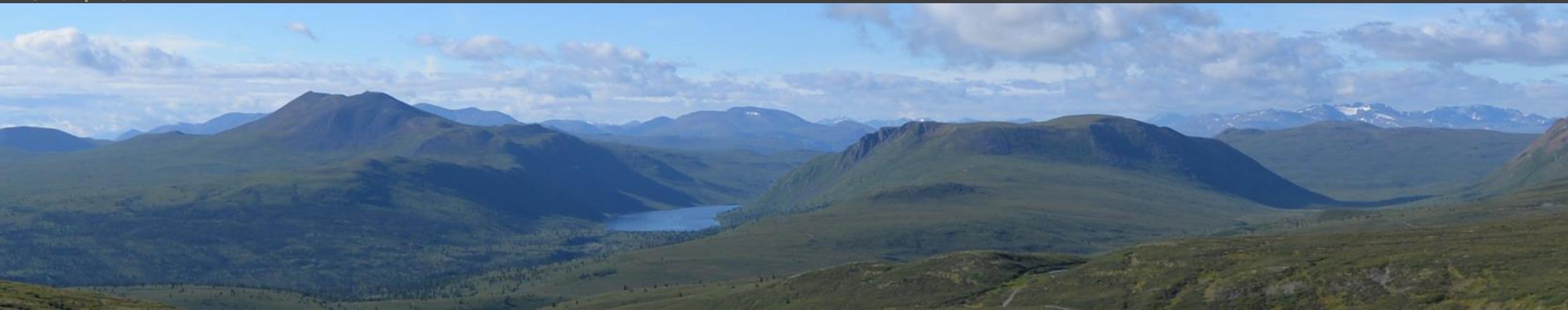


# Hydrological implications of vegetation change in a subarctic, alpine catchment, Yukon Territory, Canada

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[Introduction](#)

[Research Objectives](#)

[Study Sites](#)

[Instrumentation](#)

[Results](#)

[Discussion: Hydrological Implications](#)

[Conclusions](#)

[References](#)

[Climate](#)

[Albedo](#)

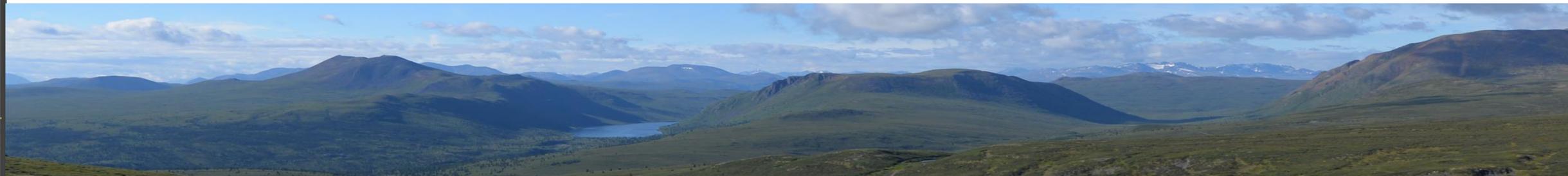
[Surface Energy Partitioning](#)

[Interannual ET](#)

