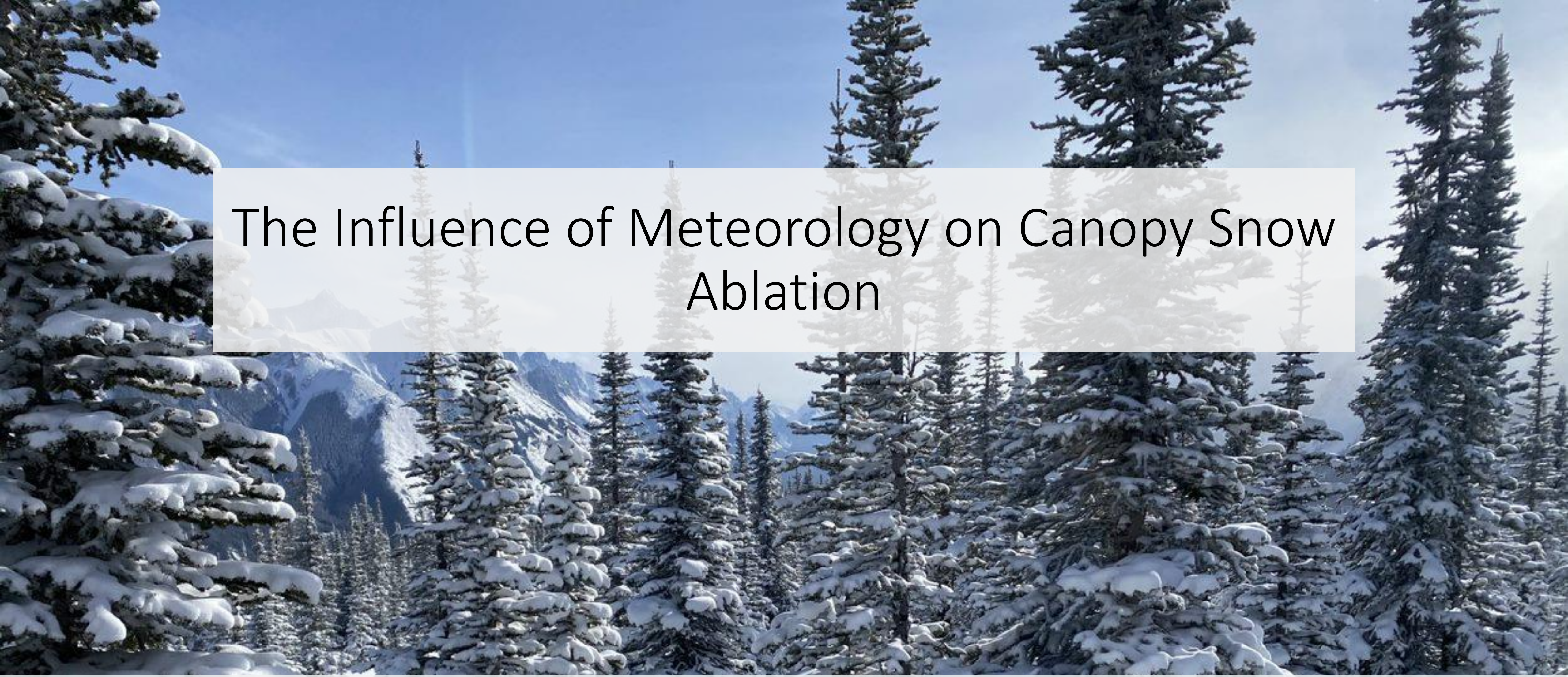
The Influence of Meteorology on Canopy Snow Ablation



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Background

- Snowmelt from forested mountains provides a crucial source of streamflow
- We need reliable models of snow redistribution to estimate snow accumulation in mountain forests
- Existing parameterizations are based on few observations from distinct climates and have not been tested thoroughly
- Thesis Objective: To better understand the processes that govern snow accumulation and redistribution in mountain forests

Processes important for canopy snow ablation

- Increase in **branch elasticity** with **air temperature** (Schmidt & Pomeroy, 1990)
- Increase in **snow cohesion** with air **temperature** (Kobayashi, 1987)
    - **ice-bulb temperature** is closely related to the snow surface temperature.
    - accumulation of rime-ice (Lumbrazo et al., 2023)
- Canopy snow **unloading** is proportional to the **canopy snow load** (Hedstrom & Pomeroy, 1998)
- Canopy snow transport by **wind speed** (Katsushima et al., 2023)
    - shear stress may be a better indicator which corresponds to the drag force acting on the branch
- **Sublimation** is a function of **air temperature, wind speed and humidity** (Pomeroy et al., 1998)

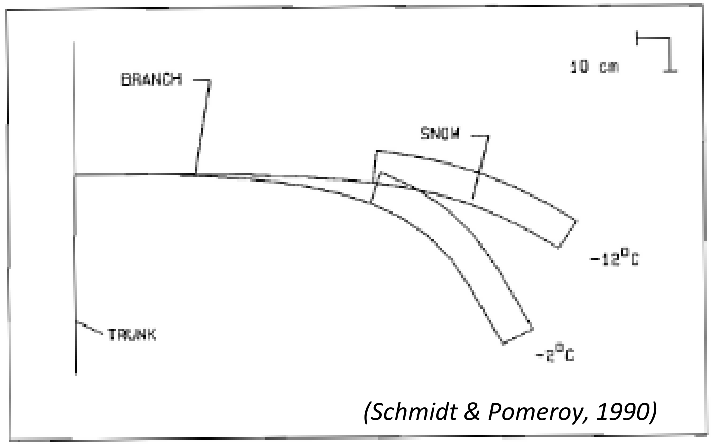


FIG. 3. Bending of the fir branch predicted by the segmented model, with an arbitrary snow load of 0.25 kg on each 10-cm segment from 90 cm to the tip, as temperature warms from −12 to −2°C.

