Insights Into Forest Canopy-Snow Interactions from 2 Years of Summit-to-Shore Observations at Mt Mansfield, VT

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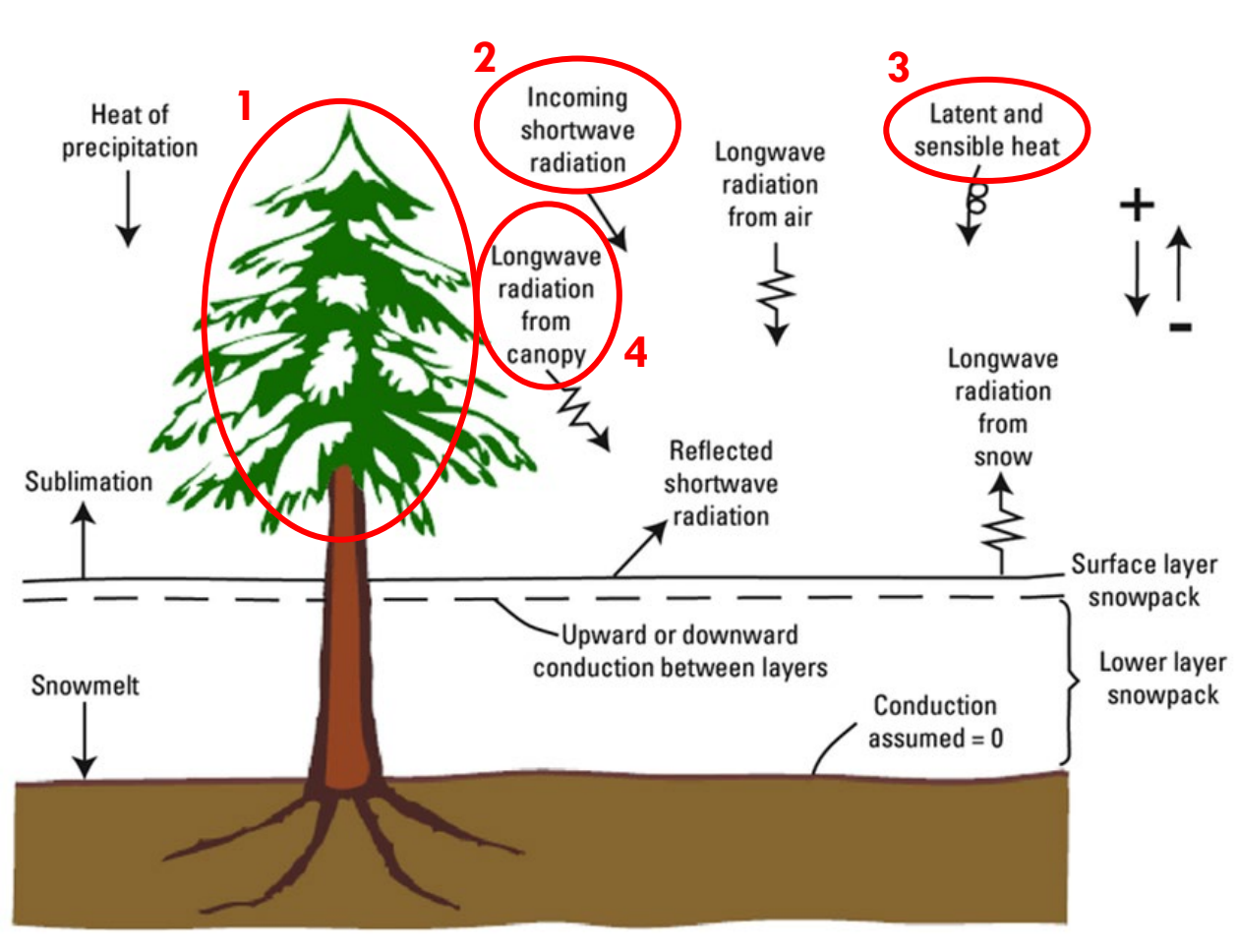
11/20/2025

FEMC Conference 2025

How Do Forests Affect Snow?

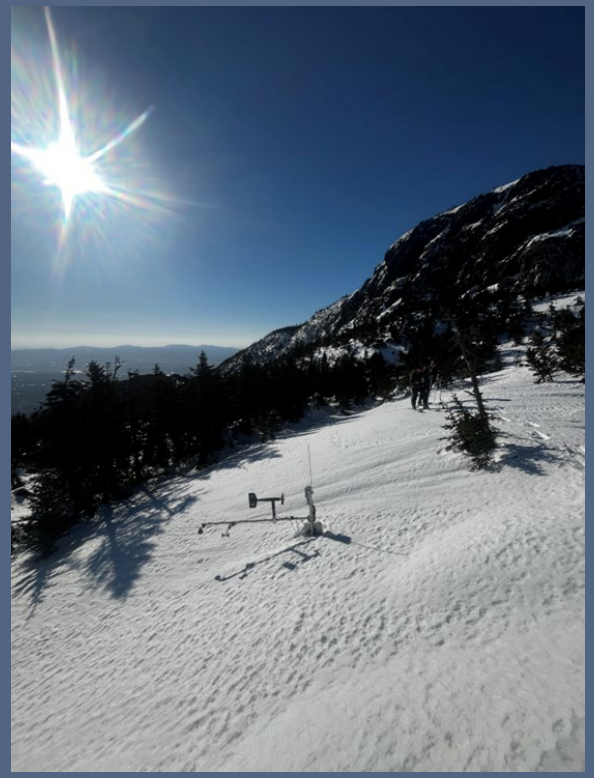


Components of the snowpack mass-energy balance (Koczot et al. 2021)

- Effects on snowpack dynamics:
  1. Interception of snowfall
  2. Shading of sunlight
  3. Wind buffering
  4. Emission of longwave radiation

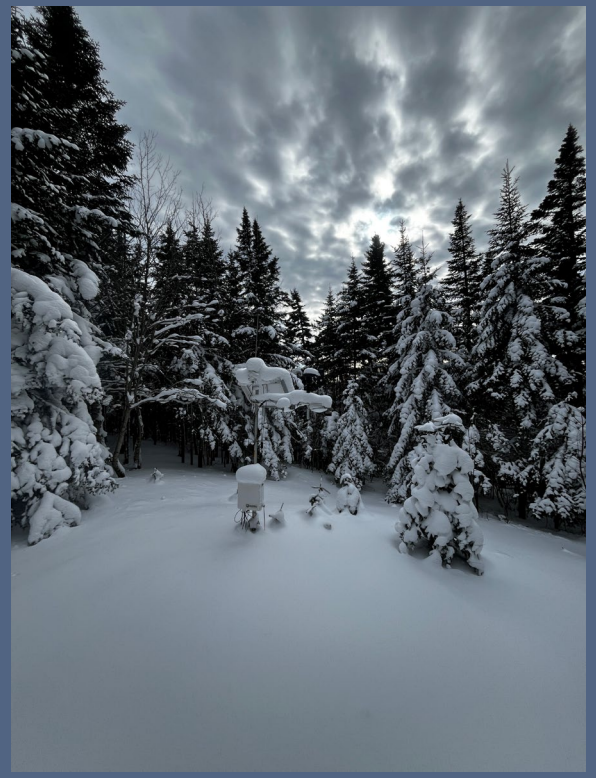
- Most interactions have been studied in the US West with open conifer forests

Research Question: How does forest canopy structure influence daily snow depth change at different locations around Mt Mansfield?



