Thesis Defense
Jonathan Wagner

When: Oct. 30 at 1:00 pm
Where: Room 1715, M. Library

Department of GEOGRAPHY
THE UNIVERSITY OF UTAH

Evaluating the impact of dust on snowmelt timing in Senator Beck Basin using a physically based and spatially distributed snowmelt model informed by in situ albedo observations

Motivation

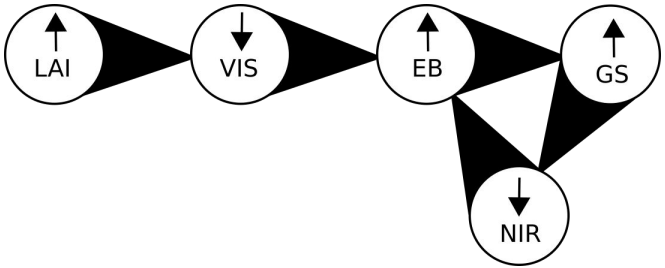
- The Colorado River is fed primarily by snow from the Colorado River Basin (CRB)
    - Supplies water to over 30 million people
    - Reservoirs are used to capture, store, and help manage water resources from the Colorado River
- Effectively managing water resources requires accurate forecasts of snowmelt timing and magnitude
    - Temperature based snowmelt forecasting in the CRB is complicated by dust radiative forcing (DRF)

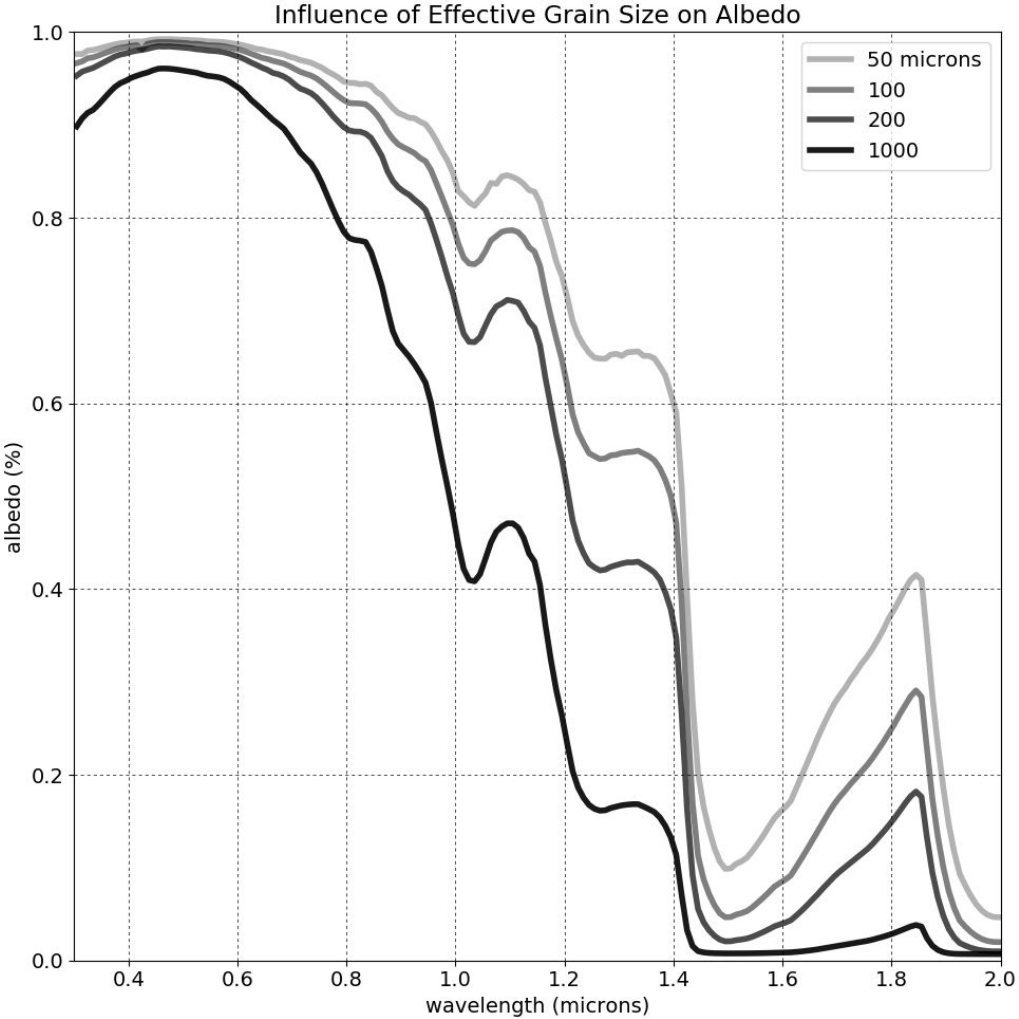
Dust loading in Senator Beck Basin

Images courtesy of CSAS

Dust Radiative Forcing

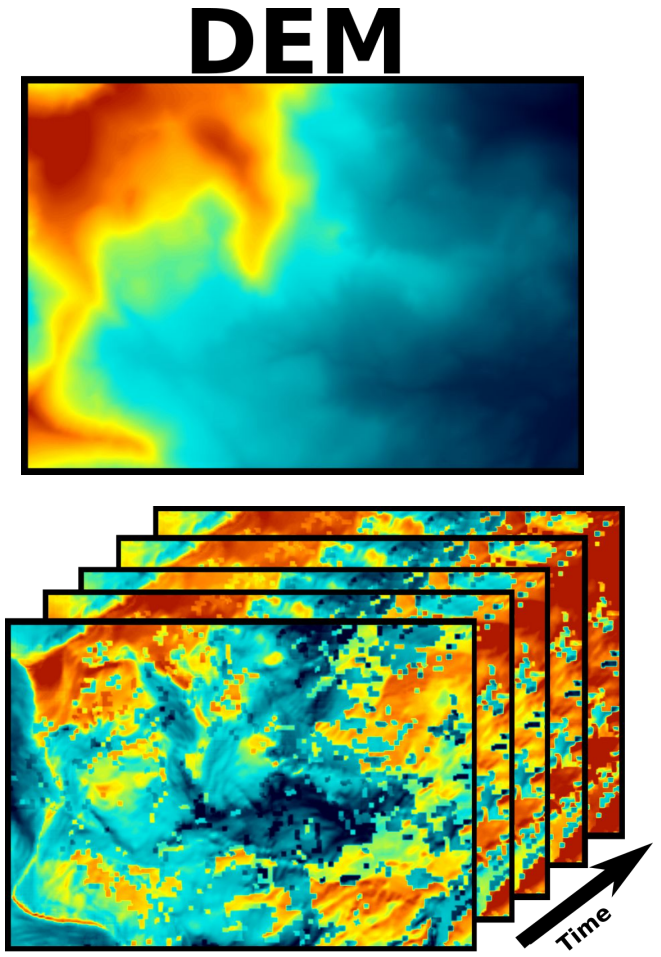
- **Light Absorbing Impurities (LAI)**
  - Primarily dust and black carbon
  - Decrease albedo in the visible wavelengths (VIS)
- **Grain Size**
  - Increases due to melt/refreeze cycles
  - Decreases albedo in the near-infrared (NIR) wavelengths
- **Positive Feedback Loop**