Rime-ice observed on Vancouver Island, BC

Wind-induced unloading Fortress Mountain, AB

Research Plan

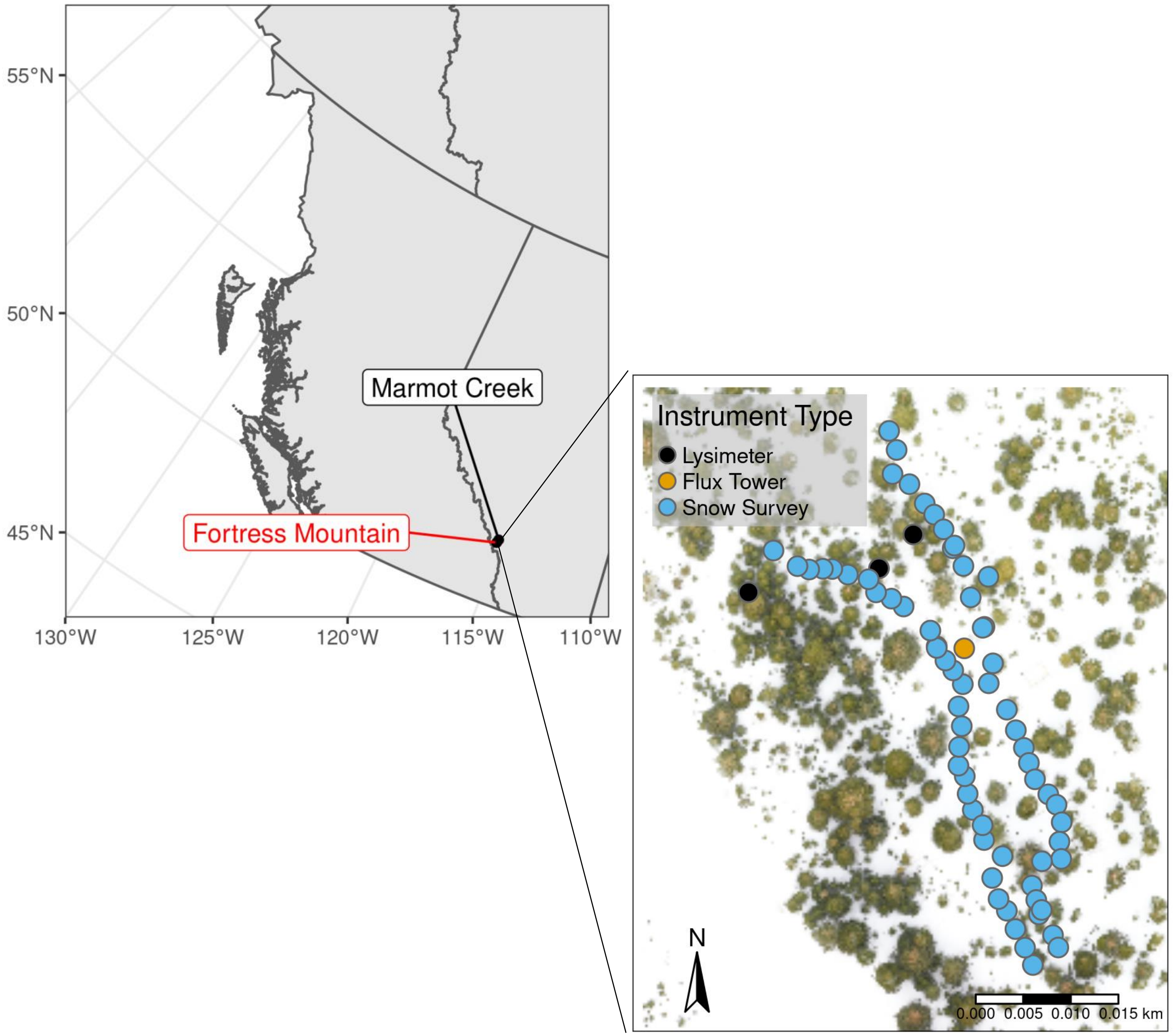
Objective: To advance understanding and prediction of canopy snow ablation

Research Questions:

- What are the dominant canopy snow ablation processes observed?
- Are there patterns in unloading associated with meteorological variables?

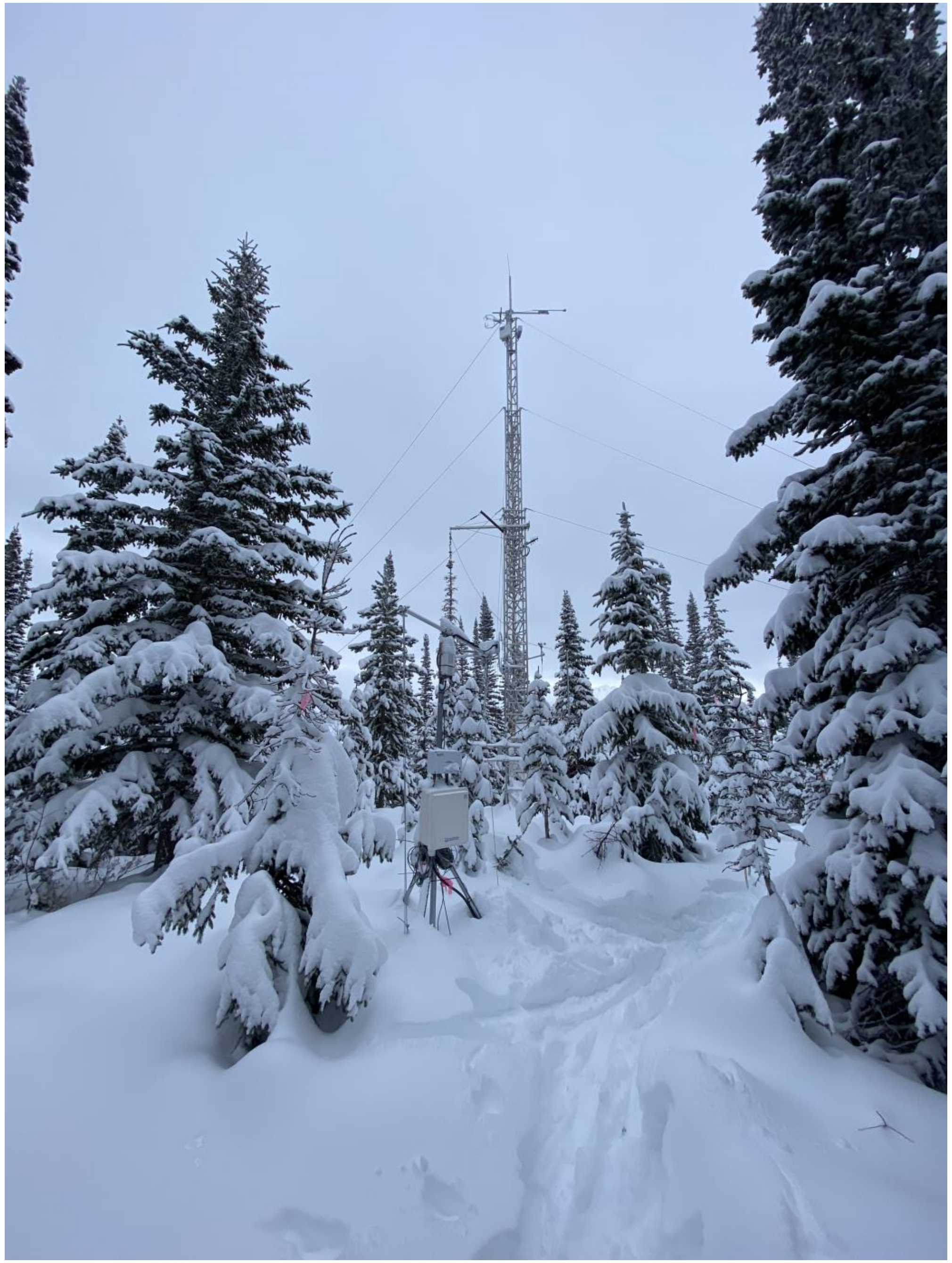
Study Site:

- Fortress Mountain Research Basin, Alberta
- Subalpine Ridge Forest, 2100 m asl.