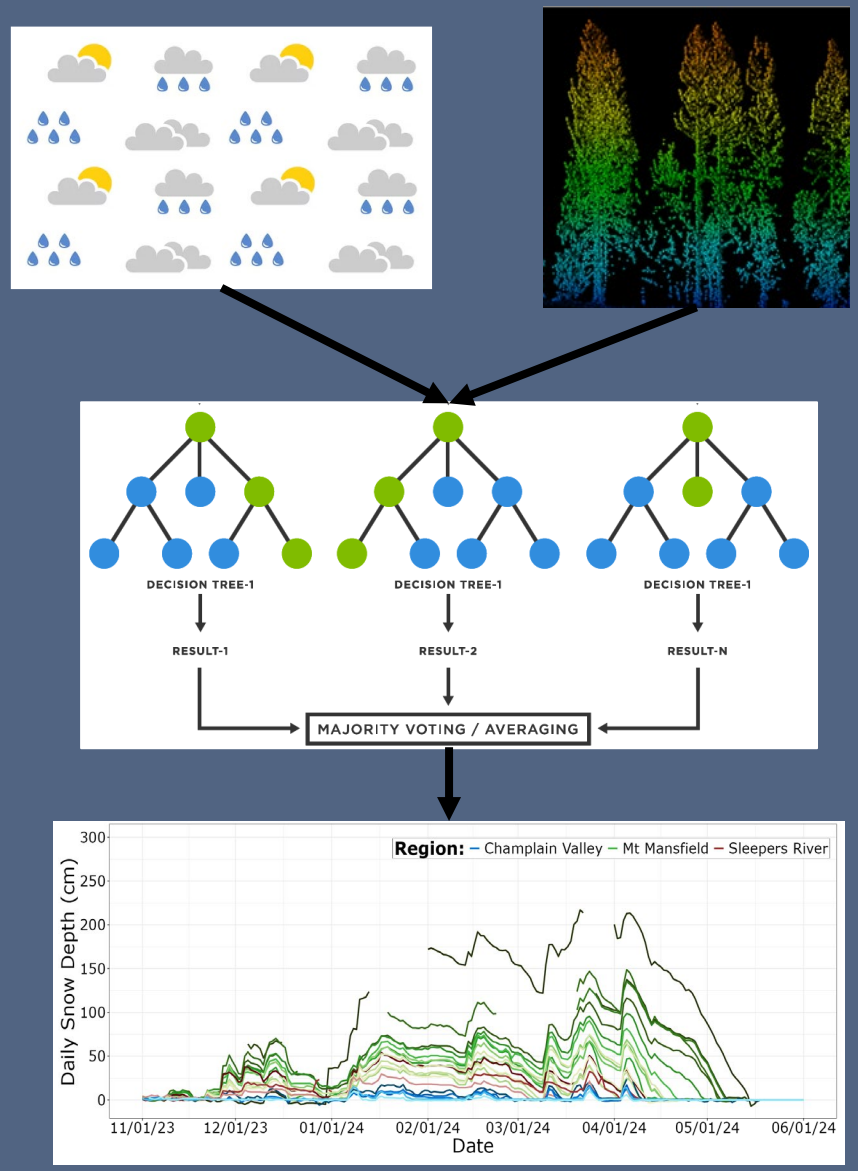
Site SUMM on 3/24/2025

Site RB01 on 1/12/2025



Site RB12 on 1/23/2024

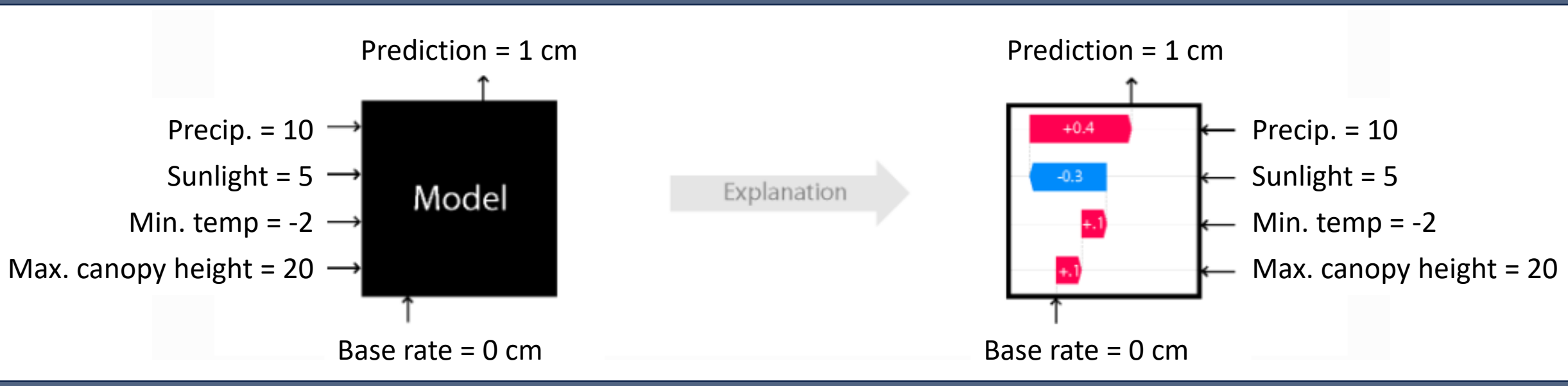
Analysis Methods



1. Characterize forest canopy with ALS-derived canopy metrics
2. Select accumulation and ablation events from Mt Mansfield snow stake record from 22-23 and 23-24 winters
3. Develop spatiotemporal random forest models to predict snow depth change at each S2S site for each day in above events
   - Meteorological variables (AORC)
   - Forest canopy variables
   - Topographic variables
4. Use Shapley Additive Explanation (SHAP) analysis to investigate influence of canopy on daily snow depth change