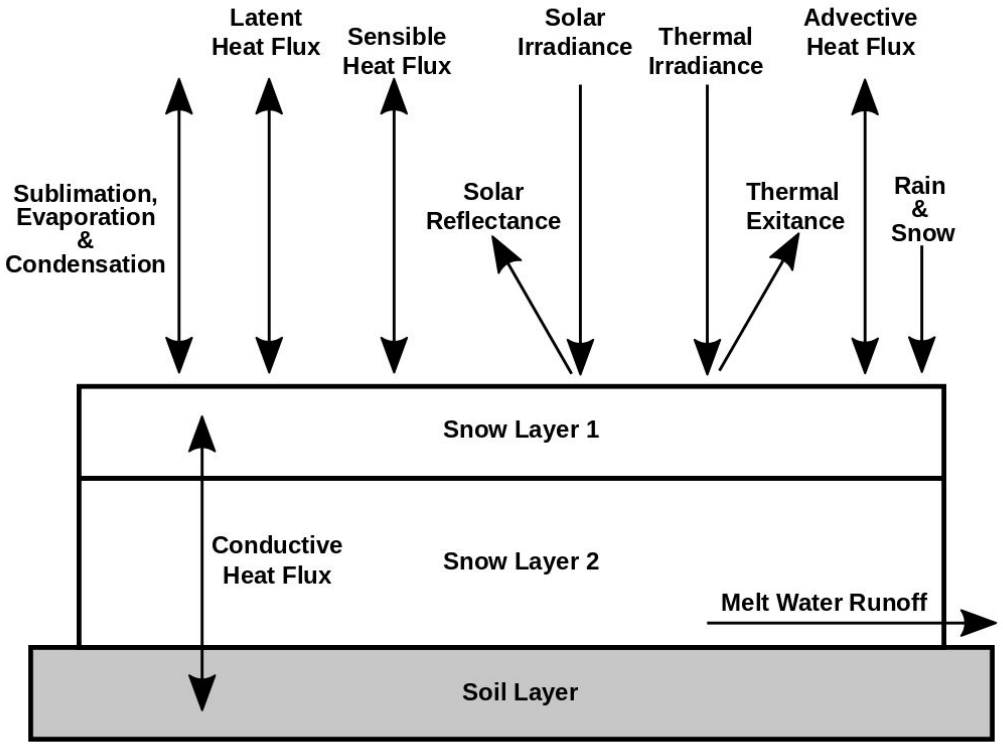
Previous Research

- DRF is the primary driver of snowmelt in CRB
- Not accounting for DRF may be a source of error in snowmelt models
    - Bryant et al. 2013 observed a significant correlation between runoff prediction errors and variability in DRF when evaluating a temperature-index-based model in southwestern Colorado
    - Skiles et al. 2012 noted enhanced snowmelt rates when informing a physically based snowmelt model with in situ observations of dust-influenced snow albedo in Senator Beck Basin
- Previous research relied on one-dimensional snowmelt models which do not fully capture spatial variability across an entire basin
- This study uses in situ albedo observations to inform a spatially distributed and physically based model to explore the effect that DRF has on snowmelt in a dust-influenced basin



Snowmelt Model

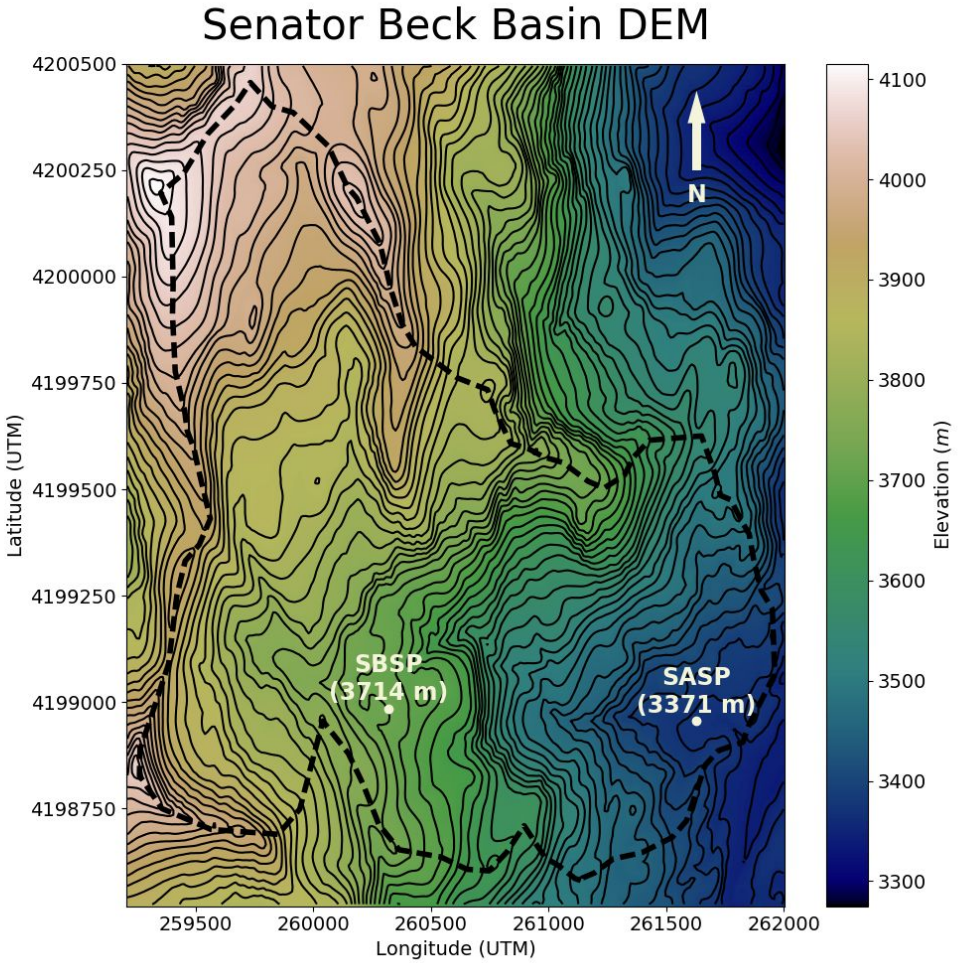
- **iSnobal**
  - Physically based and spatially distributed
  - Two snow layers (Active/Bulk)
  - Forcing inputs drive mass and energy balance of the modeled snowpack
- **Spatial Model Resource Framework (SMRF)**
  - Distributes point forcing data over a digital elevation model (DEM)
  - Requires at minimum time series of:
    1. Precipitation
    2. Air Temperature
    3. Wind Speed/Direction
    4. Incoming Solar Radiation