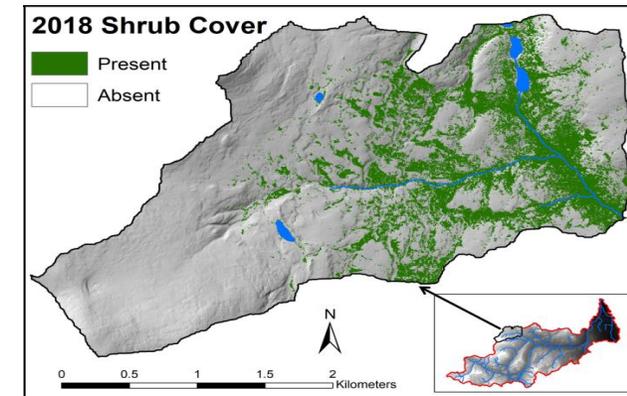
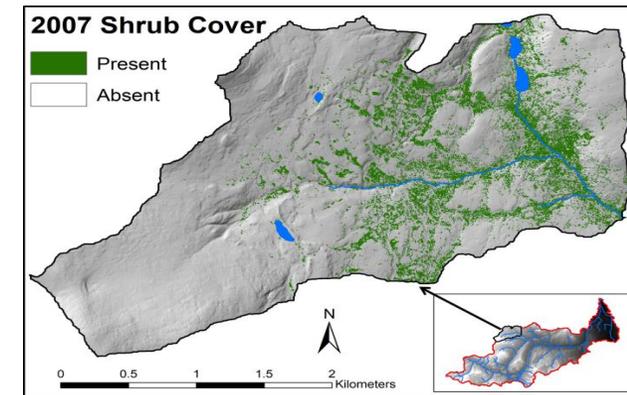
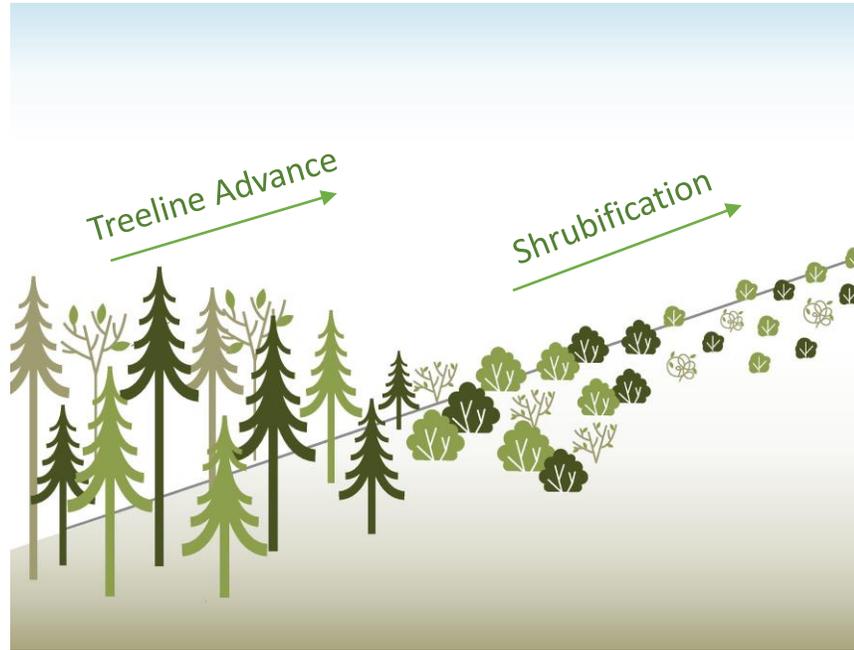
[Seasonal ET](#)

[T:ET](#)

[Contact Information](#)



- The arctic and subarctic are rapidly warming, resulting in well documented and accelerating hydrological changes across the circumpolar north.
- While the impacts of warming cause cascading hydrological and ecological impacts that include degrading permafrost<sup>3</sup>, declining glaciers<sup>4</sup>, and changes to precipitation quantity, timing and phase<sup>5, 6</sup> the most immediate ecosystem response is alteration to vegetation community composition density, distribution, and phenology<sup>7-11</sup>.
- Specifically, warmer temperatures have allowed the **expansion of shrubs** across high latitude ecosystems<sup>12-21</sup>.
- Trends of treeline advancement and infilling at high latitudes have also been documented<sup>22-24</sup>.



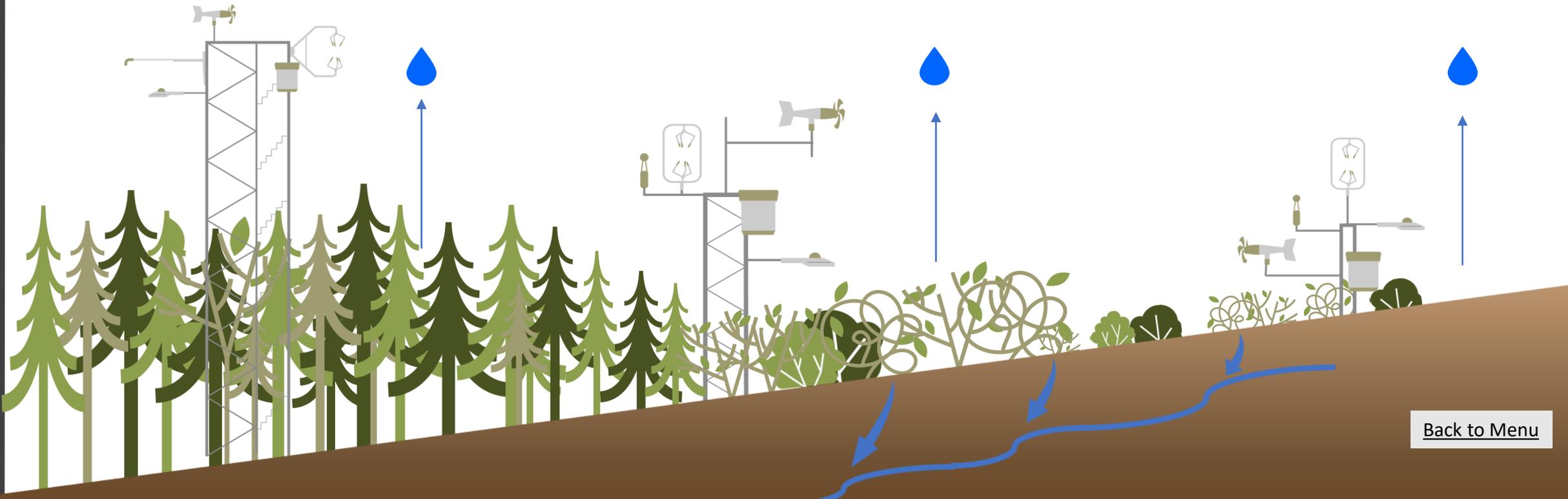
(Leipe & Carey, in review)



