Modeling dust in snow stratigraphy and concentrations using observations of snow depth and snow albedo at Senator Beck Basin

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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. Comparision of the iSnobal runs at the two tower locations show improvements in modeled snow depth when in situ albedo observations are incorporated. We then explore a possible method for tracking snow darkening horizons using in situ snow depth and albedo observations.

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 undergo metamorphism and grow in size, decreasing snow albedo in the near-infrared (NIR) wavelengths.

Many operational snowmelt models do not currently incorporate the affect 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 capture the underlying processes that drive albedo. 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 evaluate spatially distributed snowmelt model performance as well as our understanding of the role that 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.

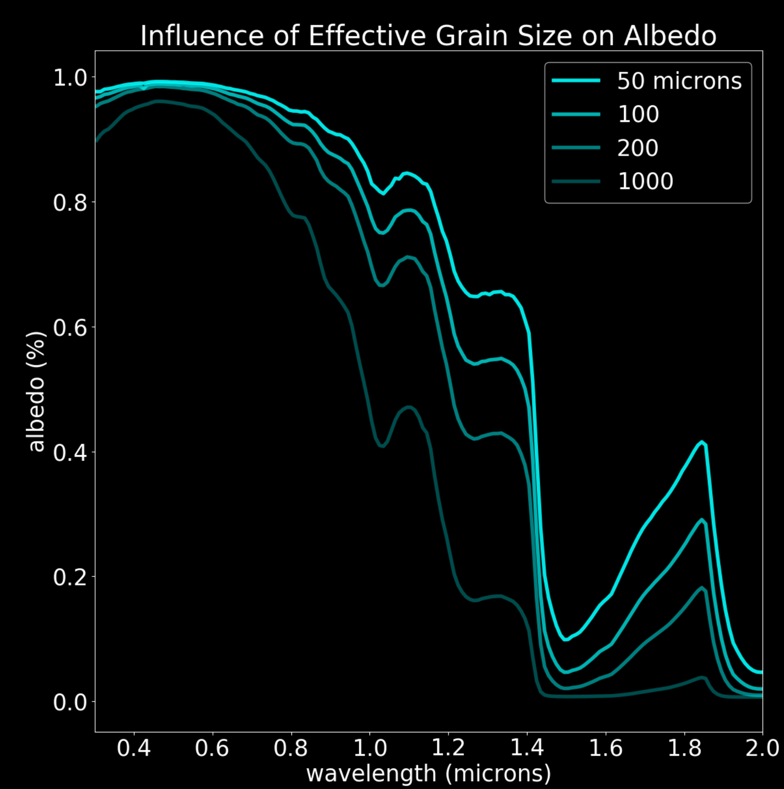


Figure 1: Graph showing the influence of effective grain size on albedo of clean snow. Relatively larger grains decrease snow albedo primarily in the near-infrared wavelengths. Modeled using SNICAR.