Based on figure from Marks et al. 1999

Senator Beck Basin

- **Senator Beck Basin Study Area (SBBSA)**
  - A 3 km^2 dust-impacted, mid-latitude mountain basin
  - Located in San Juan Mountains of Colorado
- **Center for Snow and Avalanche Studies (CSAS)**
  - Collected nearly continuous data since 2005
    1. Stream Gauge
    2. Snow Pits
    3. Micrometeorological Towers
- **Airborne Snow Observatory (ASO)**
  - Made periodic flights over SBBSA since 2013
    1. Lidar (Snow Depth)
    2. Spectrometer (Albedo)



Study Plots

- **Swamp Angel Study Plot (SASP)**
  - 30 m x 30 m plot
  - Elevation: 3371 m
  - Sits on a flat, treeless subalpine meadow
  - Well sheltered from the wind
- **Senator Beck Study Plot (SBSP)**
  - 12 m x 36 m plot
  - Elevation: 3714 m
  - Sits on alpine bench above the treeline
  - Strongly influenced by wind which prevents collection of precipitation

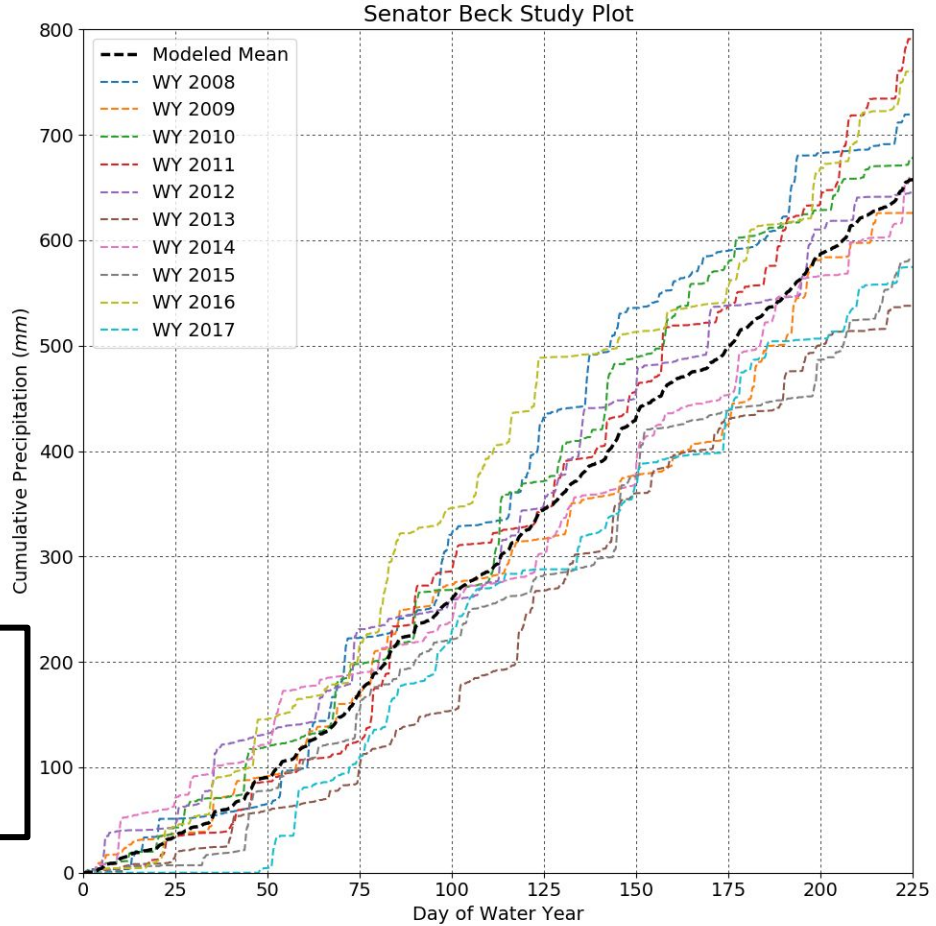
Images courtesy of McKenzie Skiles

SASP **SBSP**

Estimating Precipitation at SBSP

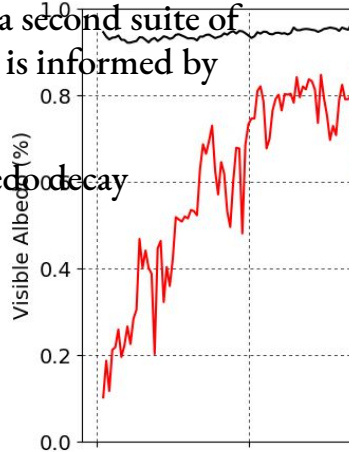
- SMRF requires data from at least two different points on a DEM to make a spatial distribution
- Precipitation at SBSP estimated using a simple mass-balance model
    - Estimates the liquid water needed to account for observed increases of fresh snow in depth sensor data
    - Uses air temperature data to estimate percent of liquid water that fell as snow (Susong et al. 1999)
    - Also uses estimates of the density of fresh snow

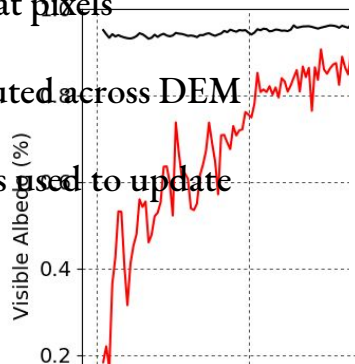
- $\text{percent}_{\text{snow}} = f(T_{\text{air}})$
- $h_{\text{precip}} = \Delta^{+} h_{\text{snow}} \cdot (\varrho_{\text{snow}} / \varrho_{\text{water}}) \cdot \text{percent}_{\text{snow}}$