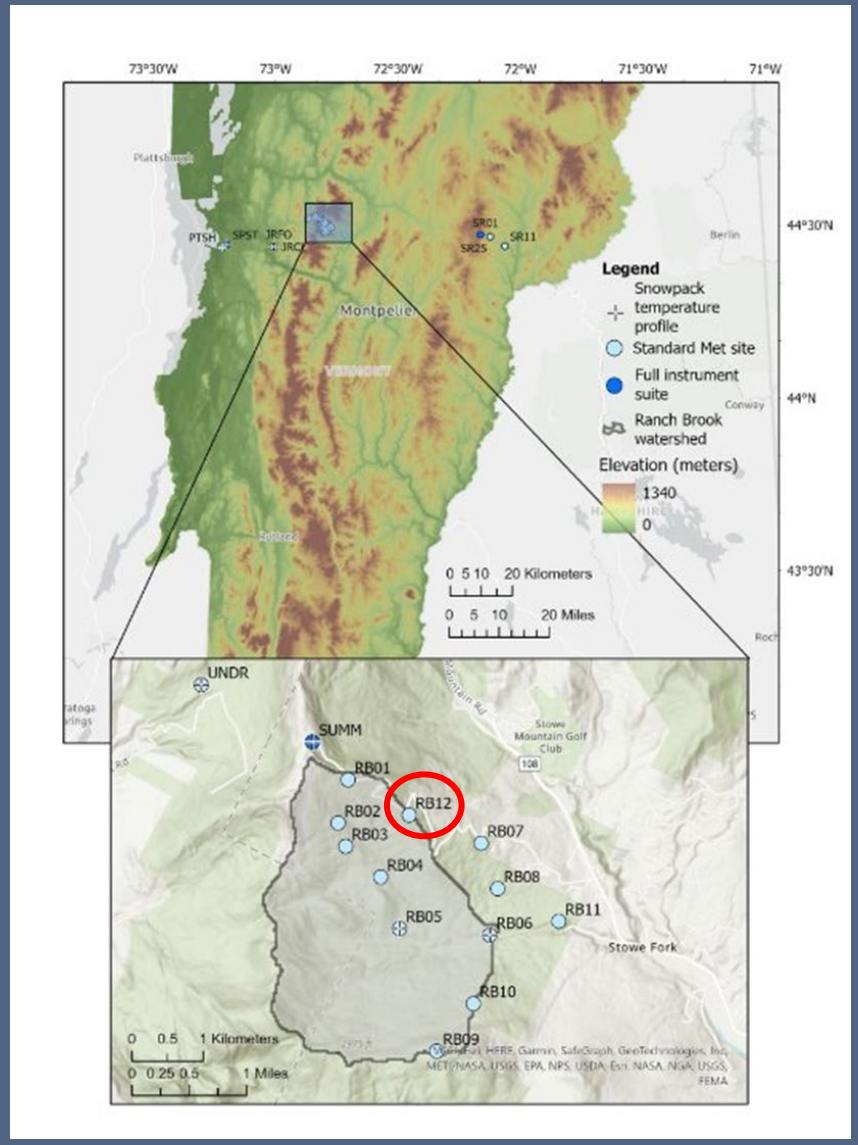
What is SHAP Analysis?

- "[A] game theoretic approach to explain the output of any machine learning model. It connects optimal credit allocation with local explanations using the classic Shapley values from game theory and their related extensions" – (Lundberg and Lee 2017)
- **Allows for interpretation of ML output**
- Prediction is sum of all positive and negative contributions



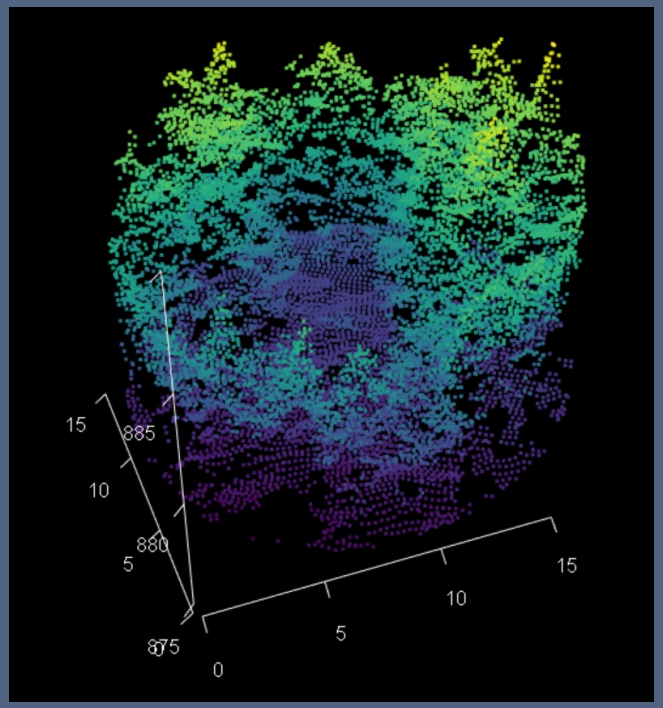
Study Site: Ranch Brook and Mt Mansfield

- Low-elevation alpine region with deciduous, mixed and coniferous forest cover
- High spatial resolution of in-situ snow and meteorological observations
- Aerial LiDAR data available in relatively high resolution (~60 points/m^2) from VT 2023 LiDAR Survey



Deriving Canopy Structure Metrics

Aerial imagery and 10m radius around site RB12



LAS point cloud around site RB12

- 10m radius around each site
- Using LidR and leafR packages, metrics were derived from raw LiDAR point clouds
- Metrics quantifying conifer canopy derived from aerial imagery