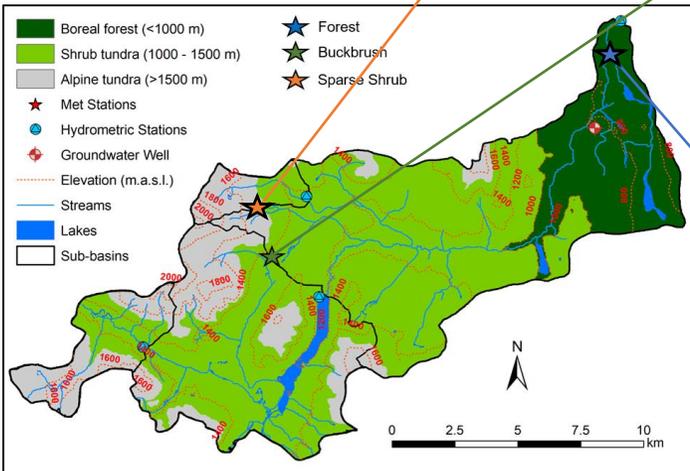
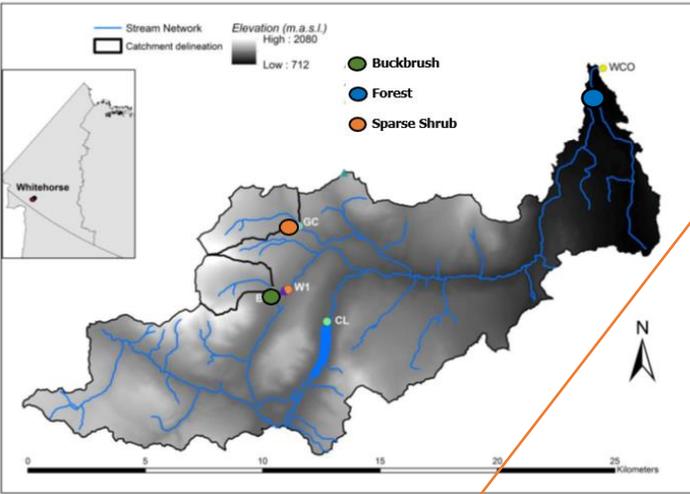
The objective of this study is to advance our understanding of surface energy partitioning and ET dynamics across an ecological functional gradient within a heterogeneous, subarctic, alpine watershed. This provides a unique opportunity to compare the potential impacts of shifting ecosystem types within a local geographic area.

Here, we present 6 years of observations of surface-atmosphere interactions from three subarctic sites across a thermal gradient and varying vegetation cover spanning boreal forest to sub-alpine taiga to address the following questions:

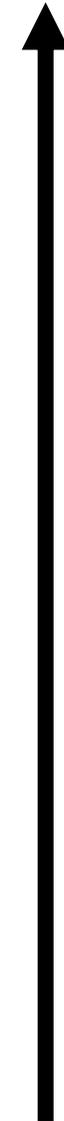
1. How do vegetation type and structure influence the **timing, magnitude, and partitioning of ET fluxes** among sites?
2. How will future changes to climate (increased temperatures and changing precipitation regimes) affect ET magnitude and partitioning?