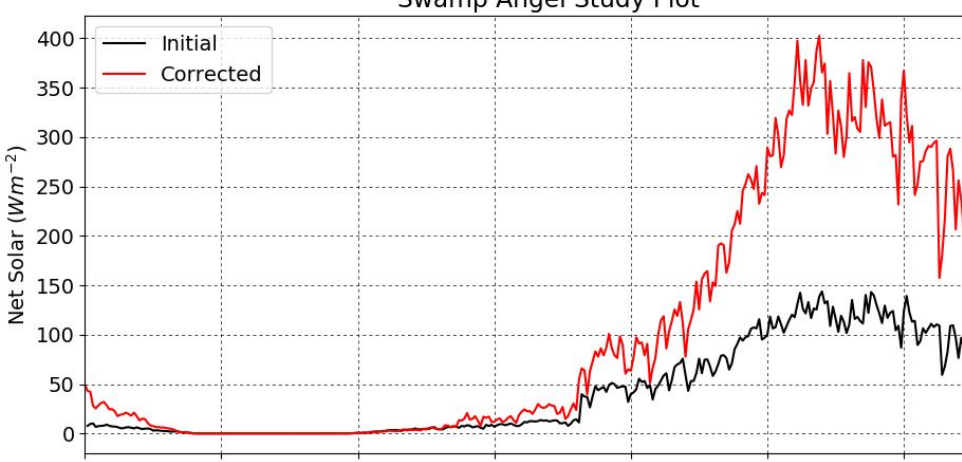


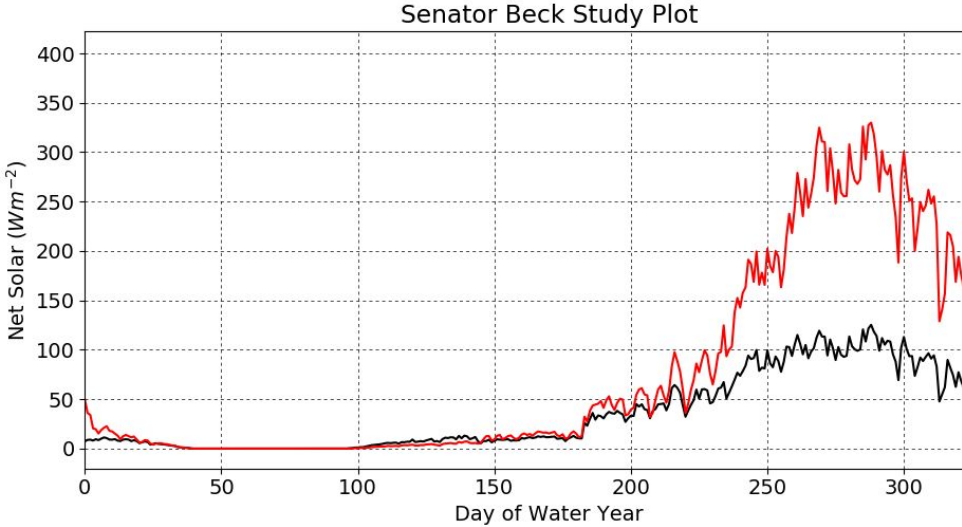
Updating Albedo

- This study compares iSnobal results from initial model runs of 'clean snow' with a second suite of model runs where the the model is informed by in situ albedo
- Initial runs use an age-based albedo decay
  - Time since last storm
  - Solar zenith angle
  - Snow grain size
- Updated VIS and NIR albedo
  - Scaling factors calculated at pixels containing towers
  - Scaling factors are distributed across DEM using detrended kriging
  - Distributed scaling factors used to update initial albedo runs