Methods

- Flux tower measurements:
  - Temperature
  - Relative Humidity
  - Incoming + Outgoing SW/LW Radiation
  - Wind Speed
  - Precipitation to forest clearing
  - Eddy covariance system (high and low)



Methods

Snowfall Gauge

Snowfall Rate (q_{sf})

Subcanopy Lysimeter

Canopy Snow Unloading and Melt Rate (q_{unld}+q_{drip})

Weighed Tree Lysimeter

Canopy Snow Ablation (q_{unld}+q_{drip}+q_{sub}+q_{wind})

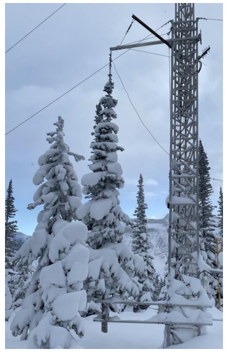
Canopy Snow Mass Balance

$$\frac{dW}{dt} = q_{sf} - q_{tf}(W) - q_{unld}(W) - q_{drip}(W) - q_{wind}^{veg}(W) - q_{sub}^{veg}(W)$$

$$\frac{dW}{dt} + q_{unld}(W) + q_{drip}(W) + q_{sub}^{veg}(W) = -q_{wind}^{veg}(W)$$

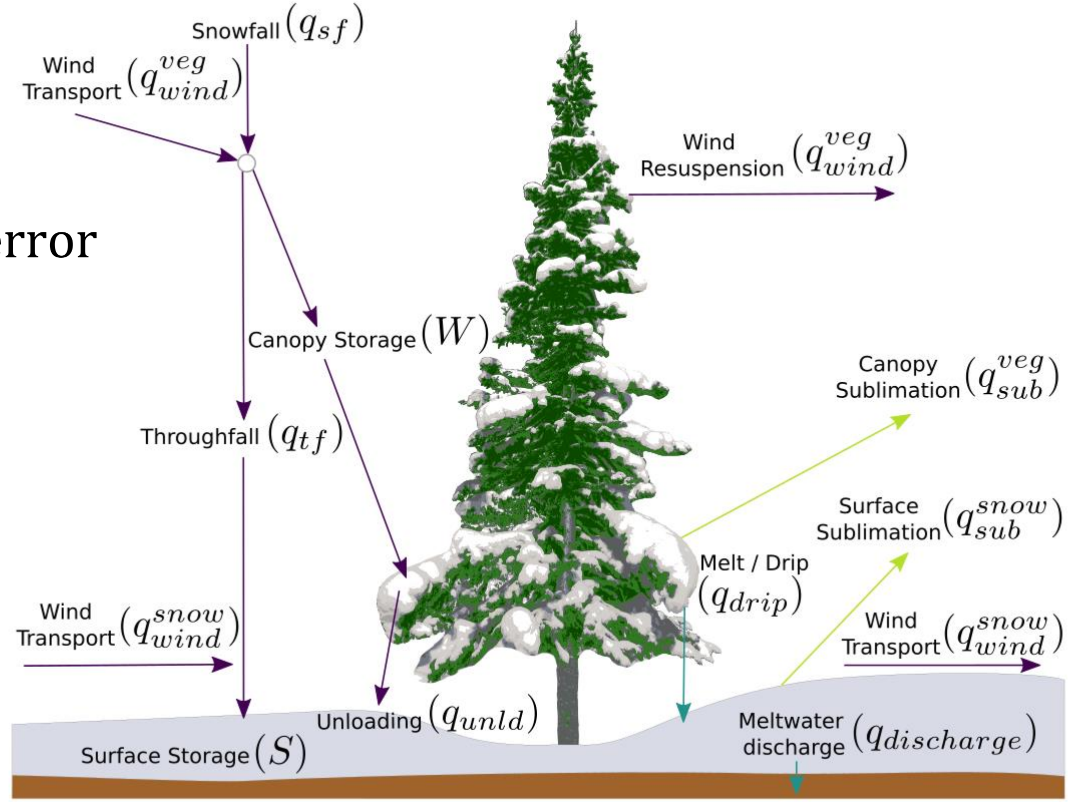
$$-\frac{\Delta W}{\Delta t} - q_{unld}(W) - q_{drip}(W) - q_{sub}^{veg}(W) = \text{residual} + \text{error}$$

Weighed Tree



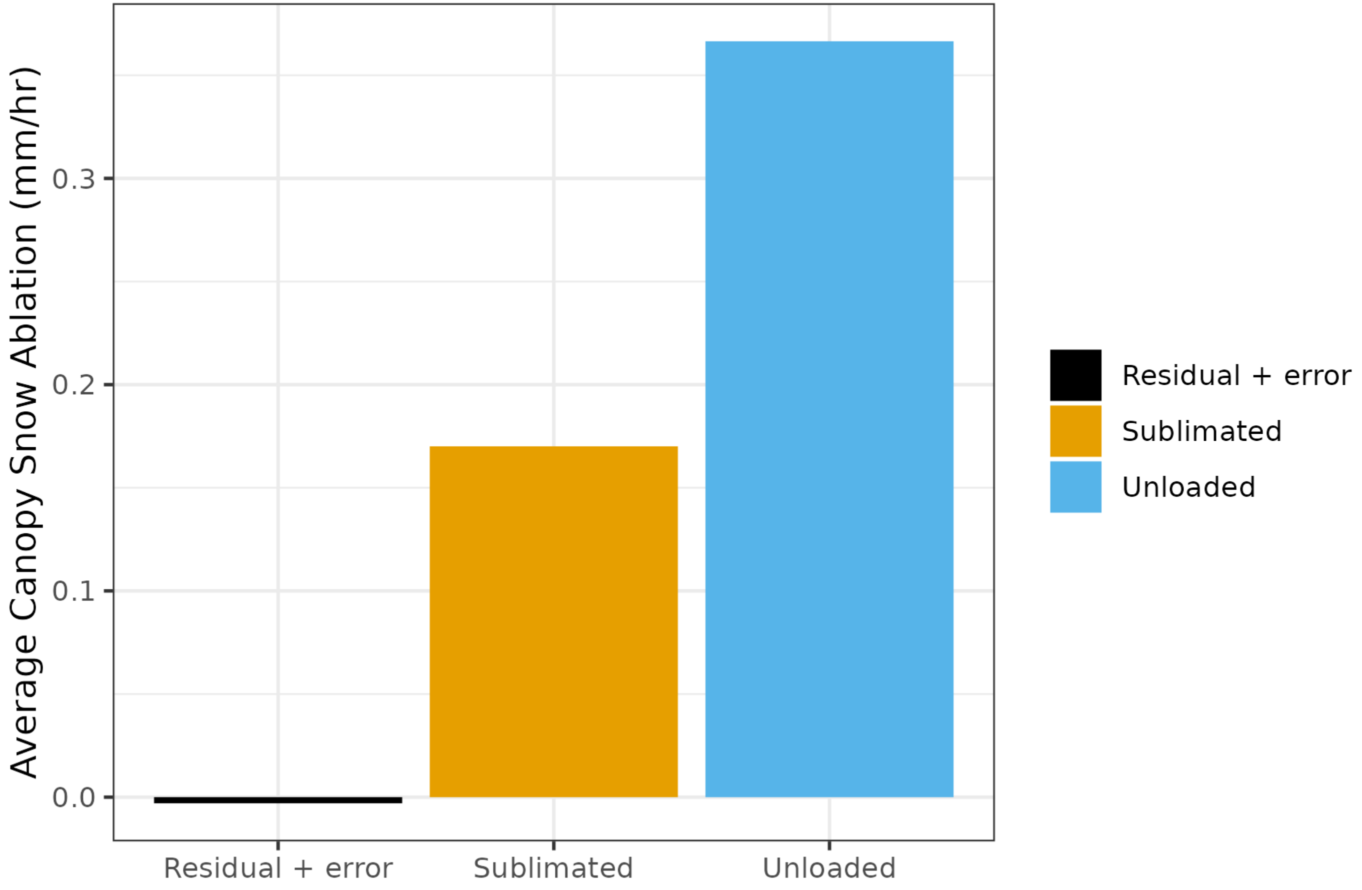
Subcanopy Lysimeter

Modelled



What are the dominant canopy snow ablation processes observed?