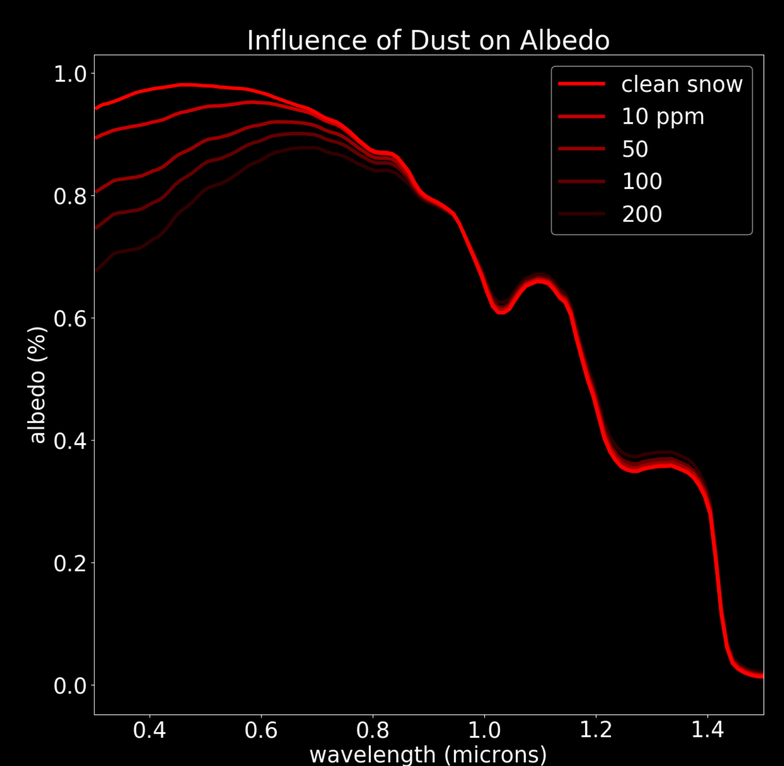
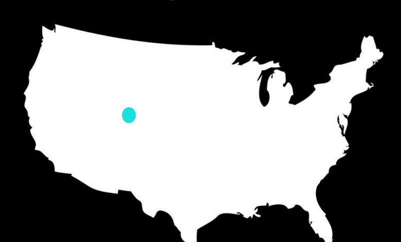
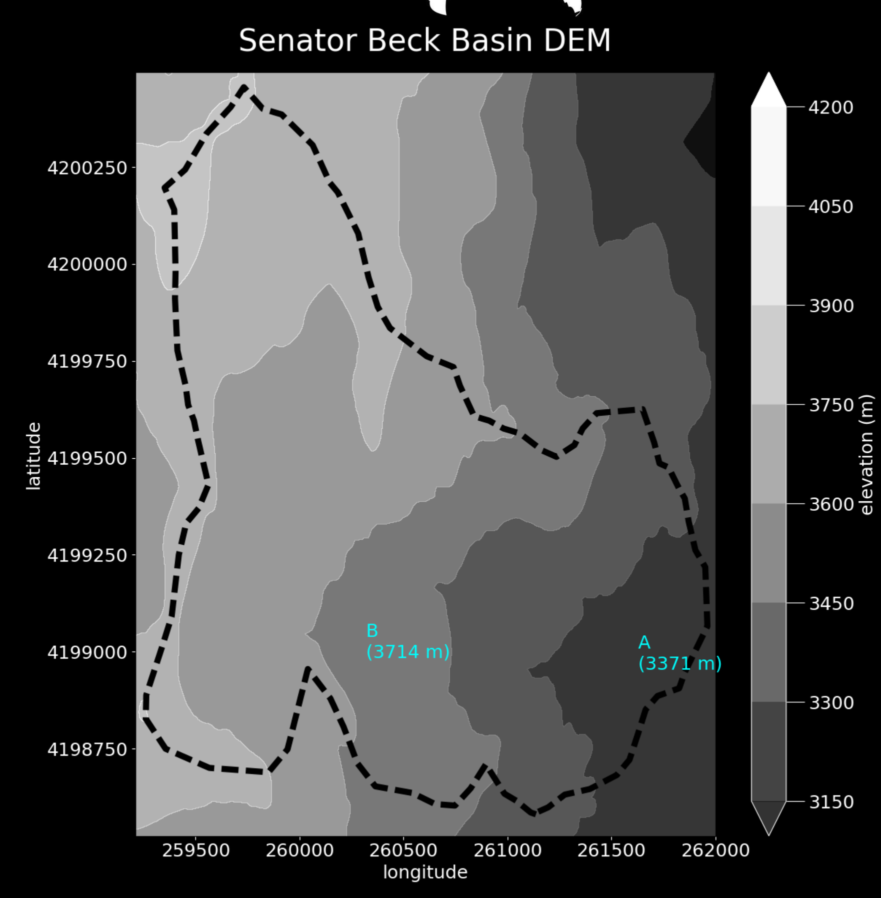


Figure 2: Graph showing the influence of dust particle concentration on albedo. Increased concentrations of dust result in a decrease of snow albedo in the visible wavelengths. Modeled using SNICAR.

METHODS

SBB is located in the western San Juan Mountains of Colorado. The basin is approximately three square km in size and is a closed basin that 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.





