# Evaluation of iSnobal performance with incorporated in situ and remotely-sensed snow albedo in Senator Beck Basin, San Juan Mountains, CO

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## ABSTRACT

*In this study we run the spatially distributed snowmelt model, iSnobal, in Senator Beck Basin using forcing data collected from two micrometeorological towers within the basin boundaries. The SASP tower is located in the sub-alpine while the SBSP tower is in the alpine. Initial model runs were performed for the 2008 to 2017 water years. A second suite of model runs was performed with modeled albedo scaled to match in situ albedo observations at each tower. Model performance was evaluated by comparing pit measurements near the towers, as well as remotely-sensed ASO albedo data. Comparision of the iSnobal runs at the two tower locations show an improvement of RMSE at the subalpine station when in situ albedo observations are incorporated. Improvements at the alpine station are not obvious. Comparison of modeled albedo to ASO albedo gives insight into possible future improvements of modeling the spatial distribution of snow albedo.*

## INTRODUCTION

Mountain snow not only provides drinking water for millions of people across the world, but it is also tied to trillions of dollars across a variety of industries such as outdoor recreation, agriculture, and hydro-electric power. Maximizing the utility of mountain snow therefore requires an intimate understanding of the factors that influence the timing of snowmelt, as well as an ability to correctly model snowmelt processes.

Several studies have shown the presence of dust particles on snow to be the primary driver of snowmelt timing and magnitude during the runoff season in the western US. Dust deposited on the snow surface decreases the snow surface albedo, resulting in an increased amount of absorbed solar radiation in the visible (VIS) wavelengths. Additionally, snow grains may under-go metamorphism and grow in size, decreasing snow albedo in the near-infrared (NIR) wavelengths.

Many operational snowmelt models do not currently incorporate the effect that dust has on snowmelt, relying instead on empirical relationships between snowmelt and air temperature, or time-based albedo decay mechanisms to drive snowmelt, neither of which fully integrate physically-based albedo observations into the model. Skiles et al., 2012 demonstrated that updating the point model, Snobal, with albedo observations significantly improved the models performance in the Colorado Basin.

Recent availability of remotely-sensed snow albedo and snow depth data from NASA's Airborne Snow Observatory (ASO) over Senator Beck Basin Study Area (SBBSA) has created an opportunity to improve spatially distributed snowmelt model performance as well as our understanding of the role which dust plays in snowmelt. In our study we integrate in situ albedo observations from Senator Beck Basin (SBB) into iSnobal, a spatially distributed snowmelt model, to explore the limitations of using physically-based snow albedo to drive snowmelt models.

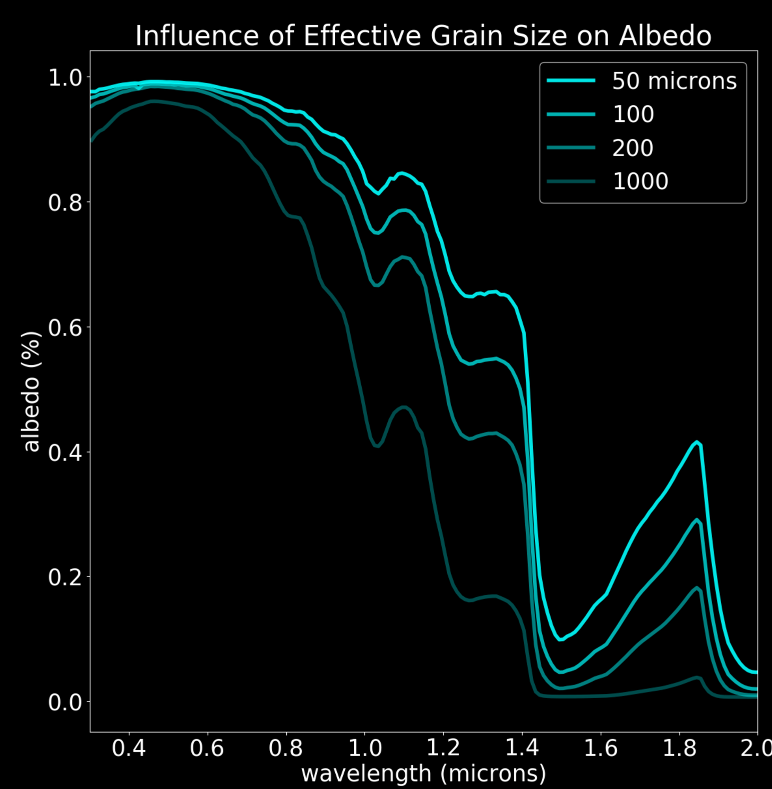



*Figure 1: Graph showing the influence of effective grain size on albedo of clean snow. Relatively larger grains decrease snow albedo primarily in the near-infrared wavelengths. Modeled using SNICAR.*