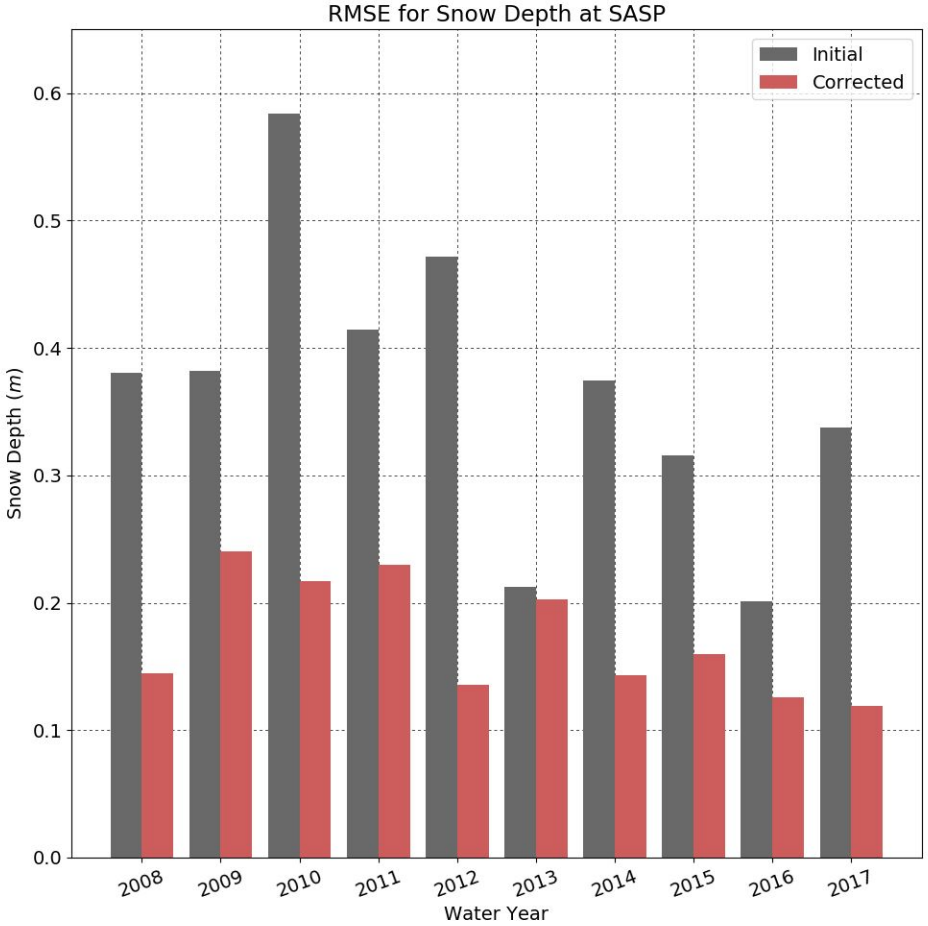


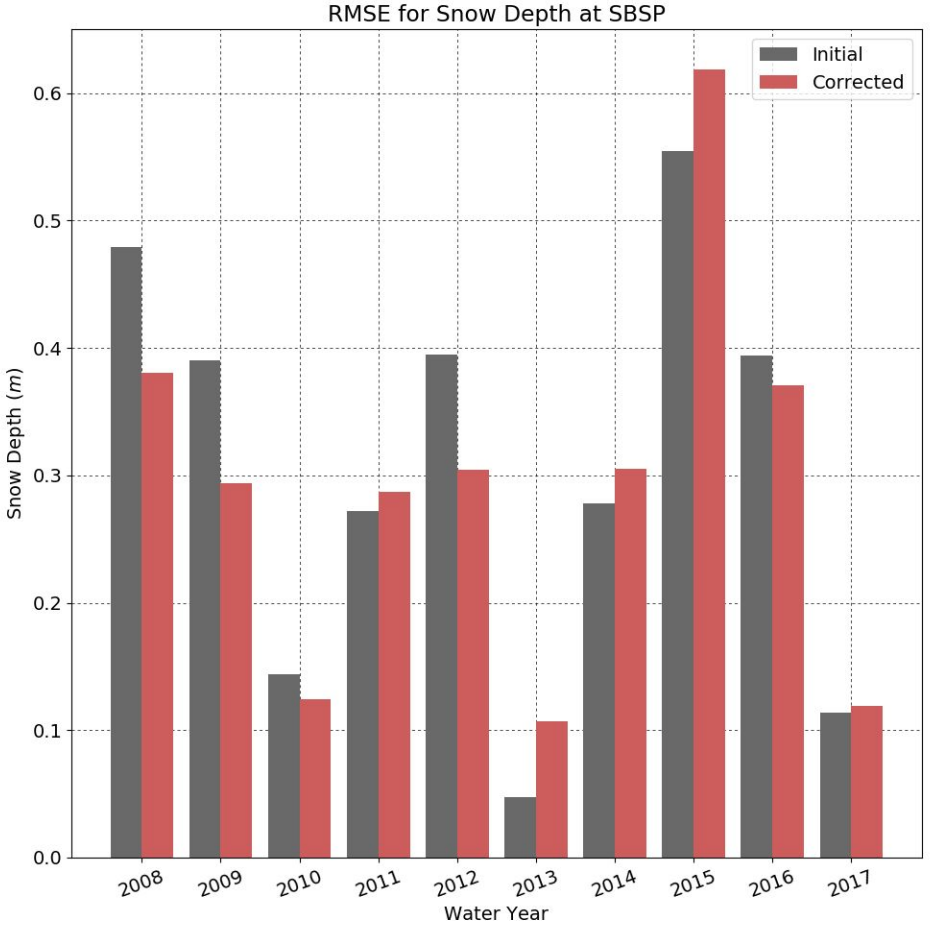




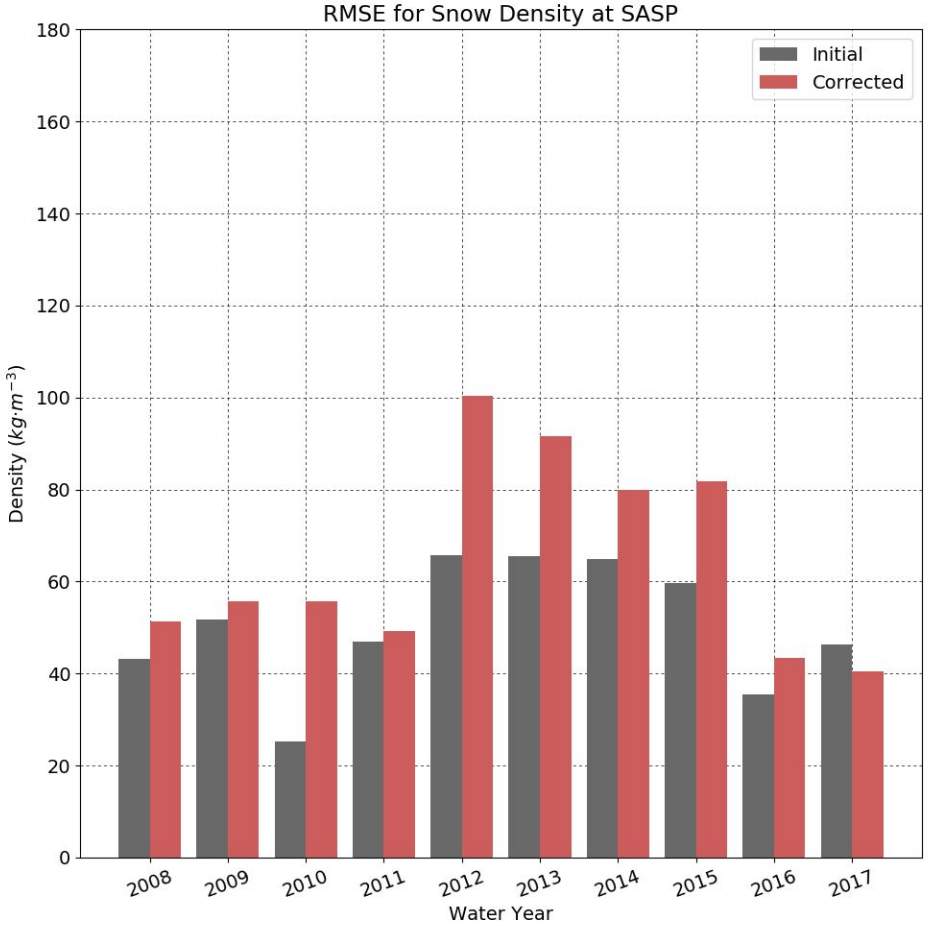


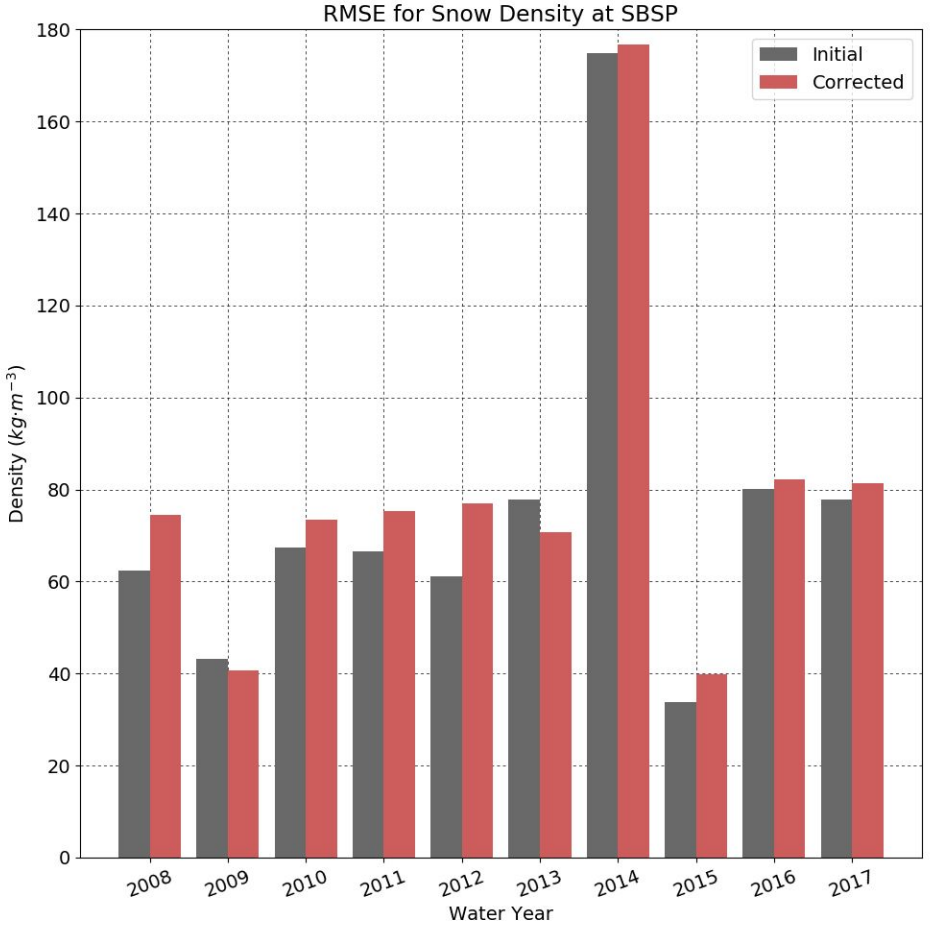
Snow Pit Comparison: RMSE Snow Depth



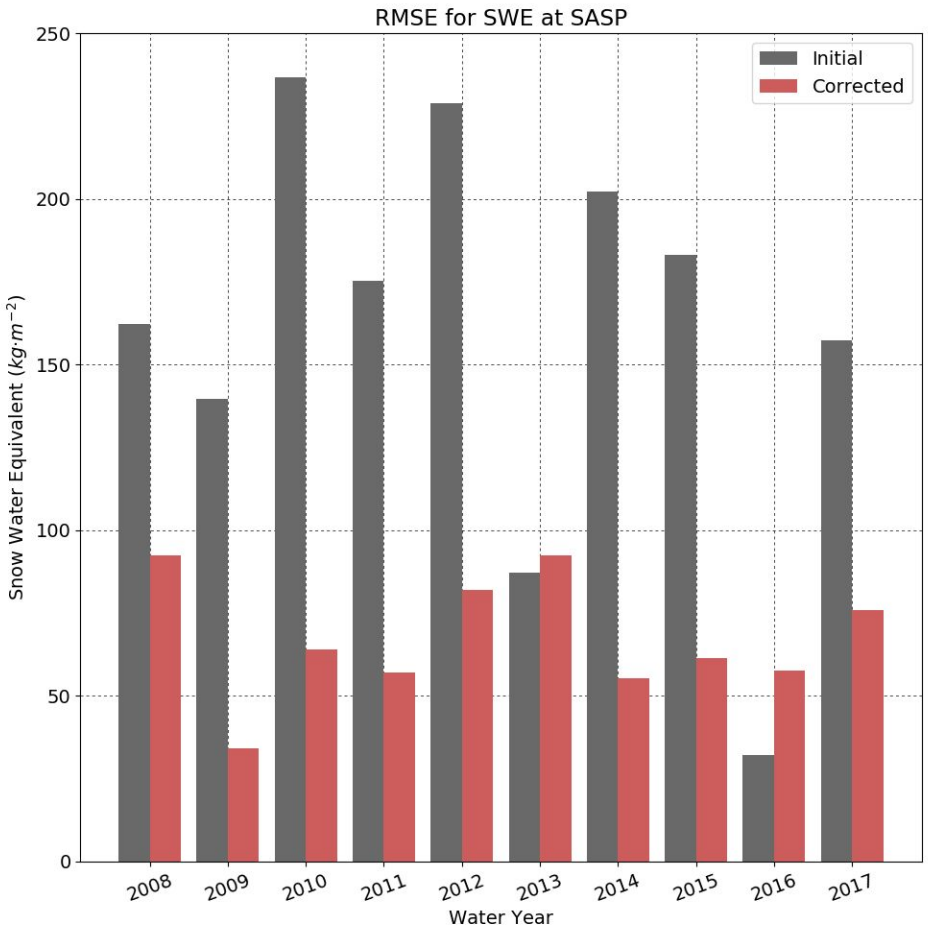


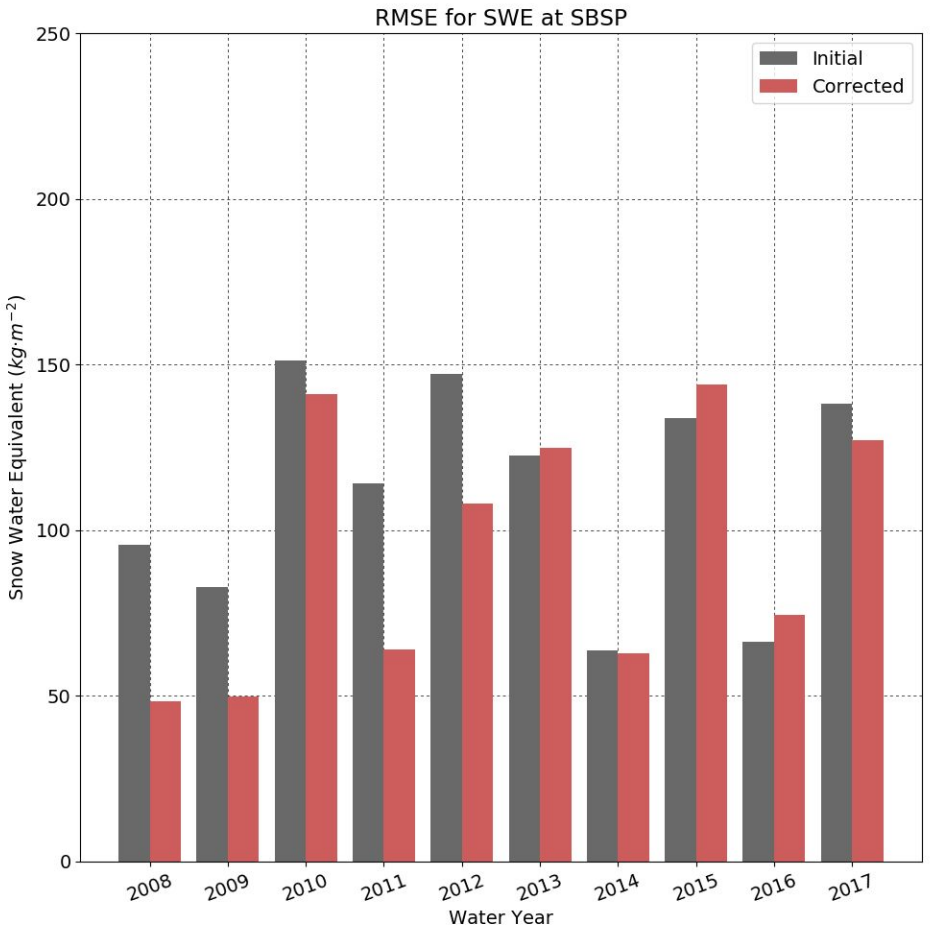
Snow Pit Comparison: RMSE Snow Density





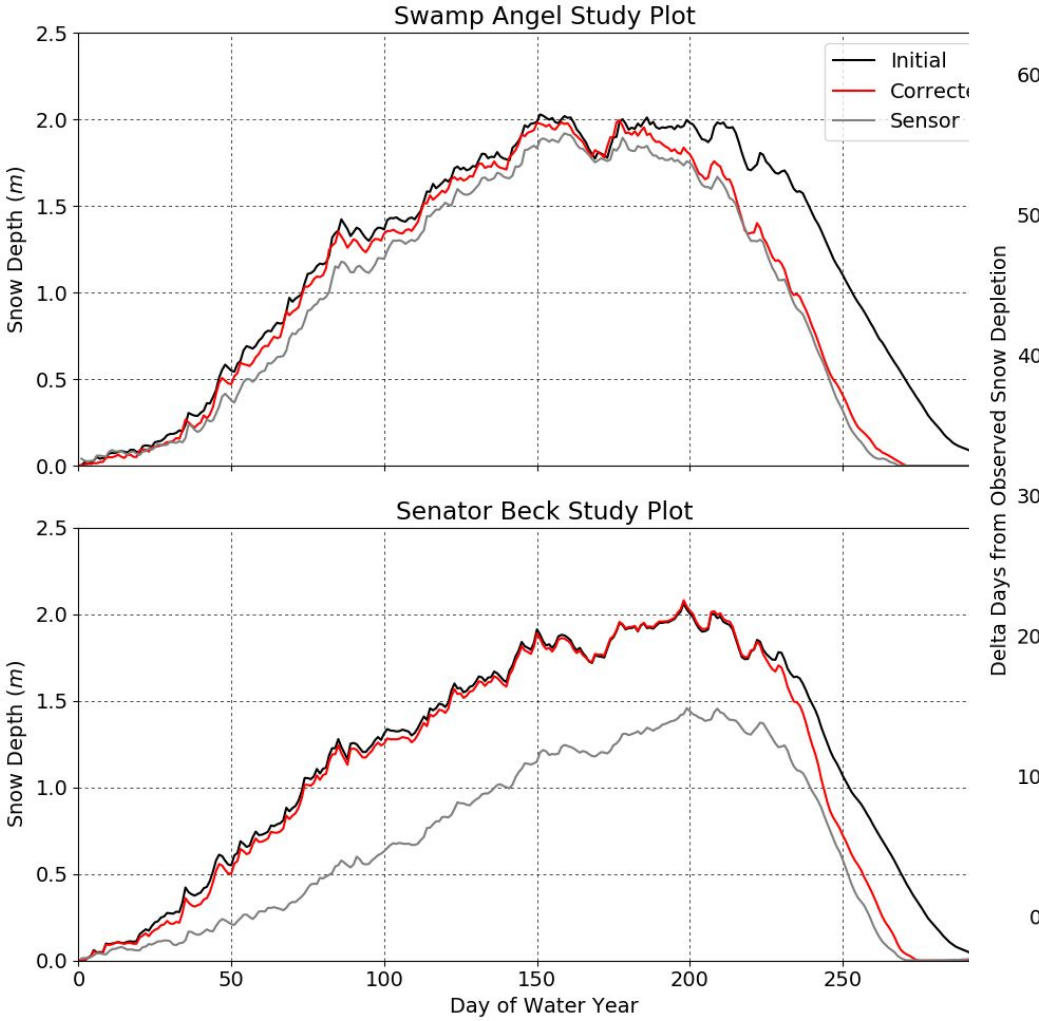
Snow Pit Comparison: RMSE Snow Water Equivalent





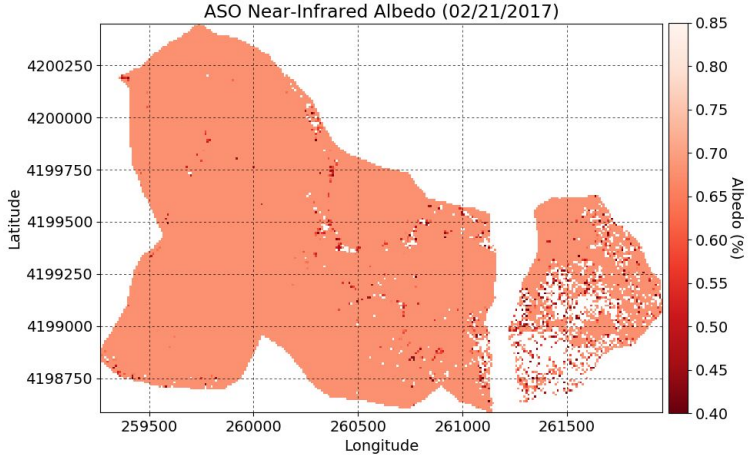
Snowmelt Timing

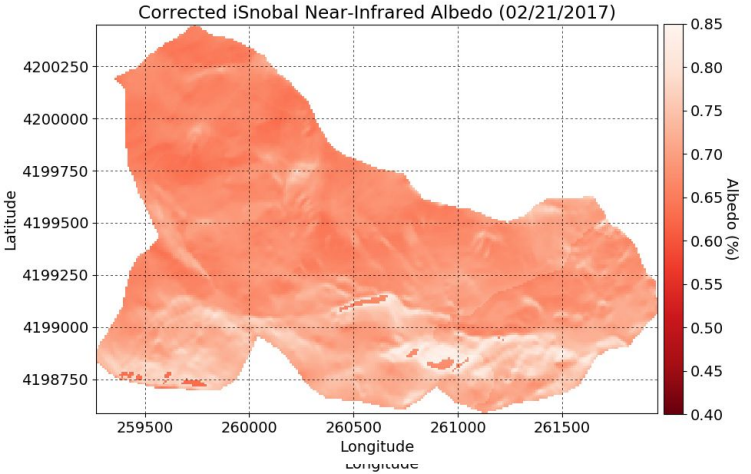