Three sites were chosen in Wolf Creek Research Basin, ~15 km south of Whitehorse, Yukon Territory, along an elevational gradient representing a space-for-time analogy of vegetation change:



Increasing  
Elevation



**Sparse Shrub**  
1450 masl  
Willow and Birch Shrubs  
<~0.5m

**Buckbrush**  
1250 masl  
Willow and Birch Shrubs  
<~1-3 m

**Forest**  
750 masl  
White Spruce  
~12-20 m

Three sites were chosen in Wolf Creek Research Basin, ~15 km south of Whitehorse, Yukon Territory, along an elevational gradient representing a space-for-time analogy of vegetation change:

### Eddy Covariance Towers

- Buckbrush + Sparse Shrub
  - Open Path
  - April to October (2015-2020)
- Forest
  - Closed Path
  - Year Round (2017-2020)



Increasing  
Elevation

**Sparse Shrub**  
1450 masl  
Willow and Birch Shrubs  
<~0.5m

### Sap Flow Sensors

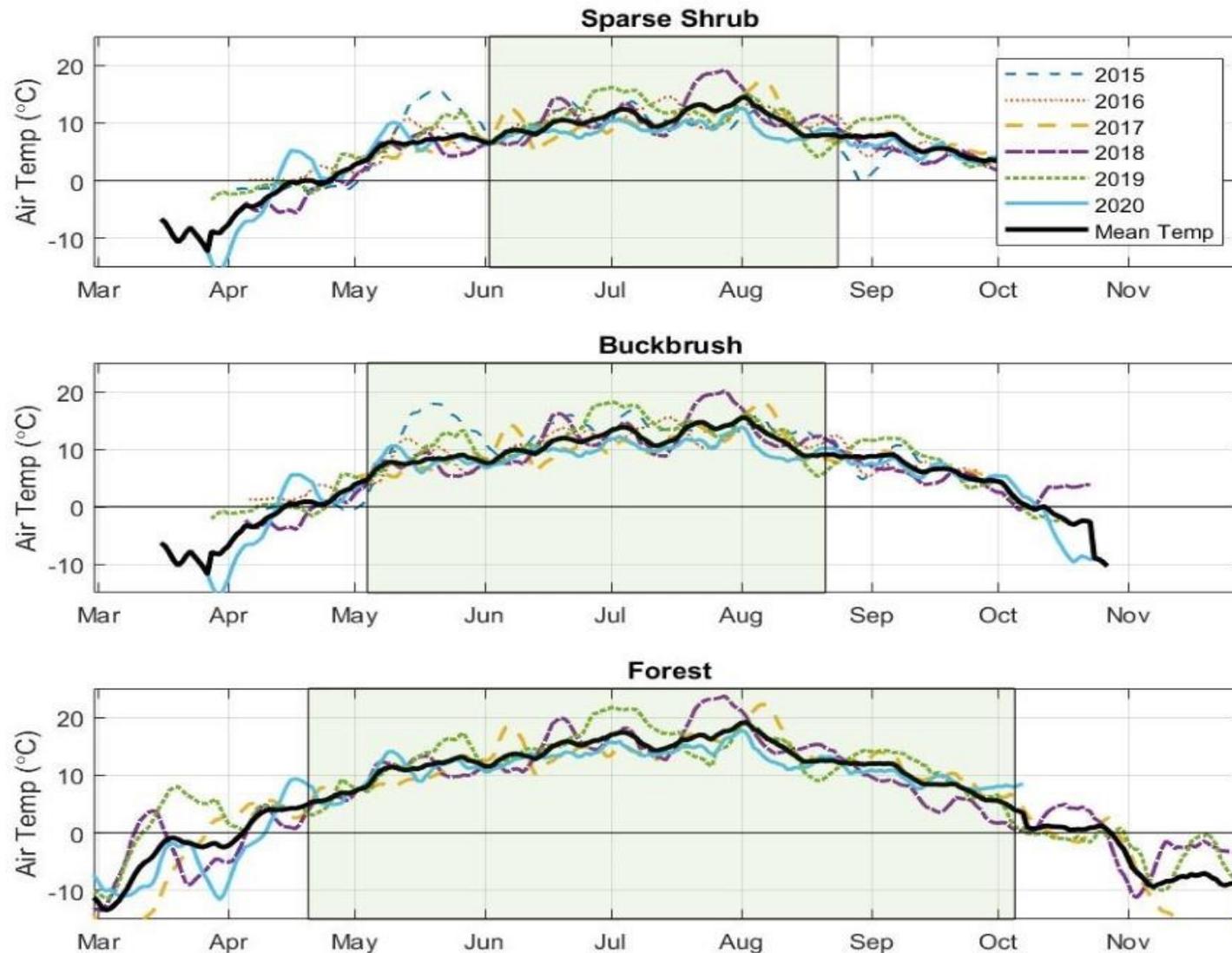
- Buckbrush
  - Dynamax EXO-Skin Sensors (2019-2020)
  - 4 Birch
  - 4 Willow
- Forest:
  - Granier Style Thermal Dissipation Probes (2018-2020)
  - 22 White Spruce