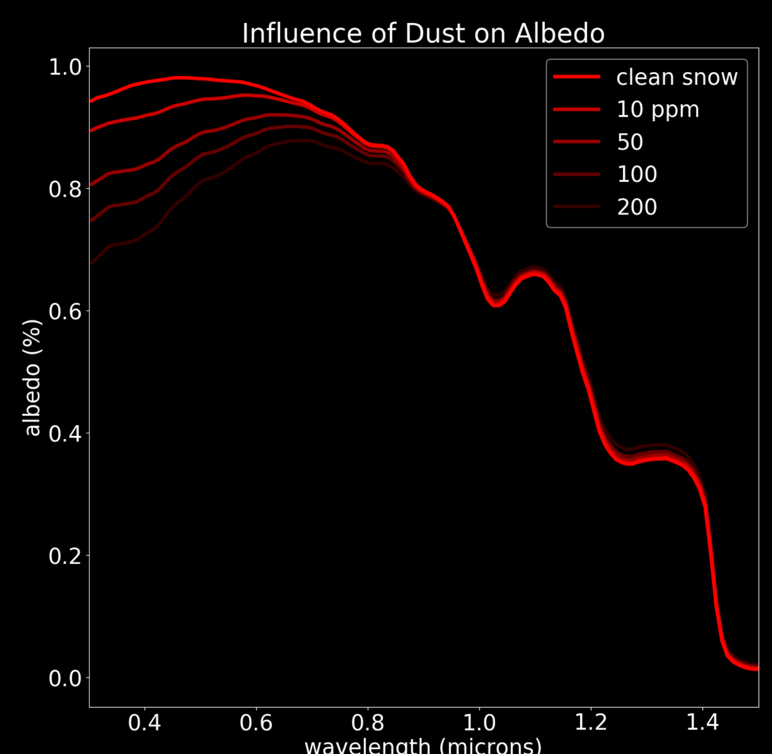
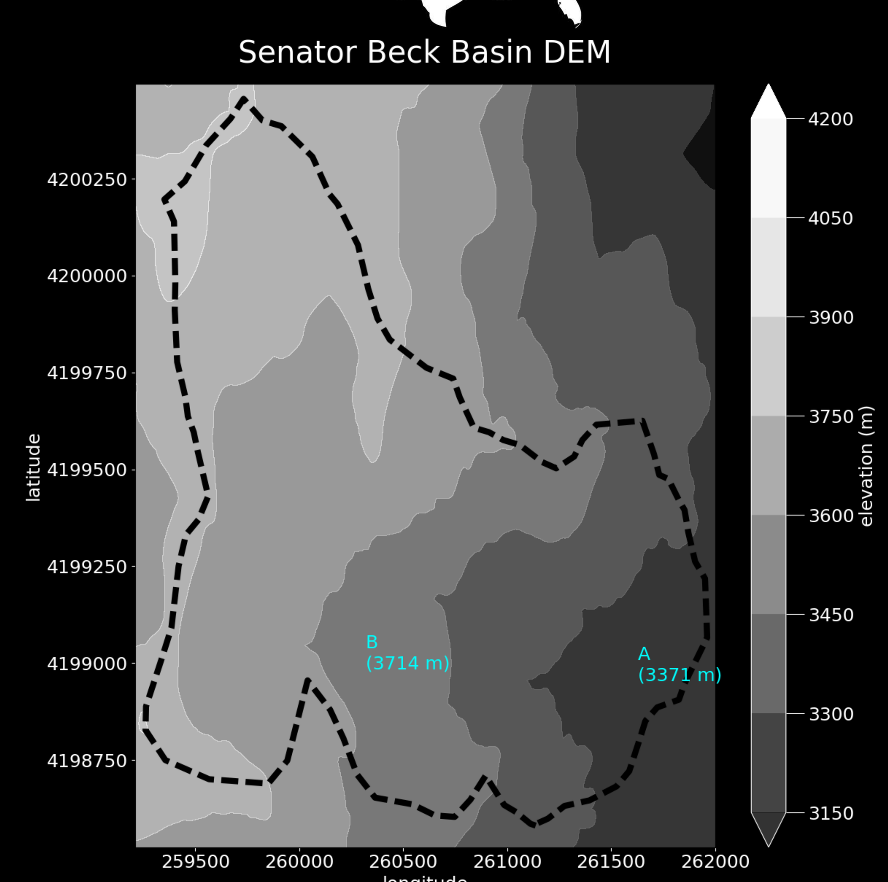