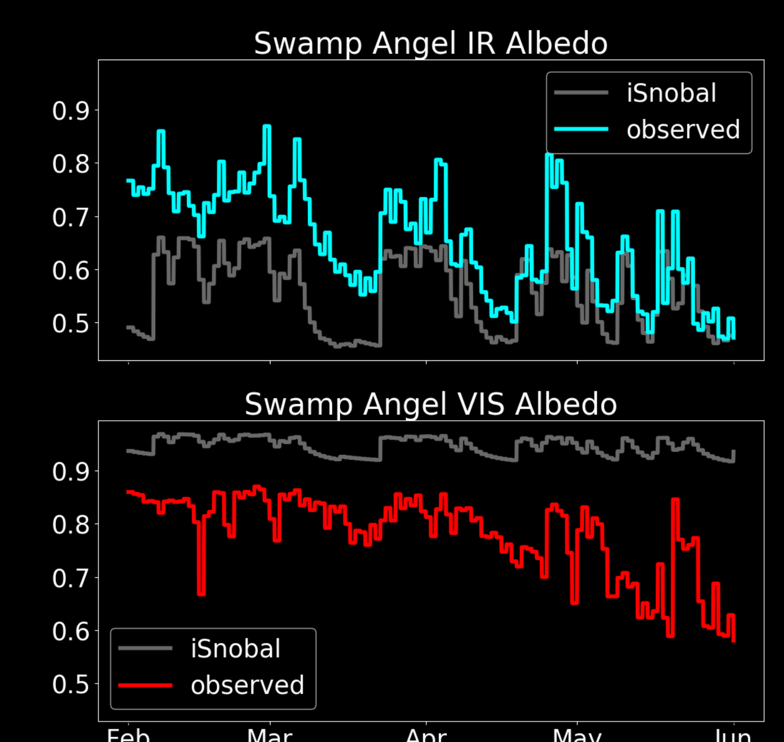


Figure 3: Comparision of an age-based albedo decay method used by iSnobal with daily tower observations from SASP for the 2017 water year. Graphs show near-infrared albedo (top) and visible albedo (bottom).

Two micrometeorological 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. Precipitation is only measured 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 model's age-based albedo decay method. A second run was then performed for each water year in which modeled VIS and NIR albedo were scaled to match observed albedo at SASP and SBSP.

We recognize that scaling modeled albedo to match observed albedo at the stations is unlikely to capture the processes that drive the spatial variability of surface albedo. To address this issue, we explore the possibility of tracking surface darkening horizons, such as dust events, using in situ albedo and depth observations from the towers. This is done by recording sharp drops in daily albedo (> 5%). We then track the potential merging of recorded horizons and compare the results with pit measurements.