- Initial iSnobal runs over estimate the day of snow depletion by 37.2 days at SASP and 32.7 days at SBSP
- Updated model runs have accelerated decline in snow depth toward the end of the snow season
- Overestimates of snow depletion are reduced to 4.6 days at SASP and 8.5 days at SBSP
- Errors in estimating SBSP precip complicates analysis of results
- Improvements in snowmelt timing is controlled primarily due by the amount of dust deposited each season
    - Relatively low dust years: 2015 , 2017
    - Relatively high dust years: 2009, 2012, 2013



ASO Comparison: February 21, 2017

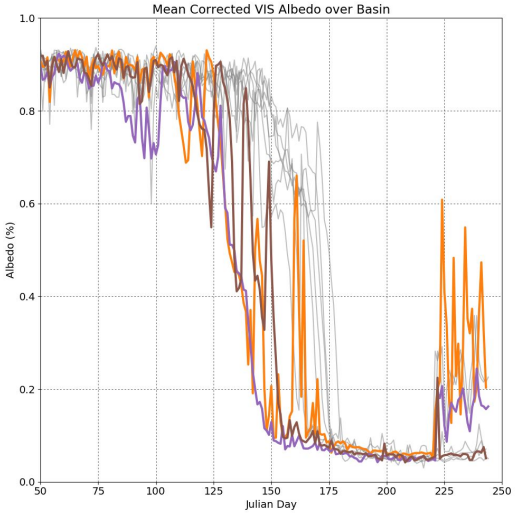
- Compare iSnobal results with lidar and spectroscopy data from ASO
- Early season snowpack of a low dust year means that initial and updated runs are very similar
- Differences in ASO and modeled snow depth are likely due to:
    - Poorly constrained precipitation lapse rates
    - Not accounting for redistribution by wind
- ASO reveals a relatively fresh/clean snowpack similar to initial and updated modeled albedos
- Method of distributing scaling factors likely a source of error