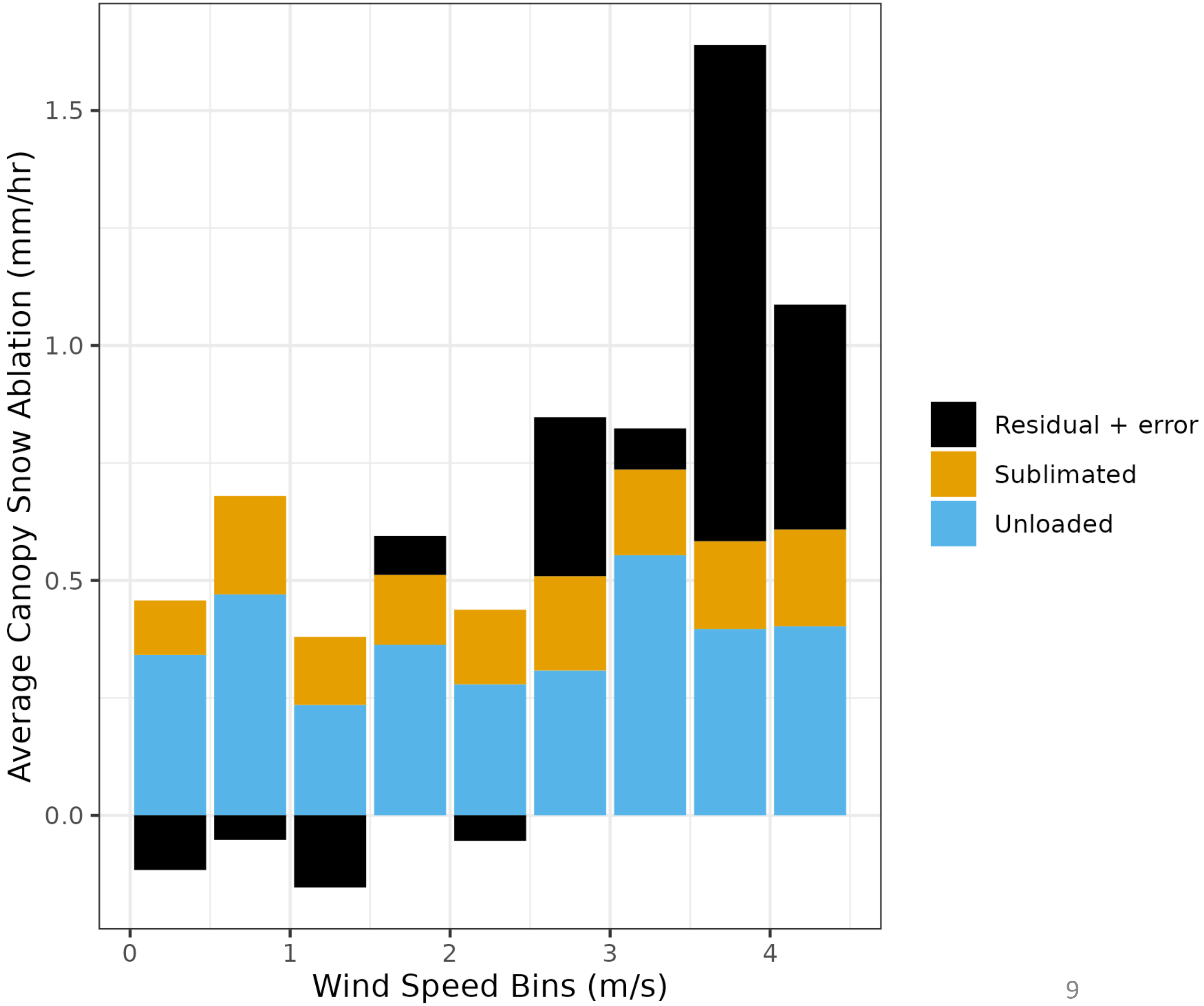
- Looking at periods over two winters where snow is in the canopy without precipitation
- Unloading is a large fraction of the canopy snow ablation mass balance
- Low overall residual as positive and negative balance



Pos. residual = weighed tree loss > subcanopy lysimeter + sublimation
Neg. residual = weighed tree loss < subcanopy lysimeter + sublimation

Does the dominant ablation process change with wind speed?

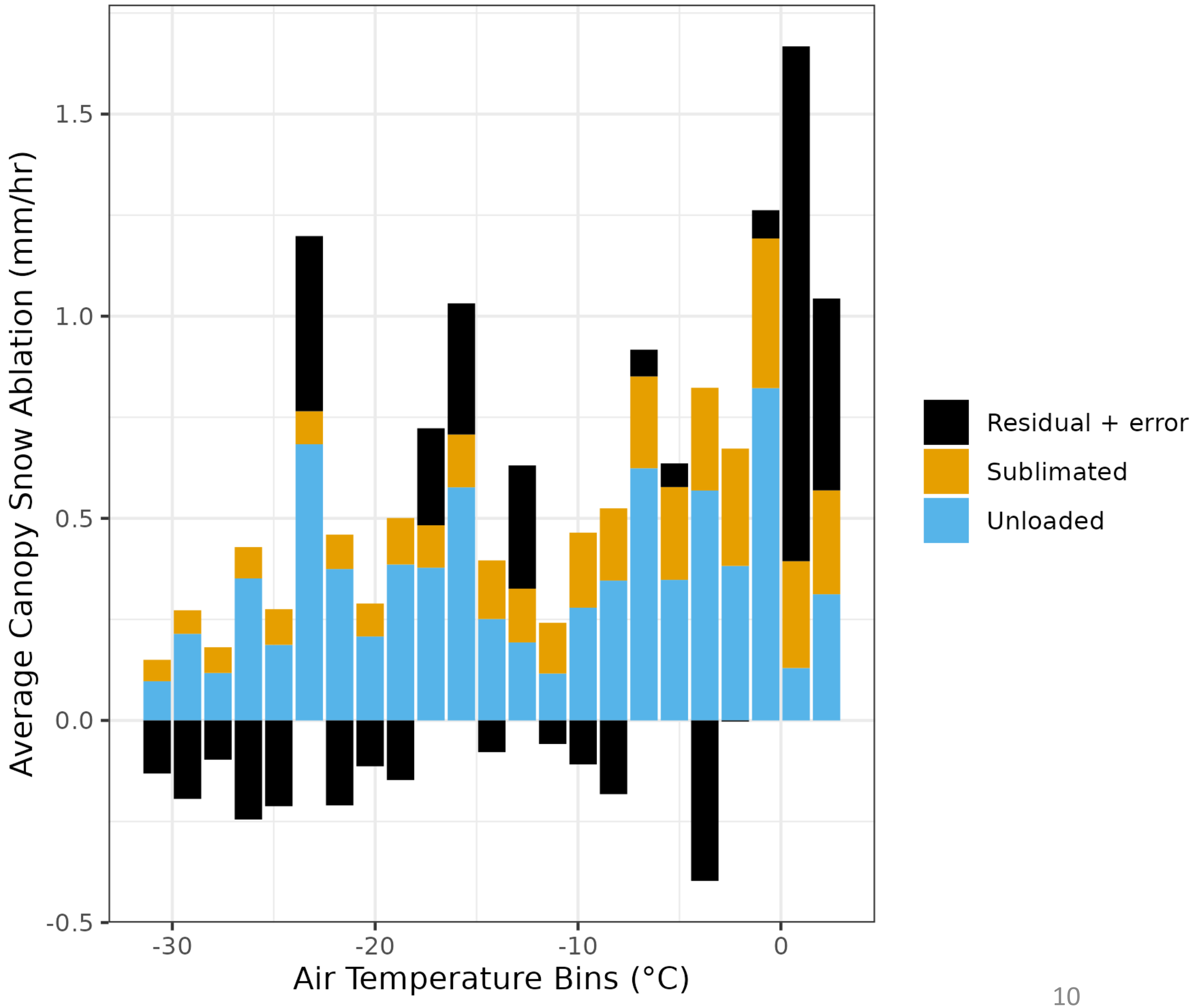
- Increase in residual is associated with higher wind speed bins
- Potentially due to increase in entrainment (wind redistribution)