**Buckbrush**  
1250 masl  
Willow and Birch Shrubs  
<~1-3 m



**Forest**  
750 masl  
White Spruce  
~12-20 m



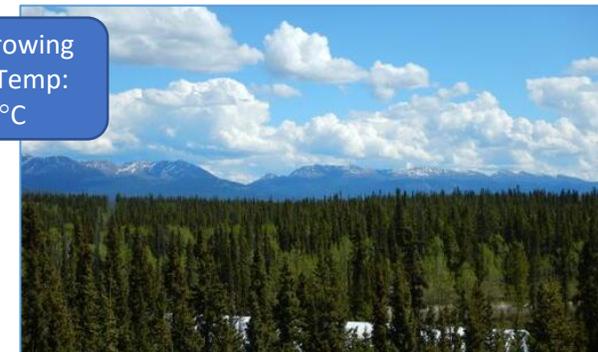
Mean Growing  
Season Temp:  
7.2°C



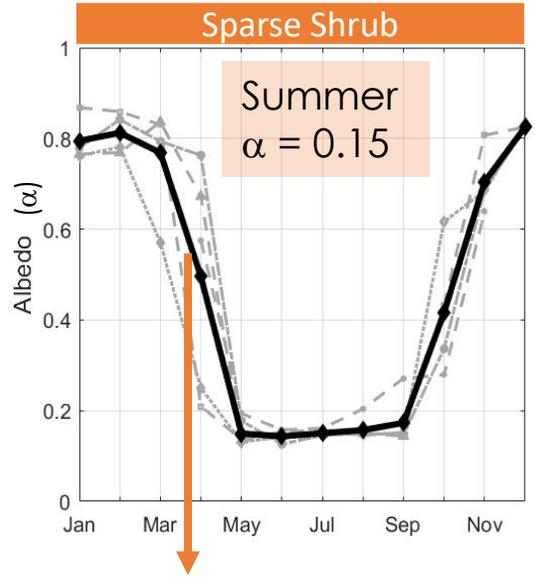
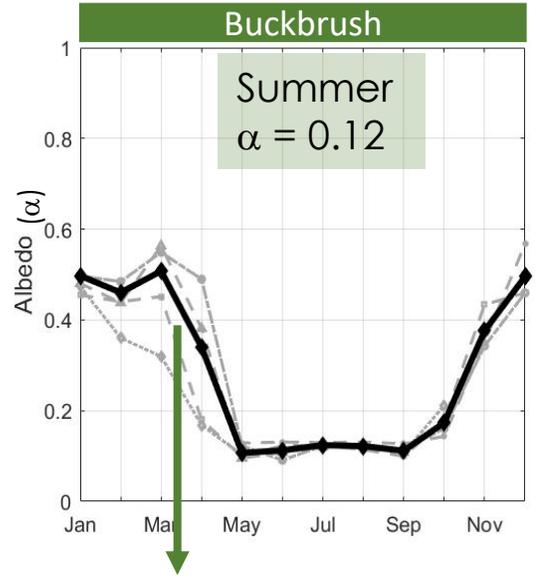
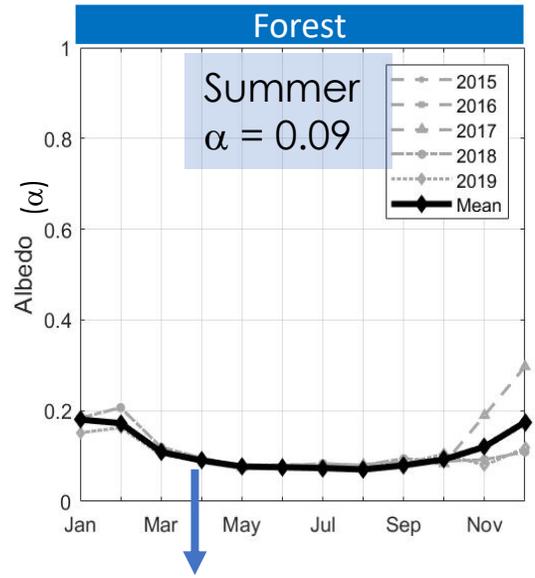
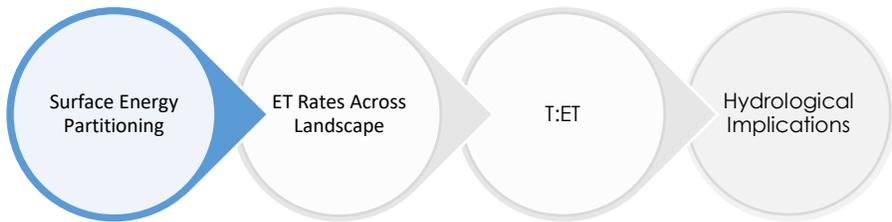
Mean Growing  
Season Temp:  
8.5°C



