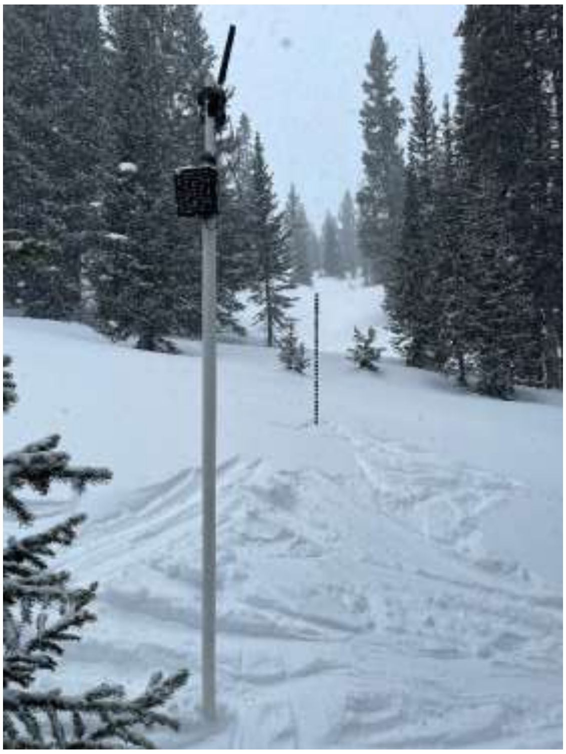

Figure 2: The Purple Ridge game camera monitoring site. In the foreground, the game camera and solar panel are mounted a meter above the snow surface on a PVC pipe. In the background, a PVC with electrical tape is used as a snow stake.

3. RESULTS AND CASE STUDY

Forecast staff used the game camera images on a daily basis to supplement weather station data and weather forecasts. The data helped identify situations when snowfall amounts diverged from forecasted amounts and promoted a better understanding of spatial patterns of snowfall totals during storms. Here, we present one case study where the use of the game cameras supported a change to a more accurate forecast for CBAC's Northwest Mountains forecast zone on April 1, 2023.

On March 30 and 31, 2023, weather forecasts were predicting 25 to 43 cm of new snow for the Northwest Mountains by April 1. On March 31, 2023, the danger was rated and assessed at Considerable near and above treeline and Moderate below treeline, with the same trend forecasted for the following day. On the morning of April 1, the two remote weather stations within the forecast area (Schofield Pass and Irwin Study Plot) were showing 23 to 28 cm storm totals, respectively. However, the remote game camera on Purple Ridge, which is centrally located between these two weather stations, showed an unexpected storm total of 61 cm. Forecast staff on April 1 adjusted the danger rating accordingly, raising the danger to Considerable below treeline. On April 1, observers documented five D2 to D2.5 storm slabs that naturally released during the day from below treeline, validating the higher danger rating (Figure 3).

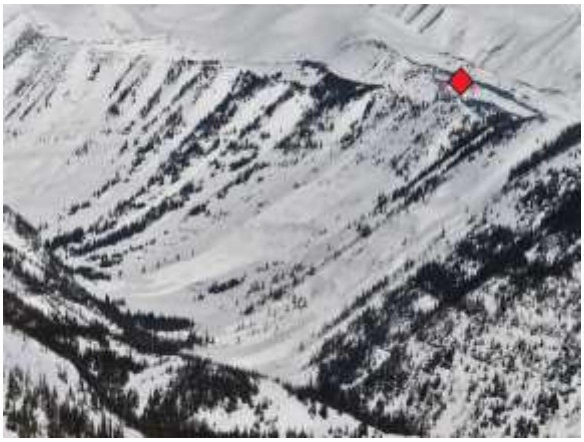

Figure 3: Several D2 to D2.5 storm slabs that released on April 1, 2023 after storm totals were larger than forecast, a pattern which was identified using the remote game camera. The camera is located on the gladed ridge in the background, symbolized by a red diamond.

This is one of numerous examples where the additional snowfall data provided by the remote game cameras supported decisions towards a more accurate avalanche forecast.

4. DISCUSSION

The successful application of remote game cameras to monitor snowfall amounts over the past two winters highlights the potential for this technology to supplement existing snow monitoring networks. Game cameras offer several advantages: 1. They are non-permanent fixtures that are easy to install or remove without machinery. 2. They are relatively inexpensive to purchase and maintain, relative to traditional weather stations. 3. They provide a visual snapshot of the snow surface, which can offer additional information regarding precipitation type, wind drifting, etc.

However, game cameras also have several important disadvantages compared to traditional weather stations: 1. They do not provide numerical data that can be automatically databased for analysis or sharing. 2. They only show snow depth and lack snow water equivalent or precipitation amounts. 3. Sites require visits throughout the season to adjust the snow stakes and cameras from getting buried. 4. Determining snow depth changes requires the user to compare previous images, a task that is relatively tedious compared to analyzing numerical data.

One of our biggest concerns going into the project was the lifespan of the batteries, especially for the cold temperatures of central Colorado. In our setup, the small solar panel powers a battery pack, and the camera draws from eight AA batteries as a reserve. Over the course of two winters, the batteries maintained an adequate charge for our modest use of three photos per day. We replaced the batteries at the beginning of each season and once during a mid-season site visit during the first winter as a precaution. Each photo comes with a battery life indicator for monitoring. The batteries may require more maintenance in snow climates with less solar radiation or if users demand a higher power draw from more photos per day.

The game cameras in this study relied on an adequate wireless cell phone signal. Careful site selection is important because cell phone service is intermittent in mountainous areas in the U.S. The technology to transmit game camera images across satellite networks is likely to emerge in the near future.

Another consideration for using remote cameras is the effect of riming. Our study area in central Colorado sees few, if any, riming events during the winter. In regions that experience frequent riming events, the effectiveness of remote cameras may be deterred.

Anecdotally, the thermometer on the camera appears to function with reasonable accuracy during night time photos or on overcast, storm days. The camera absorbs solar energy during sunny days and shows temperature readings that are too high. We made these observations by comparing the temperature readings on the camera with forecasted temperatures and observed temperatures from other stations. Calibrating or assessing the accuracy of the thermometer could be accomplished with a more rigorous study; however, the primary purpose of our project was to monitor snowfall.

5. CONCLUSION

Over the course of two winter seasons, avalanche forecasters in central Colorado installed, maintained, and utilized information from two remote game cameras. In this pilot study, the game cameras proved to be a valuable supplement to fill in gaps between remote weather station data. The cameras helped verify or occasionally highlighted discrepancies between forecasted and actual snowfall totals. Because ground observations of snowfall totals across forecast regions are relatively scarce, game cameras can be an additional and cost-effective tool for improving avalanche forecast accuracy.

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