*Figure 2: Graph showing the influence of dust particle concentration on albedo. Increased concentrations of dust result in a decrease of snow albedo in the visible wavelengths. Modeled using SNICAR.*

## METHODS

SBB is located in the western San Juan Mountains of Colorado. The basin is approximately three square kilometers in size and is a closed basin which drains to the east. Since 2003, nearly continuous micrometeorological, snowpack, and hydrological measurements have been collected from SBBSA by the Center for Snow and Avalanche Studies (CSAS), a not-for-profit organization located in Silverton, Colorado.



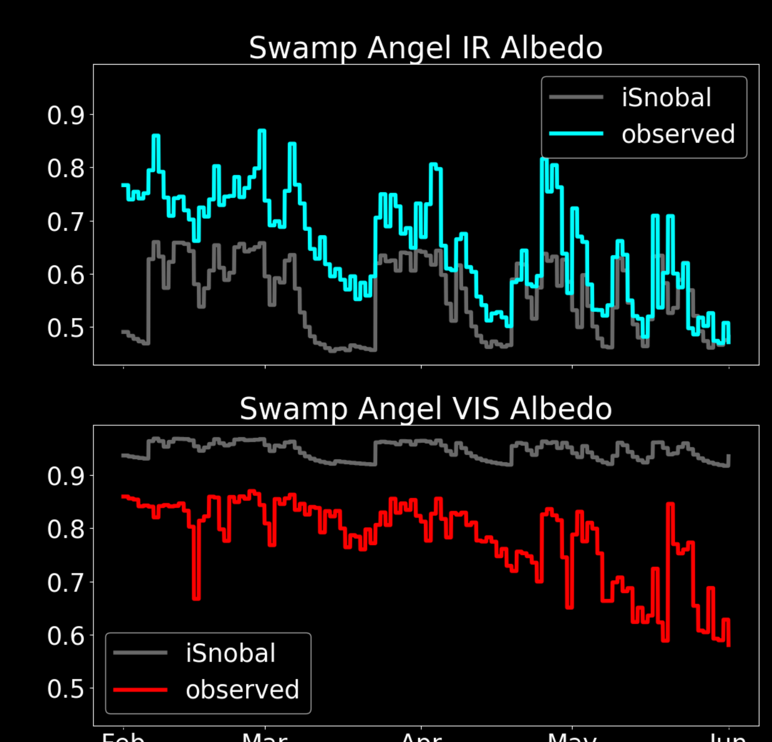




*Figure 3: Comparision of an age-based albedo decay method used by iSnobal with daily tower observations from SASP for the 2017 water year. Graphs show near-infrared albedo (top) and visible albedo (bottom).*

Two micrometelogical towers are located within the basin. The first tower is located at Swamp Angel Study Plot (SASP), a sheltered sub-alpine site with an elevation of 3371 m. The second tower is located at Senator Beck Basin Study Plot (SBSP), an alpine site with an elevation of 3714 m. The towers collect hourly measurements of air temperature (upper and lower sensors), wind speed/direction (upper and lower sensors), relative-humitity, incoming broadband solar, outgoing broadband solar, incoming near-infrared, outgoing near-infrared, incoming long-wave, snow depth, and snow temperature. Precipitation is also measured but only at SASP, due to high wind speeds at SBSP. Precipitation at SBSP was estimated using snow depth sensor measurements from SBSP in combination with estimated densities.

An initial iSnobal run for each water year from 2008 to 2017 was made using the models age-based albedo decay method. A second run was then performed for each water year in which modeled visible and near-infrared albedo were scaled to match observed albedo at SASP and SBSP. The two pixels believed to contain SASP and SBSP were then extracted from the iSnobal output raster images and compared with physical observations from the towers and adjacent snow pits. Performance of the different albedo models was evaluated by comparing root mean squared error (RMSE) of physical observations for snow density, snow depth, and snow water equivalent (SWE) for each water year. Additionally, the spatial distribution of snow albedo and was compared to currently available ASO data.