Mean Growing  
Season Temp:  
11.1°C



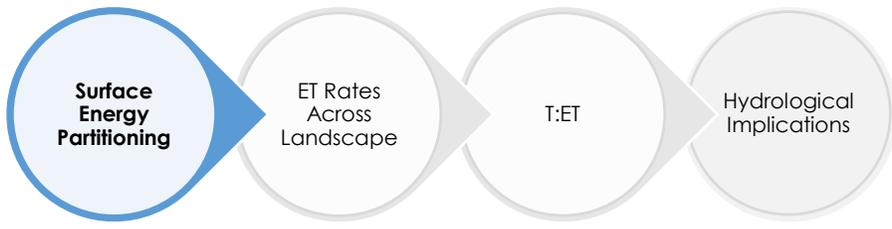
- 7-day moving mean daily temperatures for Forest (top), Buckbrush (middle) and Sparse Shrub (bottom) for all available years of data. Shaded green regions show mean growing season. The start of the growing season was defined as the first of at least three consecutive days with net ecosystem exchange (NEE) less than  $0 \text{ g C m}^{-2}$  and the end of the growing season was defined as the first day where NEE was greater than  $0 \text{ g C m}^{-2}$



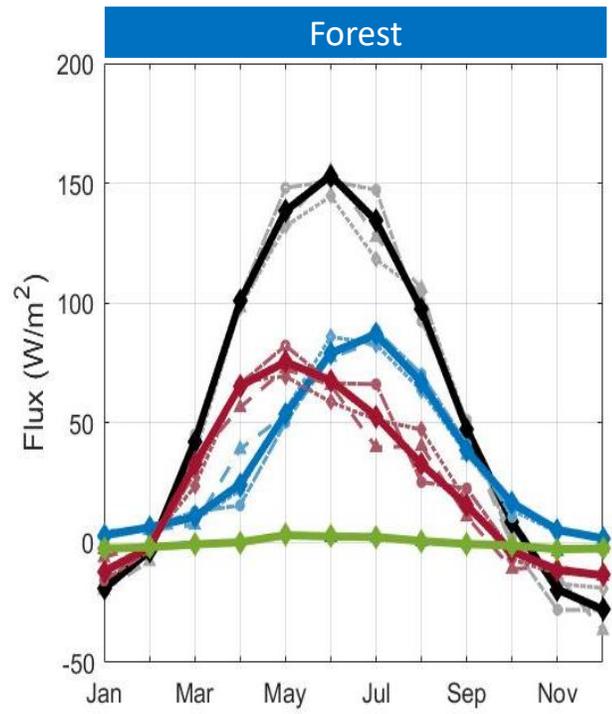
- June to August albedo increased with increasing elevation and decreasing vegetation height, with mean mid-day (11:00-14:00) albedo of 0.09, 0.12 and 0.15 at the Forest, Buckbrush and Sparse Shrub, respectively.

- At Forest, albedo was relatively consistent, ranging from 0.08 in July to a maximum of 0.21 in December. In contrast, intra- and inter-annual variability was large at the shrub sites, where peak mean daytime albedo during the snow-covered months was 0.50 at Buckbrush and 0.82 at Sparse Shrub.