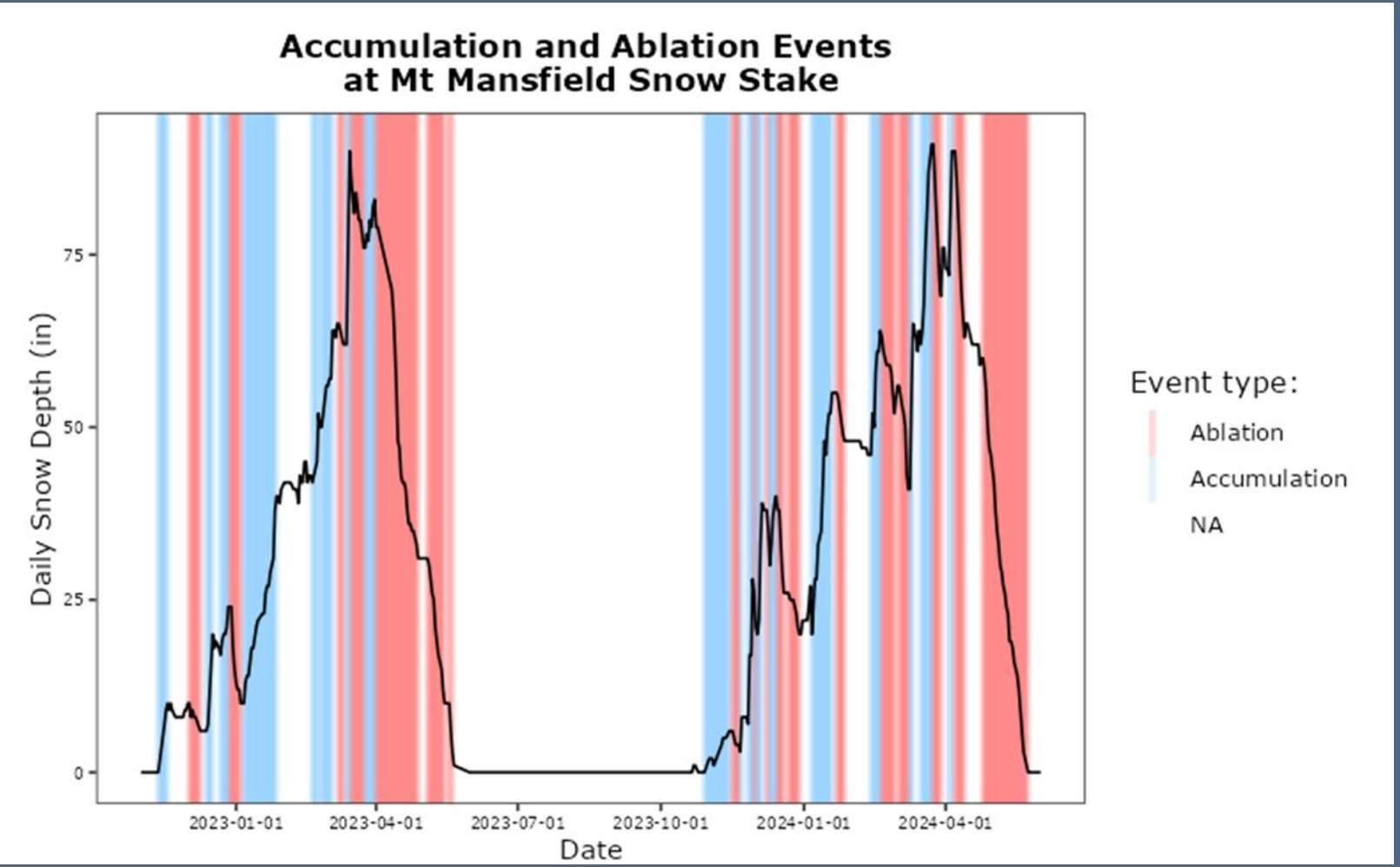
Deriving Canopy Structure Metrics

Atkins et al. 2018 proposed five classes of forest canopy structure:

1. Height (how high)
   - Max/mean/95th height
2. Openness (how open)
   - Vertical gap fraction
3. Arrangement (where)
   - Canopy relief ratio
4. Density (how much)
   - NDVI, % conifer, plant area index
5. Variability (how complex)
   - Rumple, entropy

Forest Canopy variables
Max height (m)
95%ile height (m)
Mean height (m)
Vertical gap fraction
Canopy relief ratio
Mean NDVI
Mean conifer NDVI
% Conifer
Mean plant area index
Stddev plant area index
Rumple
Entropy