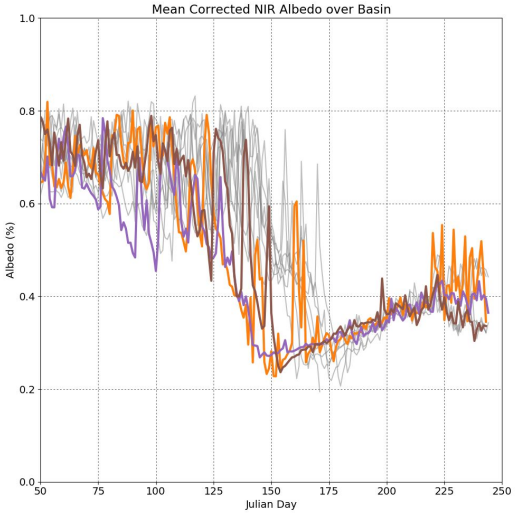


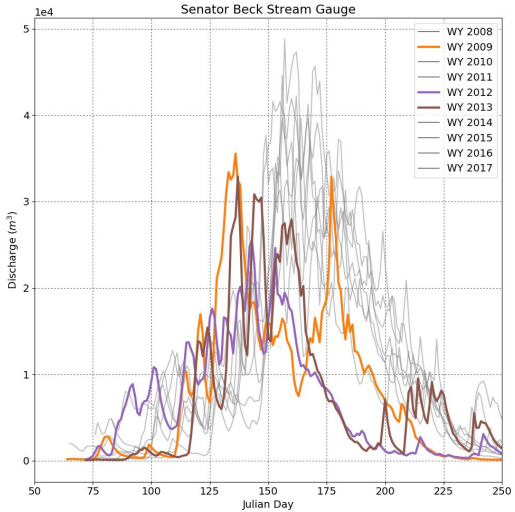


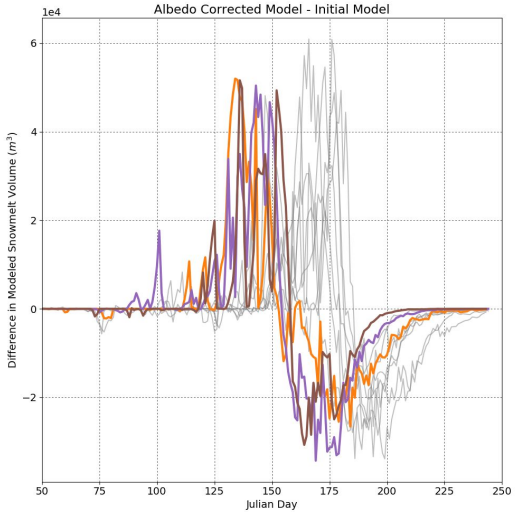
Stream Gauge Comparisor

- Compare iSnobal results with data from Senator Beck Stream Gauge (SBSG)
- Relatively low dust years: 2015 , 2017
  - Display relatively higher VIS and NIR albedo across the basin
  - Stream discharge peaks later in the season
  - Updates model runs display minor shifts in the timing of snowmelt
- Relatively high dust years: 2009, 2012, 2013
  - Display relatively lower VIS and NIR albedo across the basin
  - Stream discharge peaks earlier in the season
  - Updates model runs greatly improve the timing/magnitude of snowmelt



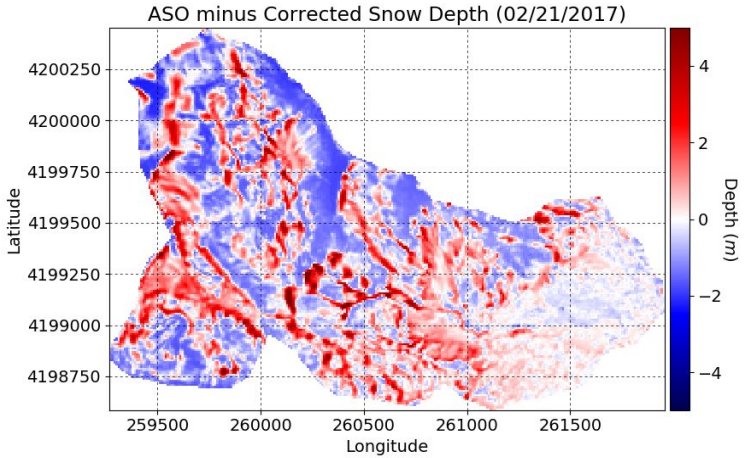


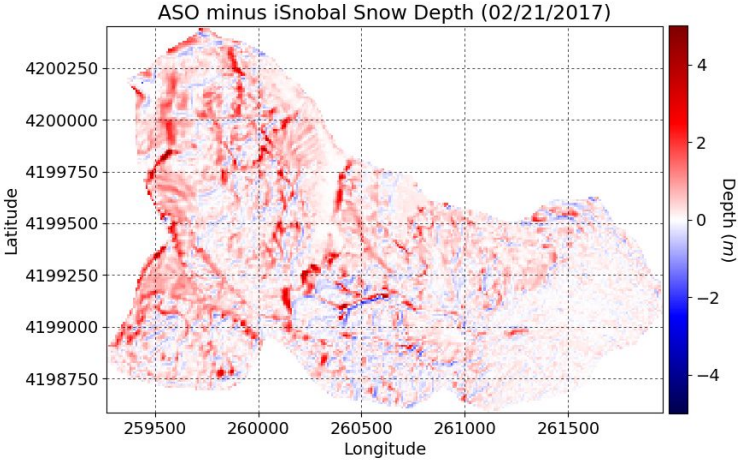




Conclusion and Future Work

- This study uses in situ albedo observations to inform a spatially distributed and physically based model to explore the effect that DRF has on snowmelt in a dust-influenced basin
    - In general, informing iSnobal with in situ albedo observations brought results closer in line with records from snow pits and depth sensors, especially during relatively high dust years
    - Overestimates in the day of snow depletion decreased by 32.6 days at SASP and 24.8 days at SBSP
    - Data from ASO can be used to evaluate modeling choices
    - The timing of snowmelt shifted to more closely match stream gauge measurements
- Future work will focus on improving precipitation lapse rates, comparing models with additional ASO flights, and improving our ability to model complex spatial pattern of snow albedo





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