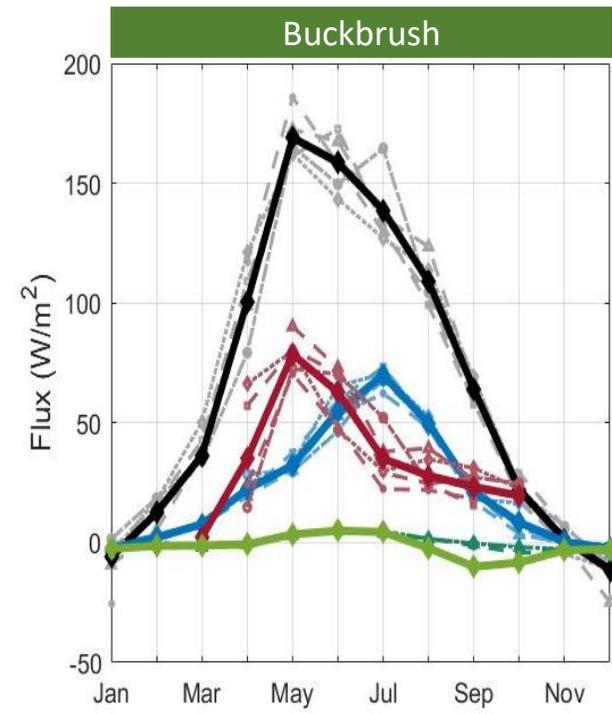
- Although the dominant species cover at Buckbrush and Sparse Shrub were similar, Birch and Willow shrubs were on average 0.42 and 0.79 m taller at Buckbrush than Sparse Shrub.



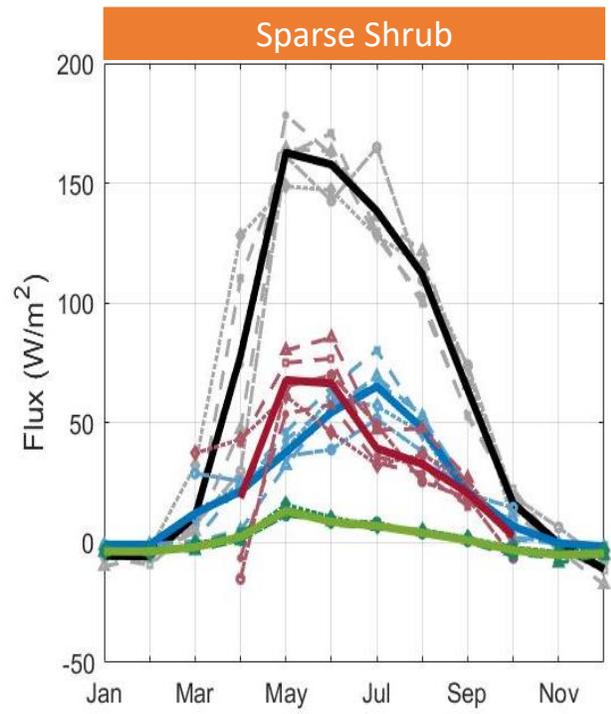
- All sites had a higher sensible heat flux (H) early in the season and then shifted to more latent heat ( $\lambda_v E$ ) dominated as the season progressed. The transition from H to  $\lambda_v E$  occurred later in the year with increasing elevation, on average occurring on May 31, June 14 and June 29 at Forest, Buckbrush and Sparse Shrub respectively.
- From May to September, mean  $\lambda_v E/R_n$  at Forest was  $0.47 (\pm 0.01)$ , while  $\lambda_v E/R_n$  was similar between Buckbrush and Sparse Shrub with  $\lambda_v E/R_n$  of  $0.31 (\pm 0.02)$  and  $\pm 0.04$  respectively.
- Generally, variability in all interannual energy balance terms increased with elevation and reduced vegetation



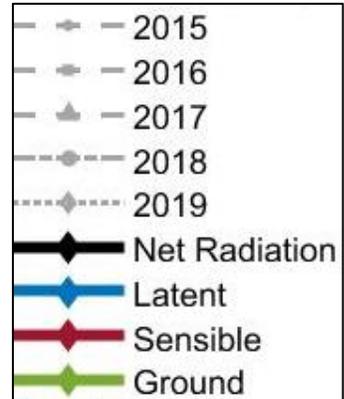
May to Sept  
 $\beta = 0.81 (\pm 0.12)$