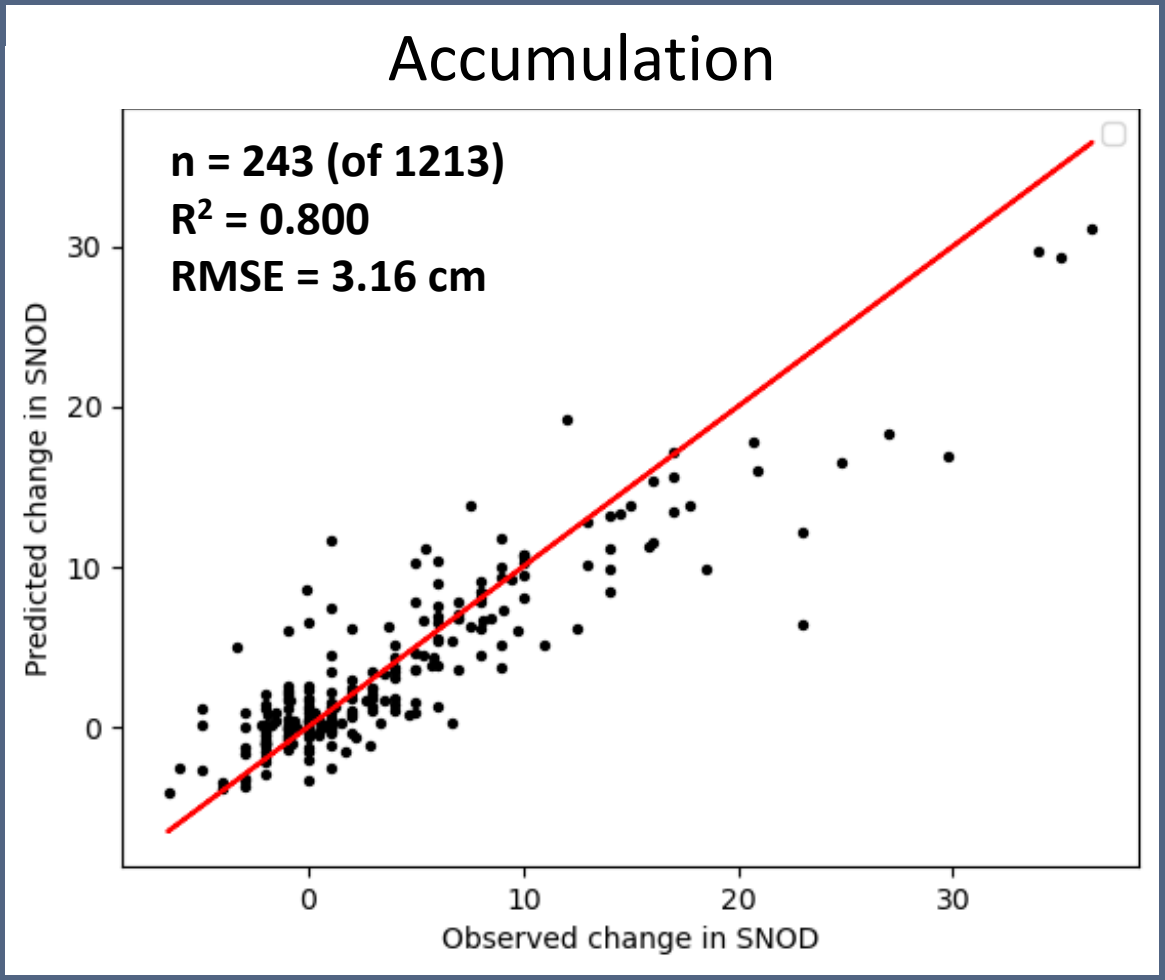
Delineating Events in Snow Depth Record



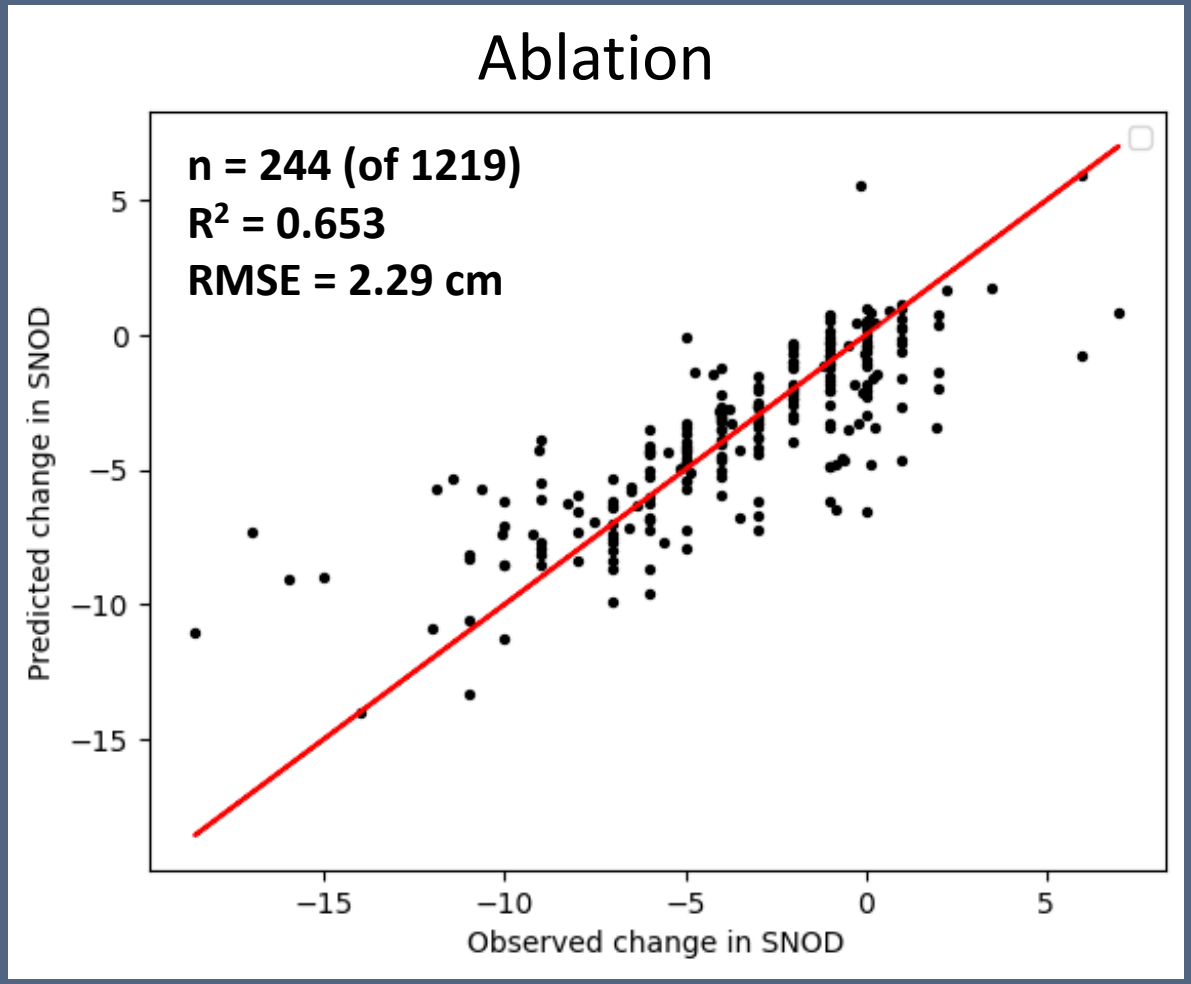
- Mt Mansfield snow stake record as baseline for winter conditions
- 47 total events
  - 28 accumulation
  - 19 ablation