## RESULTS

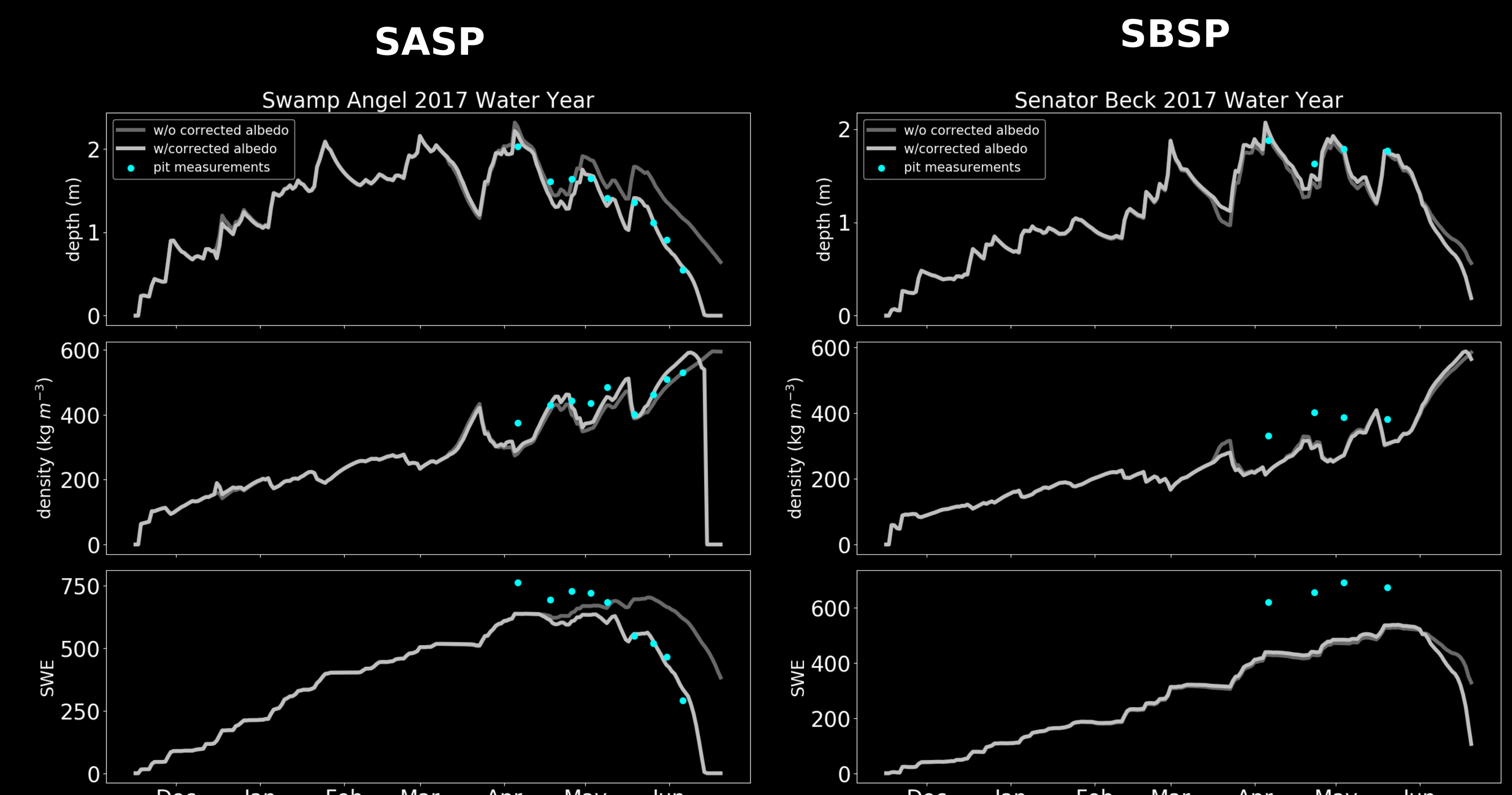



*Figure 4: Graphs showing the comparison of snow depth (top), snow density (middle), and SWE (bottom) for water year 2017 iSnobal outputs with and without corrected albedo as well as snowpit observations. iSnobal results indicate an overall improvement in snow depth and, consequently SWE predictions when modeled albedo is corrected to match tower observations at SASP (left). Changes in model performance at SBSP (right) are less clear due inpart to the timing of snowpit measurements. While both locations show a general underestimation of snow density, SBSP shows a greater bias.*