RESULTS

SASP | SBSP

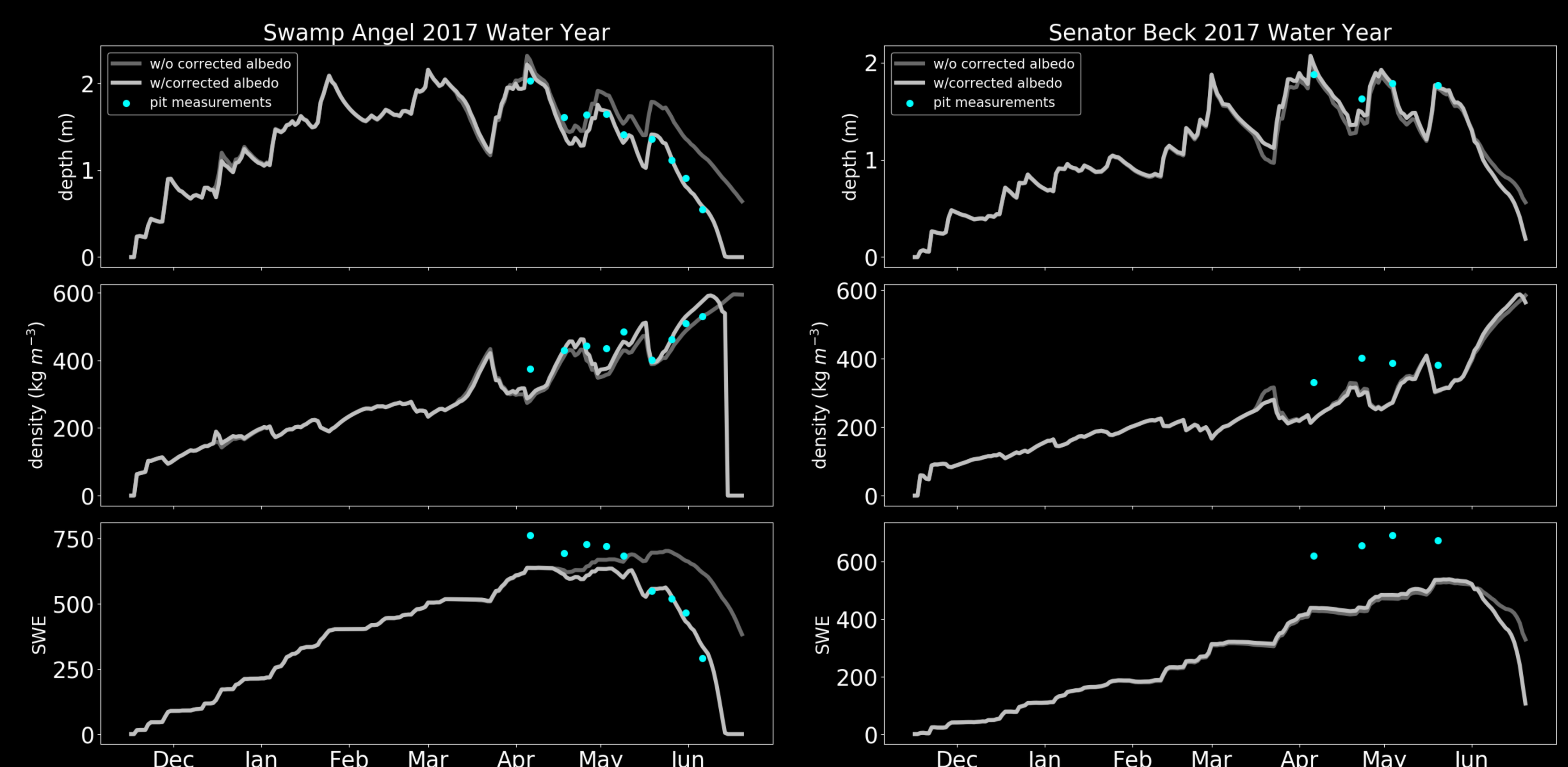


Figure 4: Graphs showing the comparison of snow depth (top), snow density (middle), and snow water equivalent (SWE) (bottom) for water year 2017 iSnobal outputs with and without corrected albedo as well as snowpit observations. iSnobal results indicate an overall improvement in snow depth and, consequently,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