Results: Random Forest Model

Accumulation

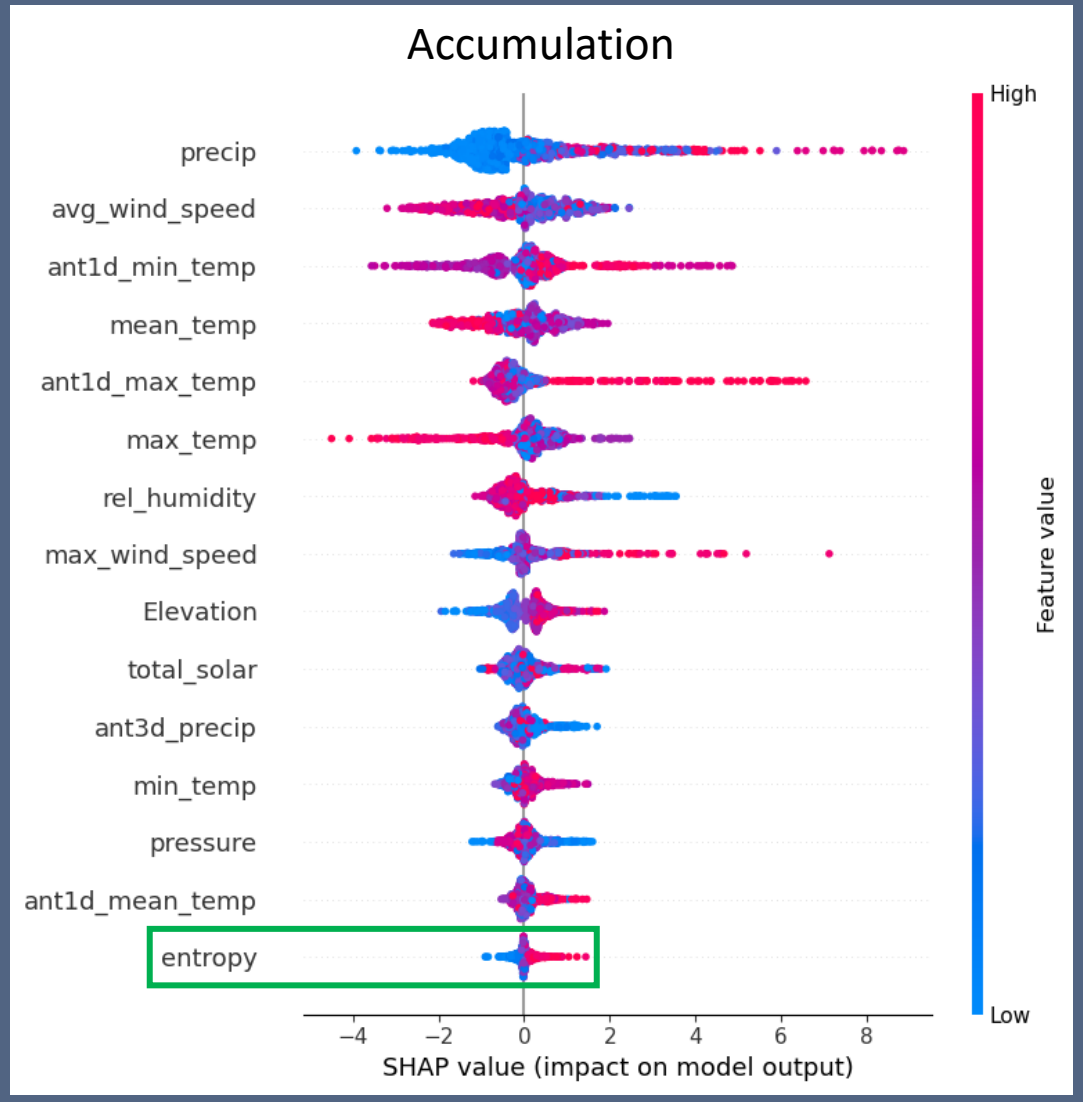


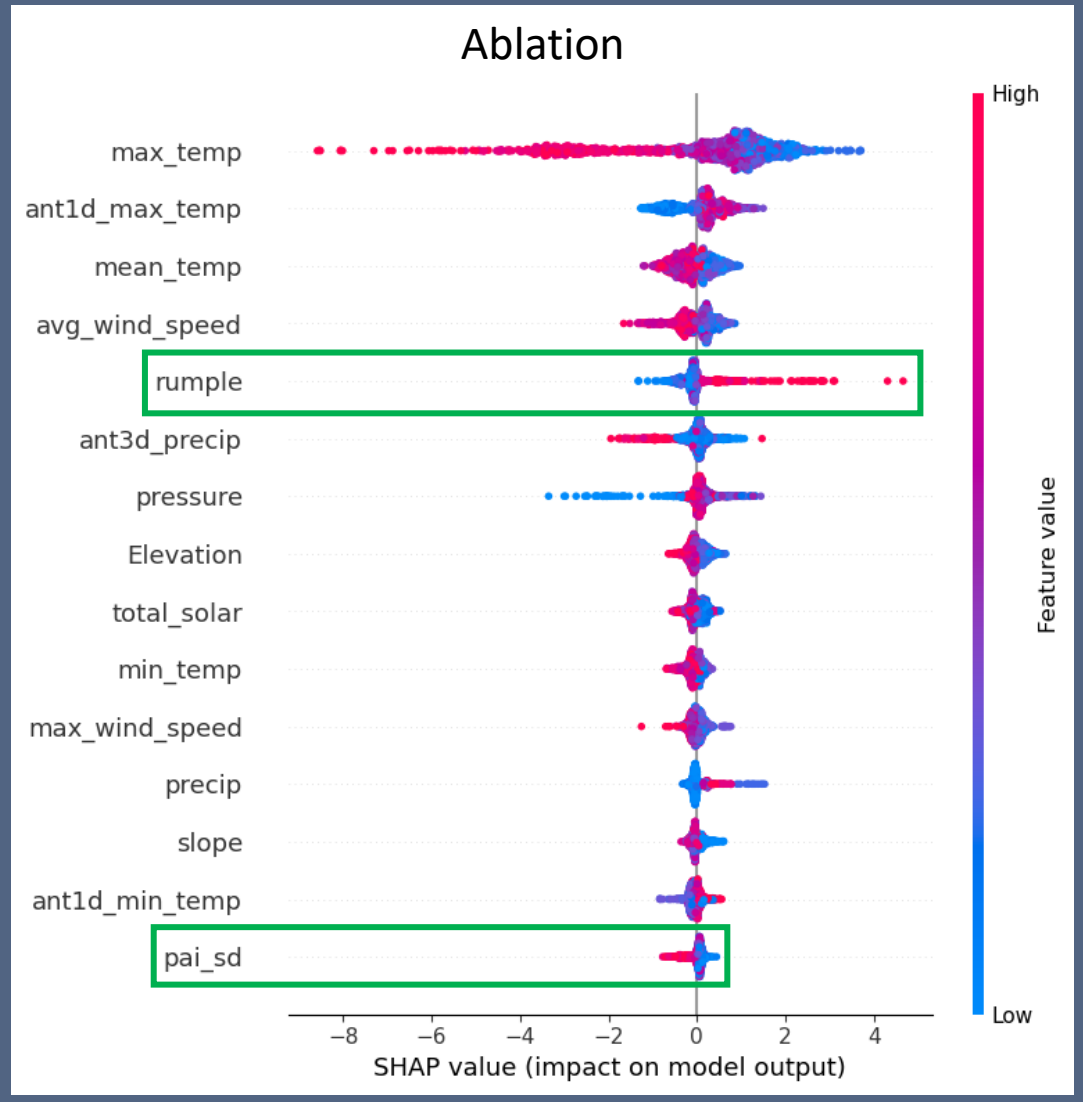
Ablation



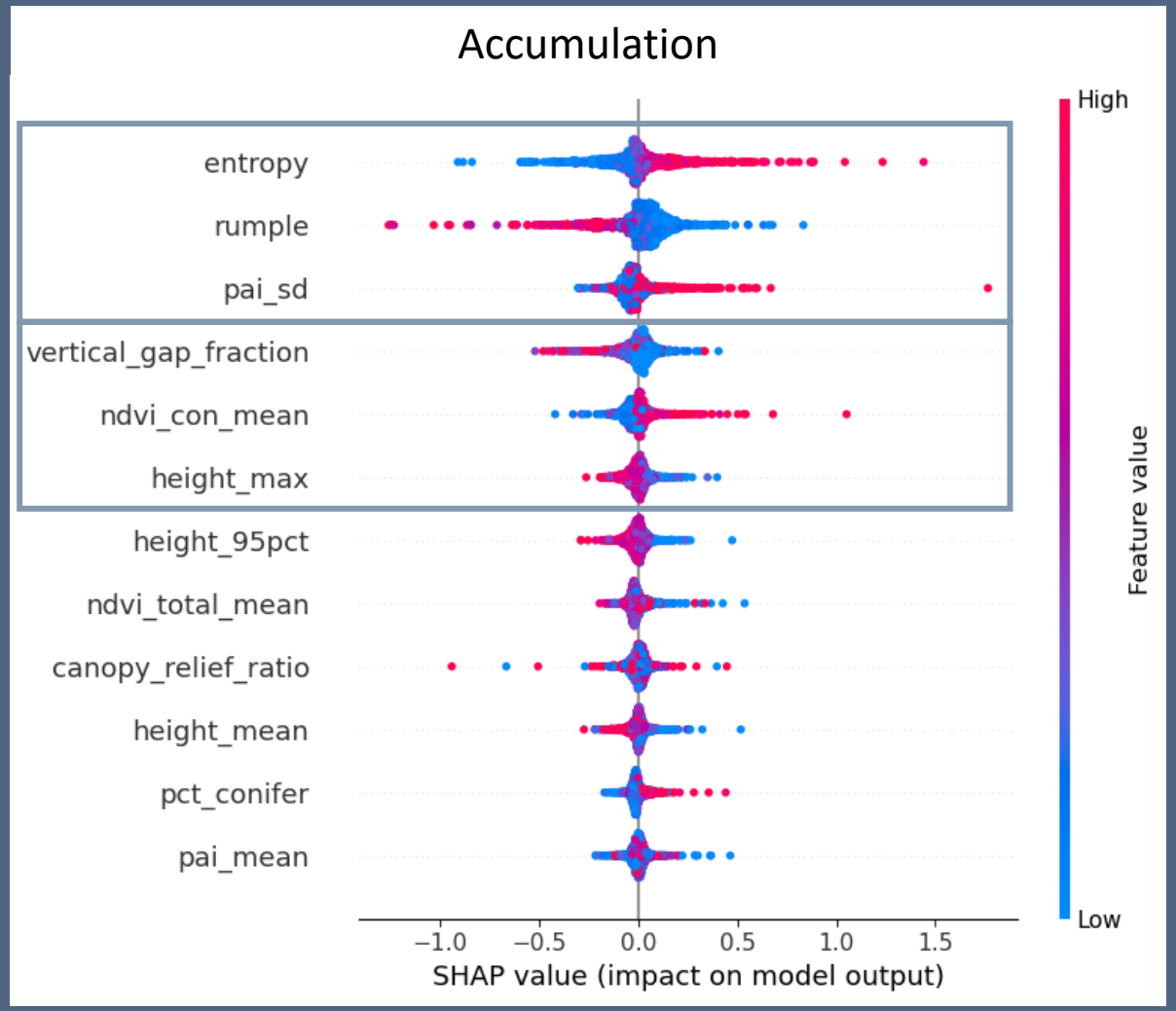
SNOD = Snow Depth (cm)