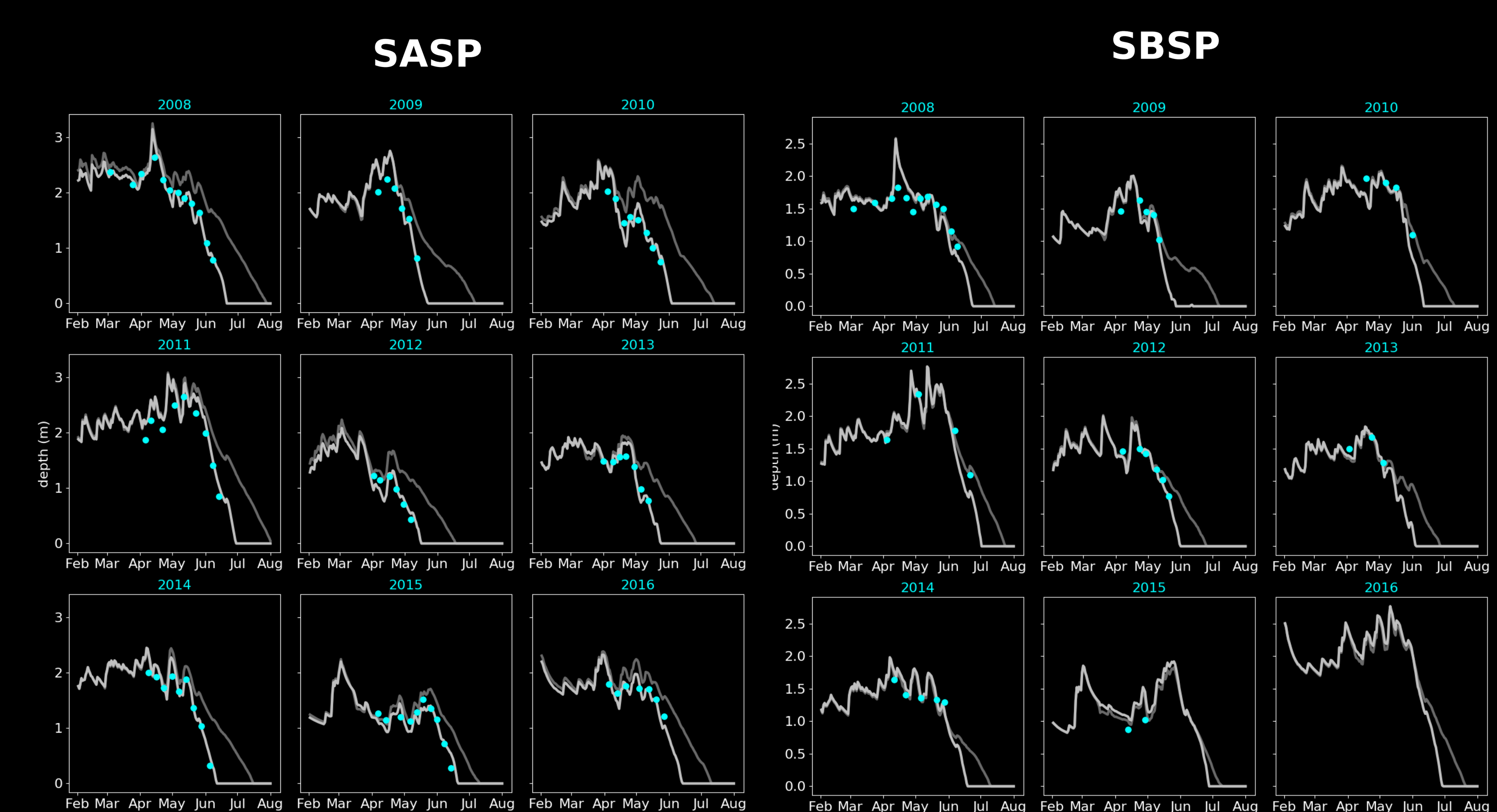



*Figure 5: Graphs showing the comparison of snow depth during the runoff season for the 2008-2016 iSnobal outputs with and without corrected albedo. Results for both SASP (left) and SBSP (right) indicate an overall improvement in model performance when modeled albedo is corrected using tower observations.*