Pos. residual = weighed tree loss > subcanopy lysimeter + sublimation
Neg. residual = weighed tree loss < subcanopy lysimeter + sublimation

Does the dominant ablation process change with air temperature?

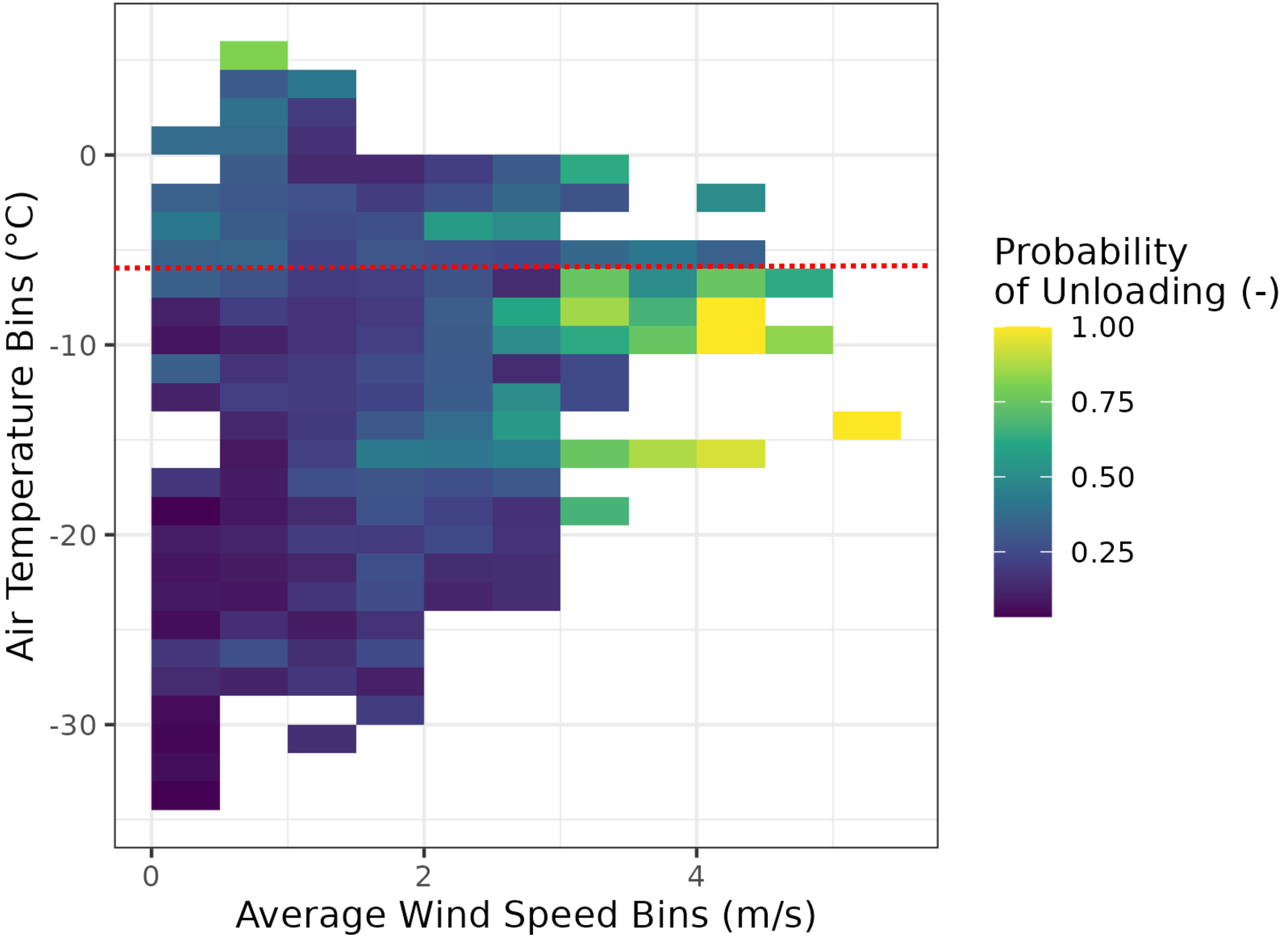
- High residual observed for temperatures above 0 °C
  - Problems with the troughs loosing meltwater above 0 °C
- High positive residual at colder air temperatures is likely due to wind redistribution



Pos. residual = weighed tree loss > subcanopy lysimeter + sublimation
Neg. residual = weighed tree loss < subcanopy lysimeter + sublimation