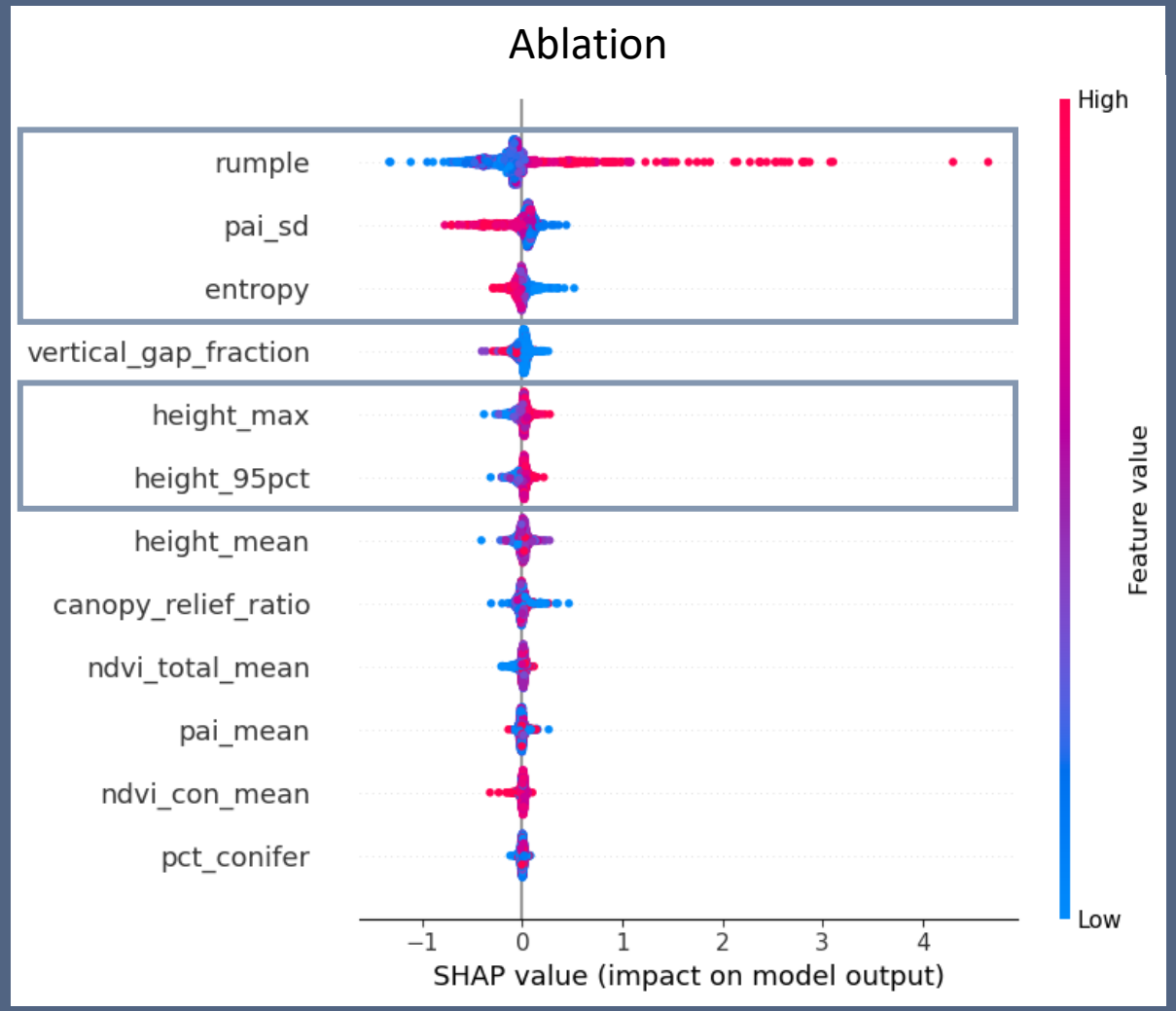
Results: SHAP Output for All Features





Results: SHAP Output for Forest Metrics





Key Takeaways

- Random forest ML models and SHAP analysis provide valuable insights into key controls on snow accumulation and ablation
  - Accumulation variability: entropy (+), rumple (-), plant area index stddev. (+), NDVI mean of conifer canopy (+), vertical gap fraction (-), max height (-)
  - Ablation variability: rumple (-), plant area index stddev. (+), entropy (+), max height (-)
- Complex forest structure holds onto more snow during melt periods
- High canopy entropy increases accumulation *and* ablation

Thank you!

Questions?

Advisors: Beverley Wemple and Arne Bomblies
Acknowledgements: Kate Hale and Anna Grunes
Collaborators: Cold Regions Research and Engineering Laboratory
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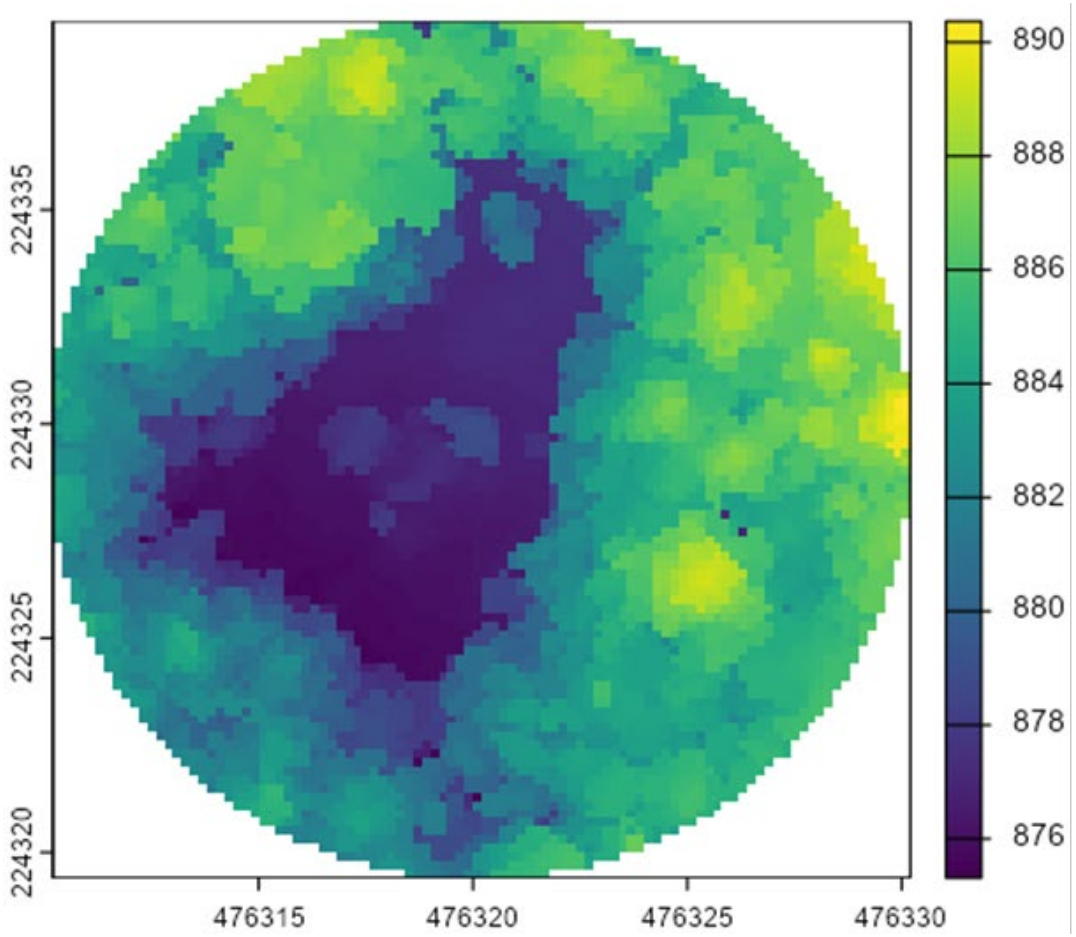
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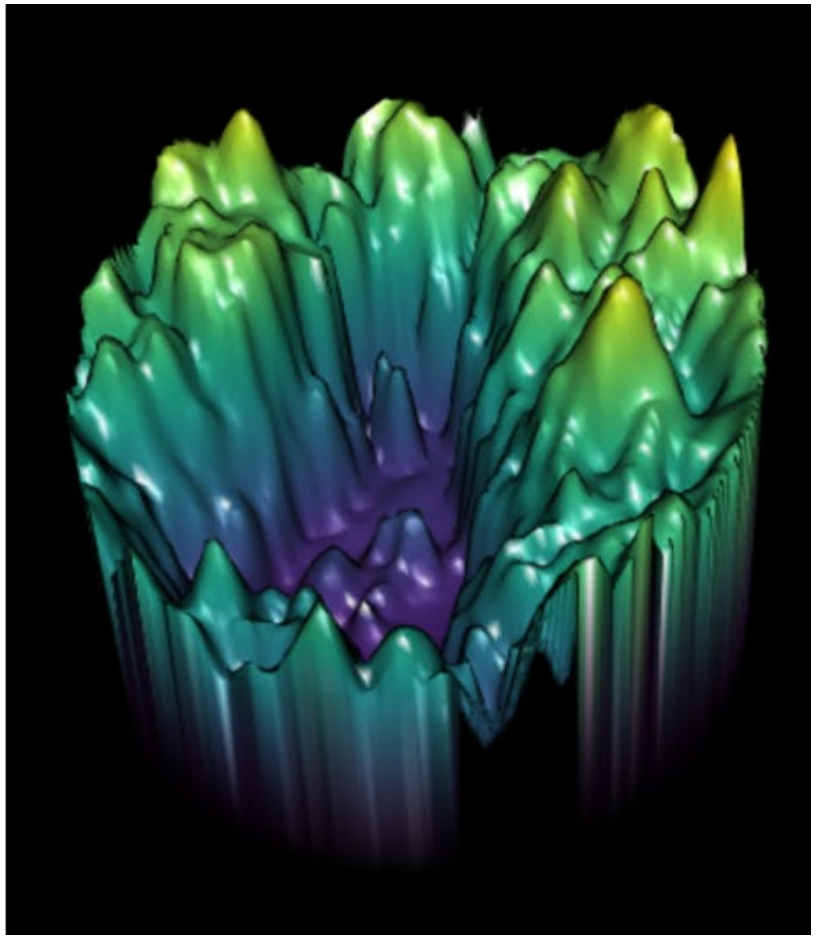