SASP | SBSP

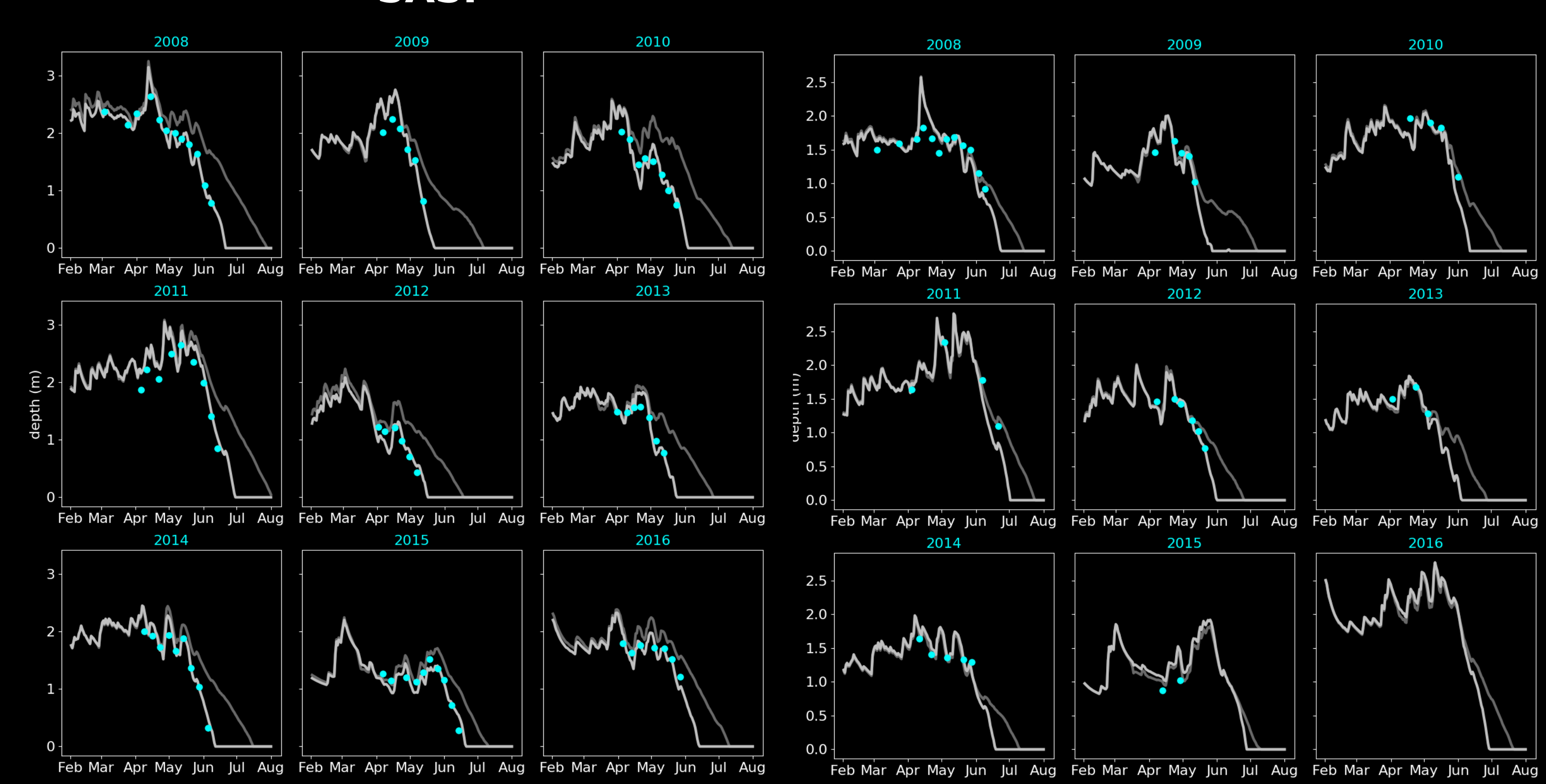


Figure 5: Graphs showing the comparison of snow depth during the runoff season for the 2008 to 2016 iSnobal outputs with and without corrected albedo. Results for both SASP (left) and SBSP (right) indicate an overall improvement in model performance when modeled albedo is corrected using tower observations.