*Figure 6: RMSE scores of SASP (left) and SBSP (right) for 2008 to 2017 comparing iSnobal with and without corrections to snowpit observations of depth (top), density (middle) and SWE (bottom). The most drastic RMSE improvements are observed at SASP where every water year indicated improved model performance in depth and SWE when modeled albedo is corrected. The RMSE scores at SBSP do not indicate an overall improvement in model performance.*

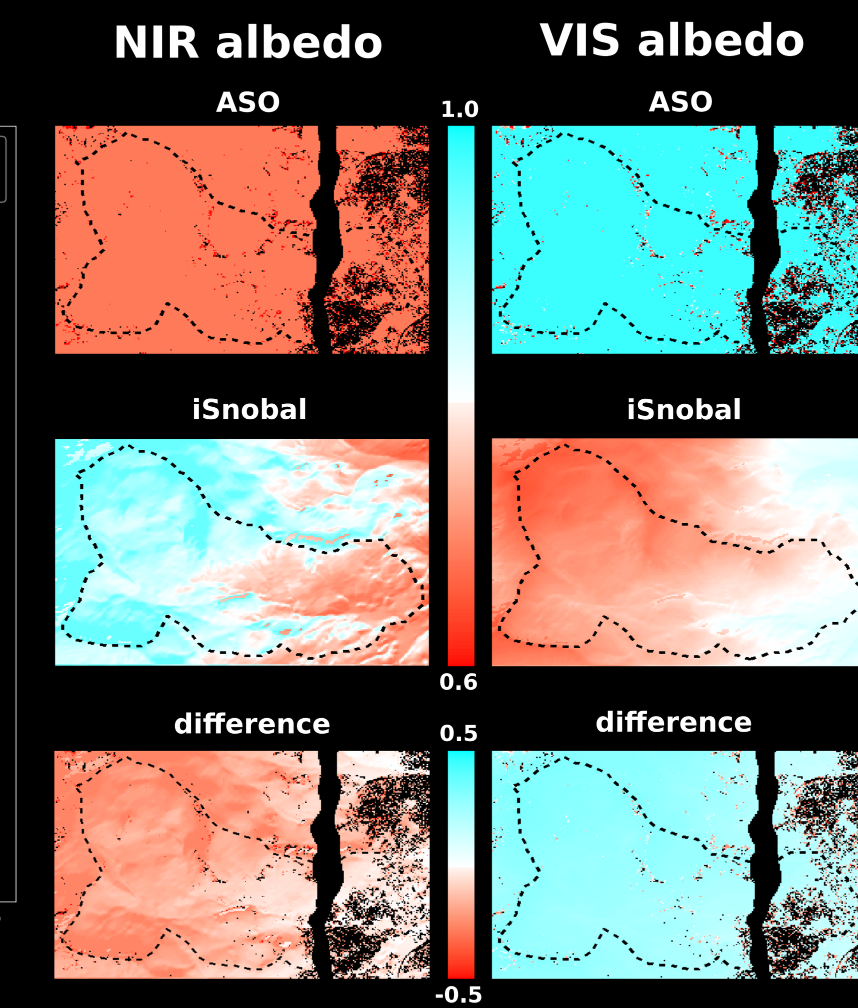



*Figure 7: Raster images comparing the spatial distribution of near-infrared albedo (left) and visible albedo (right) across Senator Beck Basin. The top images show remotely-sensed albedo aquired by ASO on February 21, 2017, with albedo values ranging from 0.6 (red) to 1.0 (blue). The middle images show the modeled albedo used by iSnobal with corrections to match tower observations for February 21, 2017. The bottom images show the difference between ASO observations and modeled albedo (ASO - iSnobal), where values range from -0.5 (red) to 0.5 (blue).*

## CONCLUSION

This study has used iSnobal to demonstrate the implications of incorporating in situ albedo observations for improving snowmelt timing predictions. We have also demonstrated the potential benefit of using remotely-sensed albedo data as a way of evaluating the spatial integrity our modeling choices. Future steps of this study will include further refinement of forcing data such as precipitation as well as further investigation into the spatial trends of albedo using ASO data as it becomes available.

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Senator Beck Basin Data: Center for Snow and Avalanche Studies

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