Overview - Variables

Meteorological variables (dynamic, daily), from AORC
Max temp (C)
Mean temp (C)
Min temp (C)
Pressure (mB)
Total solar (W/m^2-day)
Relative humidity (%)
Precipitation (in)
Sum 3-day precipitation (in)
Avg wind speed (m/s)
Max wind speed (m/s)

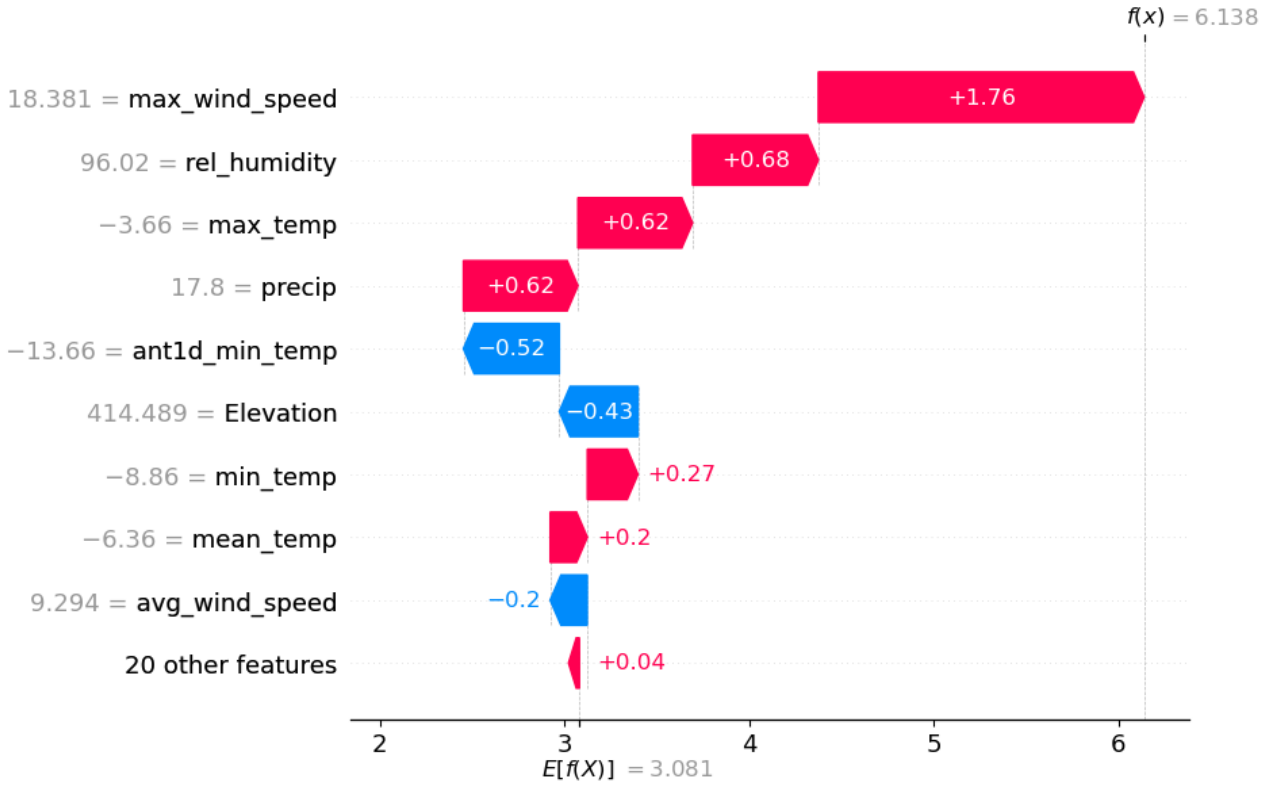
Forest Canopy variables (static), from VT LiDAR
Max height (m)
95%ile height (m)
Mean height (m)
Rumple
Entropy
Canopy relief ratio
Mean NDVI
Mean conifer NDVI
% Conifer
Mean plant area index
Stddev plant area index
Vertical gap fraction

via aerial imagery

Topographic variables (static), from DEM
Elevation (m)
Aspect (cos(azimuth))
Slope (deg.)
Topographic position index

26 variables

What is SHAP Analysis?



- Breaks down model predictions into linear combination of feature contributions
- Prediction is sum of all positive and negative contributions

<u>RB06 on 3/4/2023</u>
Observed change in snow depth: 6.0 cm
Predicted change in snow depth: 6.1 cm