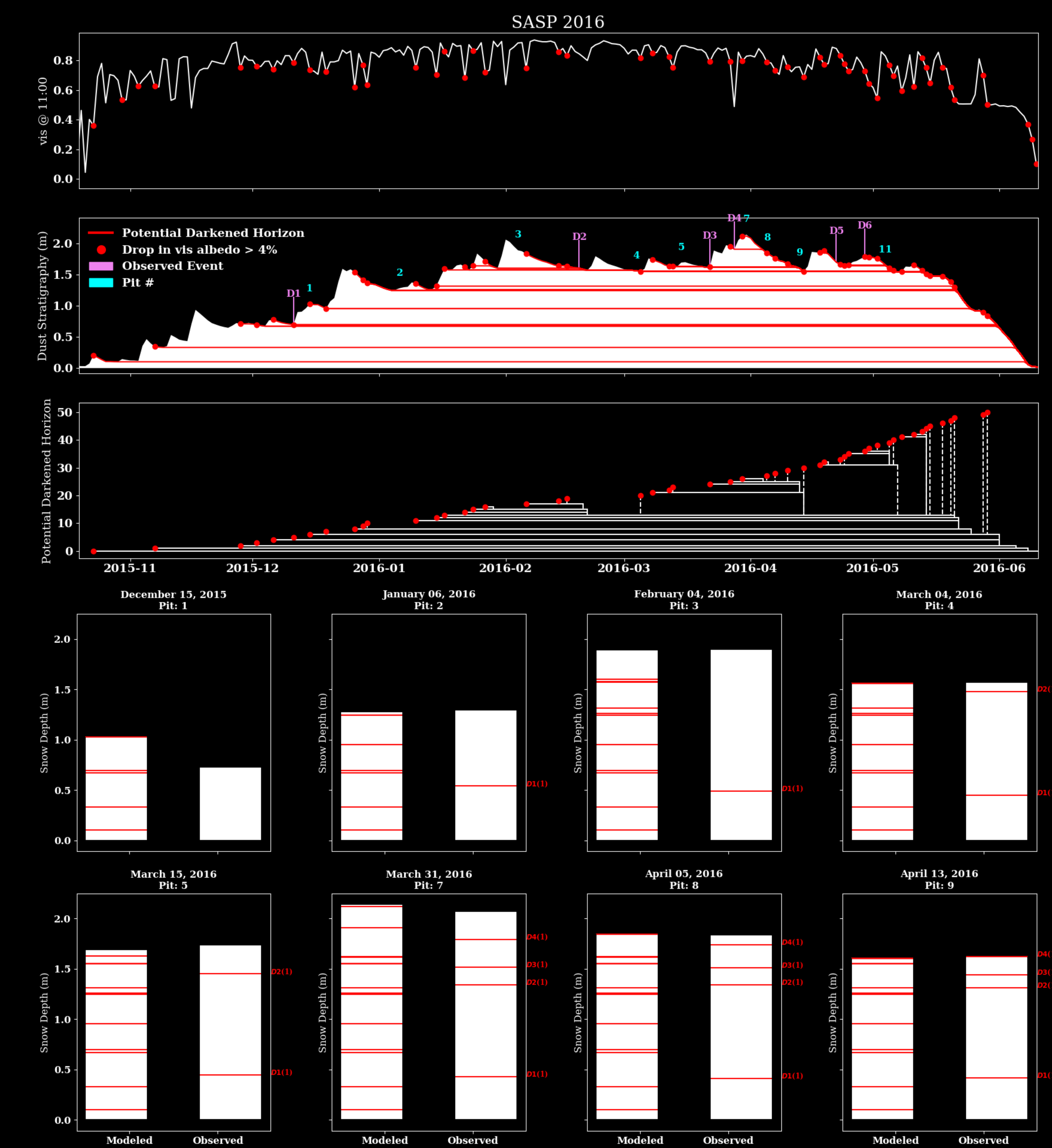


Figure 6: Darkening horizons model results for the 2016 water year. VIS albedo with drops > 5% are shown as red dots in the top three graphs. Also presented are a comparison of the modeled and observed snow pit profiles. Red lines indicate the location of a modeled darkening horizon (Modeled) or an observed dust event (Observed). Observed dust events are marked with the event number as well as the number of events incorporated into that layer (in parenthesis).

DISCUSSION

Results from iSnobal show a marked improvement when in situ albedo observations are incorporated into the model. In some cases the timing of snow melt is improved by weeks (figure 5). Difficulties in determining precipitation at SBSP likely account for the majority of mass balance errors at this station (figure 4). Results of the stratigraphy model appear to capture drops in albedo that often coincide with observed dust events. Additional darkening horizons may be due to the compaction of snow, emerging of previous horizons, or noise in albedo observations. One major limitation of the current stratigraphy model is that it does not account for snow compaction from overburden, or dust concentrations. Future research will attempt to better classify darkening horizons by using NIR and VIS albedo observations together. Ideally, model improvements will lead to an increased ability to capture the processes that drive the spatial variability of snow albedo, which in turn can be used to improve current snow melt models.

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Senator Beck Basin Data: Center for Snow and Avalanche Studies

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