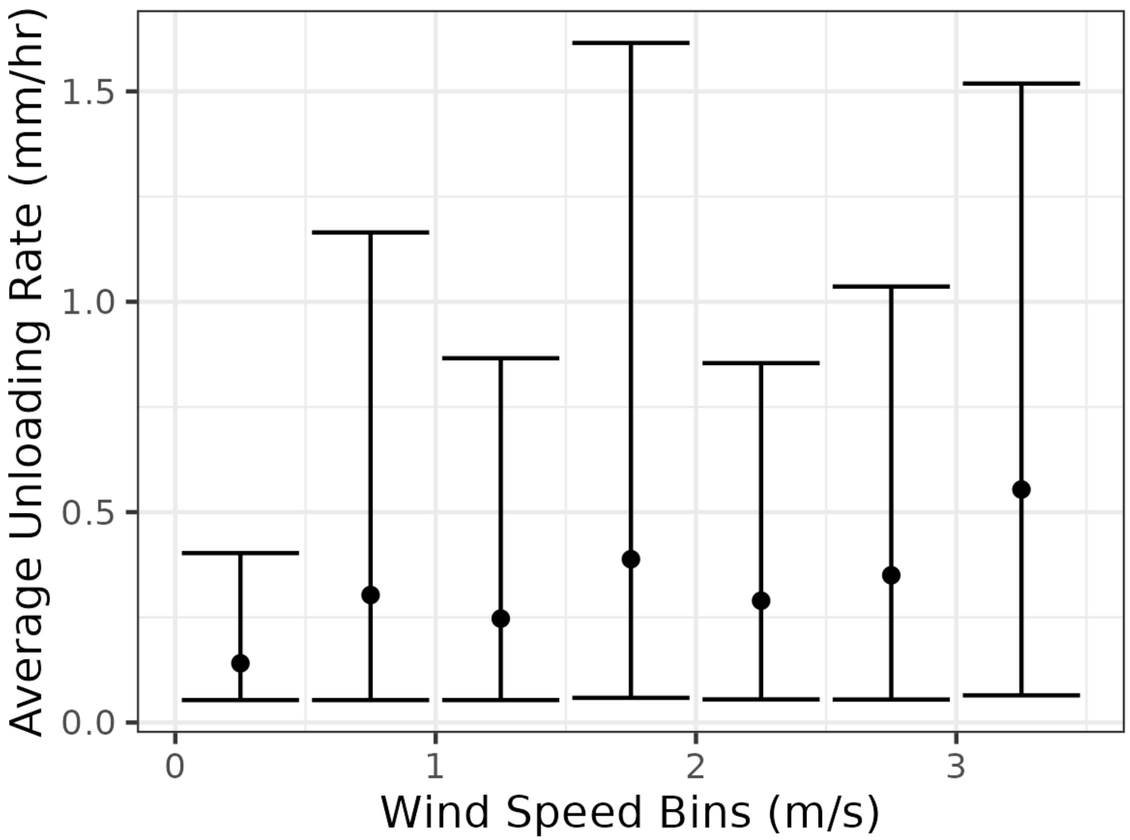
Are there patterns in the probability of unloading associated with meteorological variables?

- The probability of unloading was calculated as:
  - # of unloading events / total # of occurrences of each bin
- The probability of unloading is highest when wind speeds are high and the air temperature is cold
- Unloading at air temperatures above -6 °C shows a weaker association with wind speed
- Also experimented with ice-bulb and shear stress here but showed very similar results



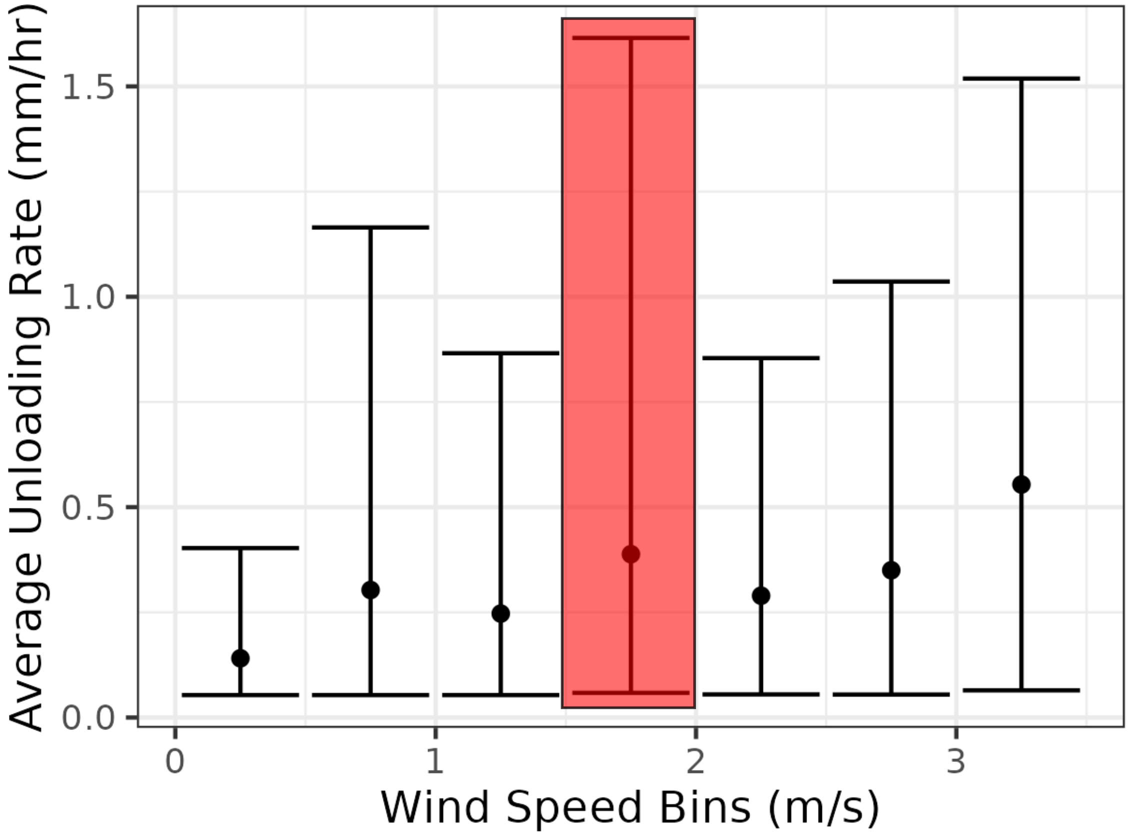
The Influence of Wind Speed on Unloading

- To isolate the wind speed effect records were filtered to air temps below -6 °C
- Little to modest increase in the average and peak unloading rate with wind speed



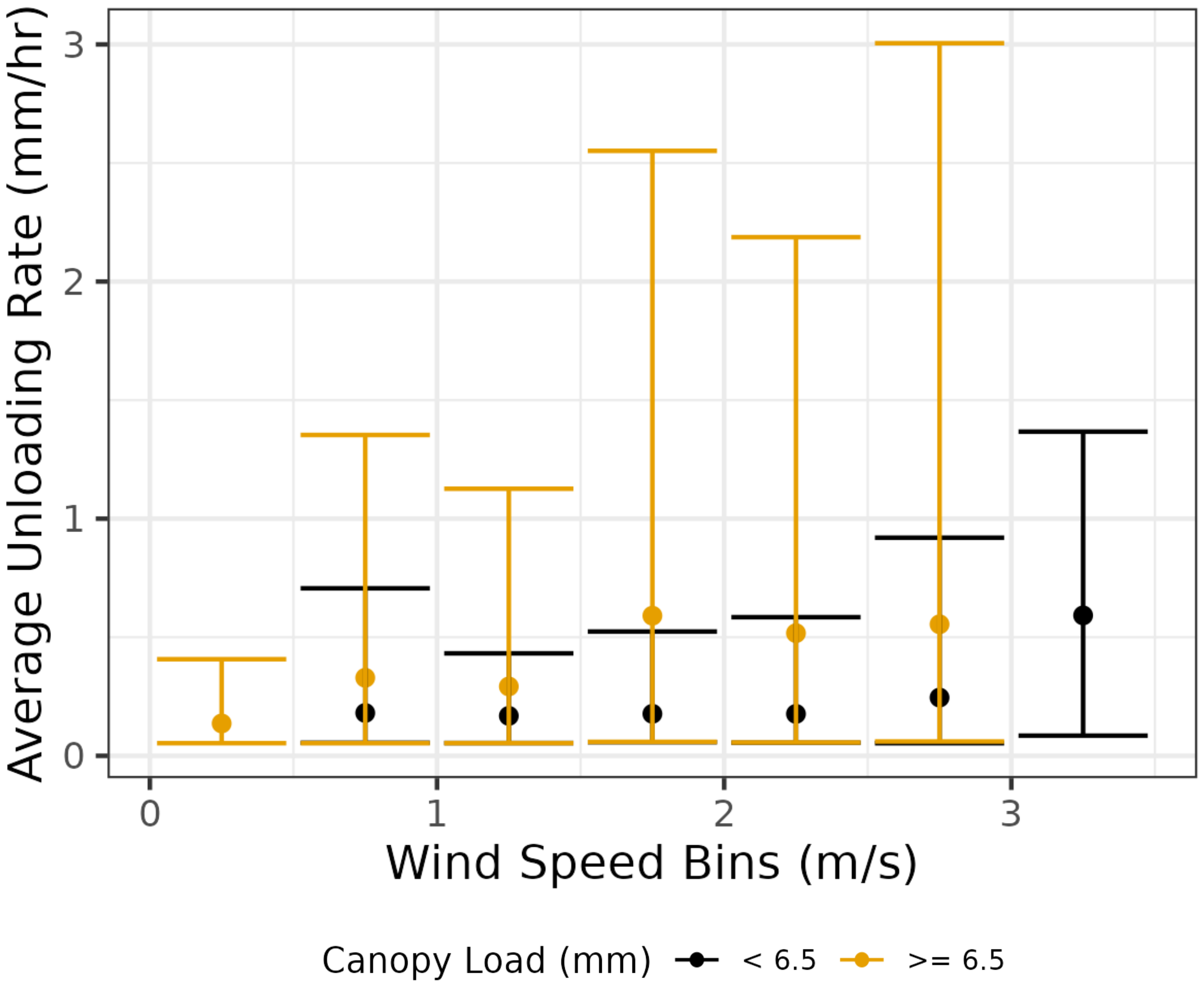
The Influence of Wind Speed on Unloading

- To isolate the wind speed effect, focus on observations with air temp. below -6 °C
- Lower average unloading rates were associated with lower wind speed bins
- High unloading rates observed within lower wind speed bins were associated with snow loads near peak canopy snow capacity



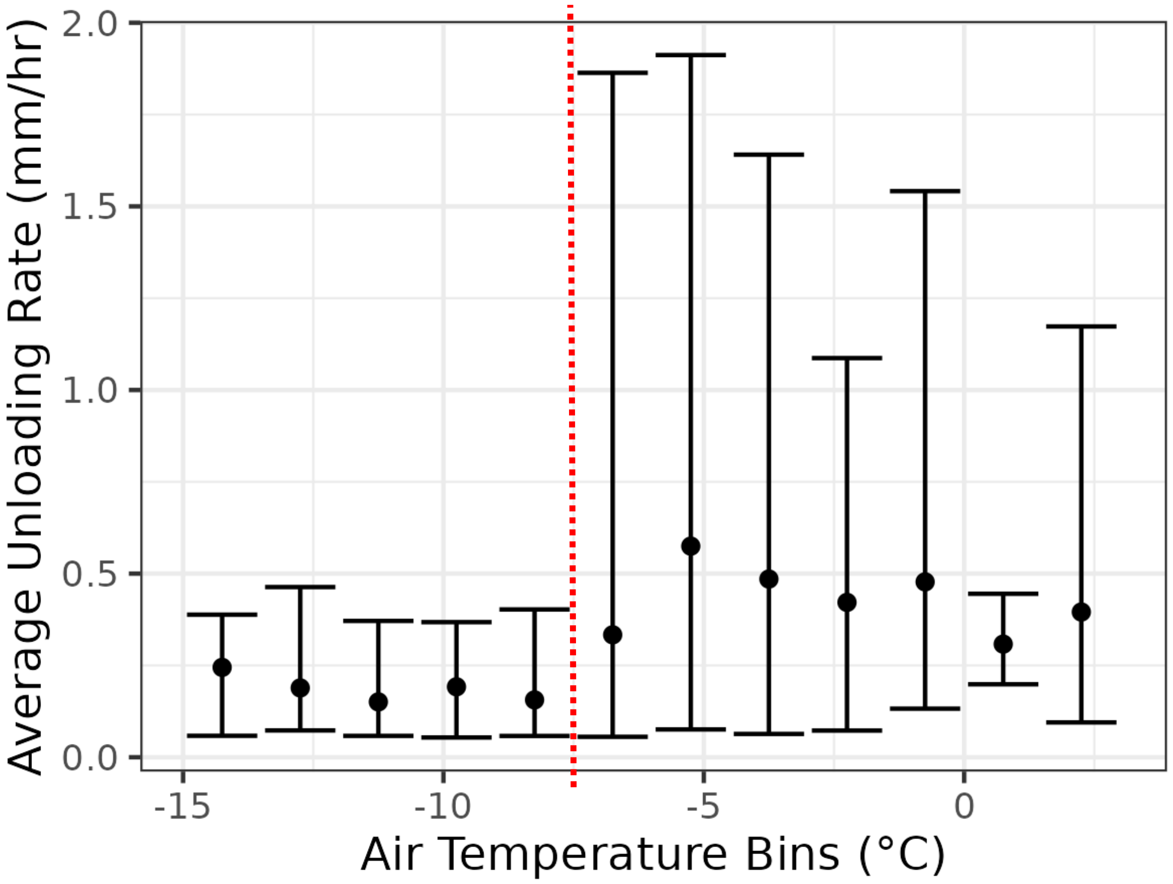
The Influence of Wind Speed on Unloading

- Observations were classified into canopy snow loads above or below 6.5 mm
- For snow loads < 6.5 mm in the canopy:
  - Lower unloading rates were observed with lower wind speeds Higher unloading rates were observed with higher wind speeds
- For snow loads >= to 6.5 mm in the canopy:
  - High unloading rates were observed for all wind speeds
- When there is more snow in the canopy it may take less force to remove it



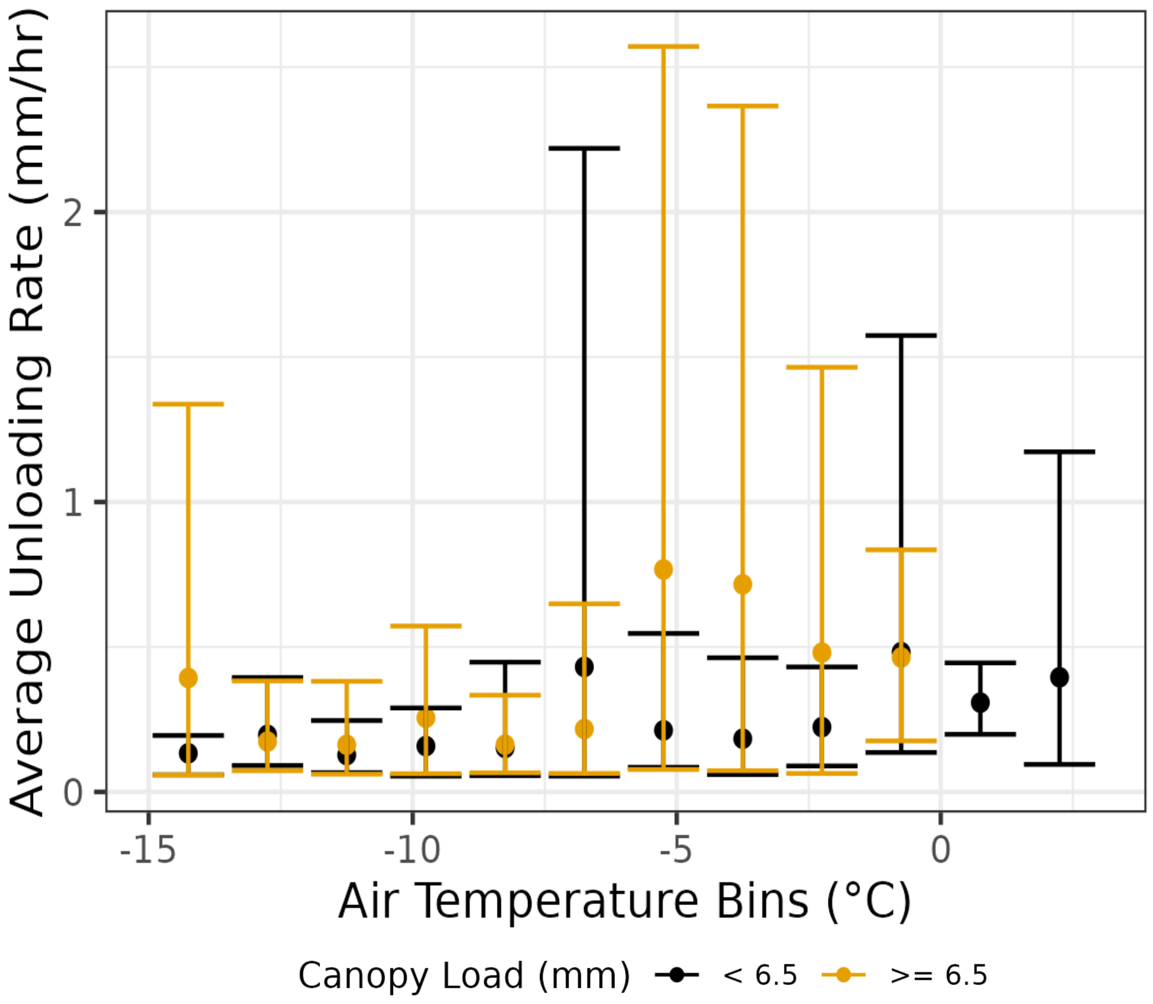
The Influence of Temperature on Unloading

- Wind speed < 1 m/s
- Higher unloading rates were observed with air temperatures temperatures > -7.5 °C



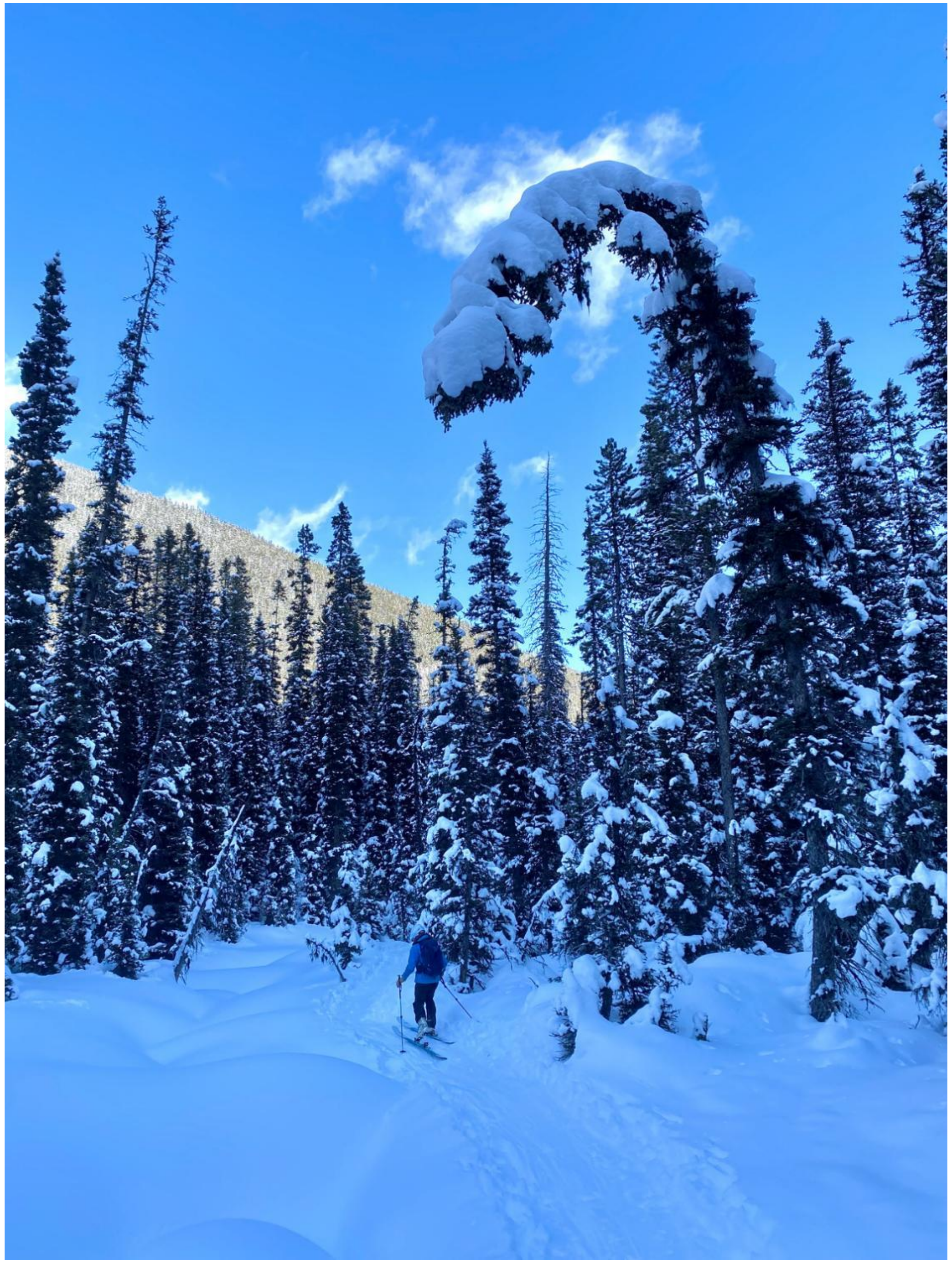
The Influence of Temperature on Unloading

- Wind speed < 1 m/s
- Higher unloading rates were observed with air temperatures temperatures > -7.5 °C
- The relationship is not as clear when looking at low vs. high canopy loads.
    - high rates of unloading at low temps with high canopy load
    - low rates of unloading at high temps with low canopy load



Conclusions

- Unloading makes up a large fraction of canopy snow ablation for this windswept subalpine forest
- An increase in the residual term was observed at higher wind speeds indicating wind entrainment or resuspension of canopy snow
- Higher unloading rates were positively associated with wind speed when air temperatures were less than -6 °C and the relationship was stronger for lower canopy snow loads
- Increased unloading rates were observed for air temperatures above -7.5 °C when there was little to no wind
- The high residuals for unloading above 0 °C suggest rates of melt and drip may be higher than observed



Questions?

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