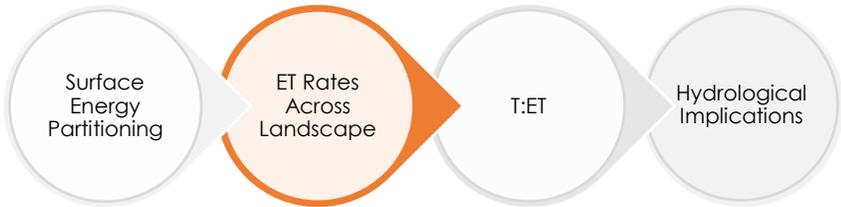


May to Sept  
 $\beta = 1.31 (\pm 0.12)$

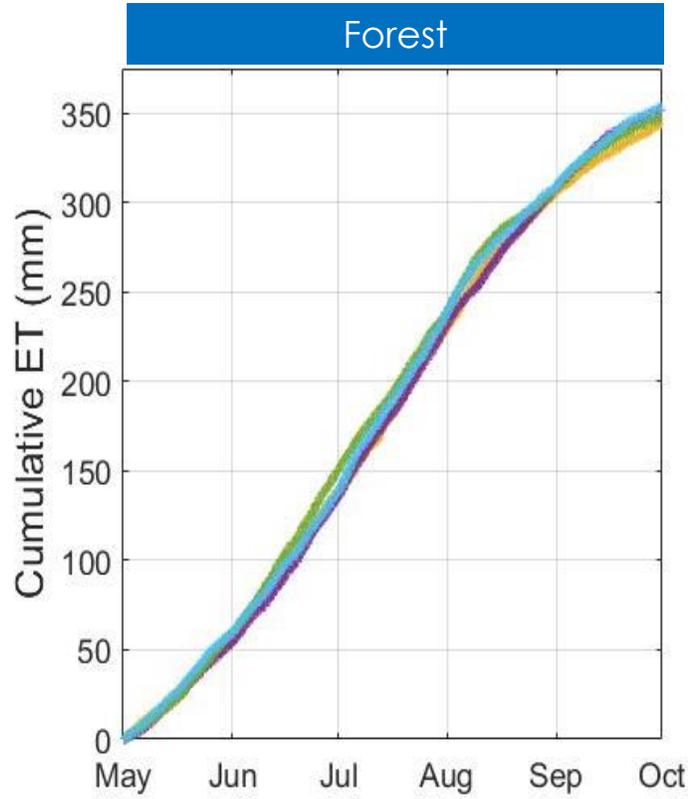


May to Sept  
 $\beta = 1.12 (\pm 0.31)$

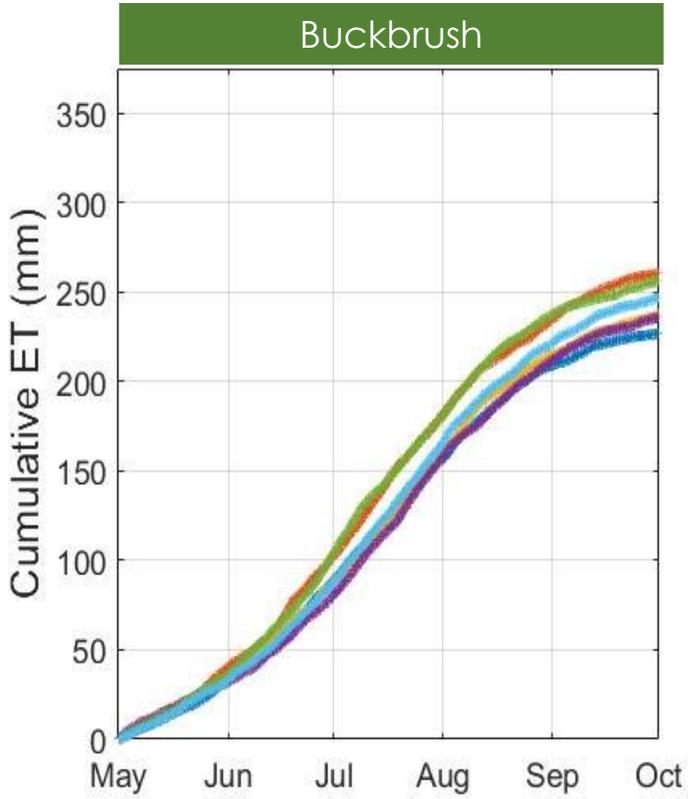




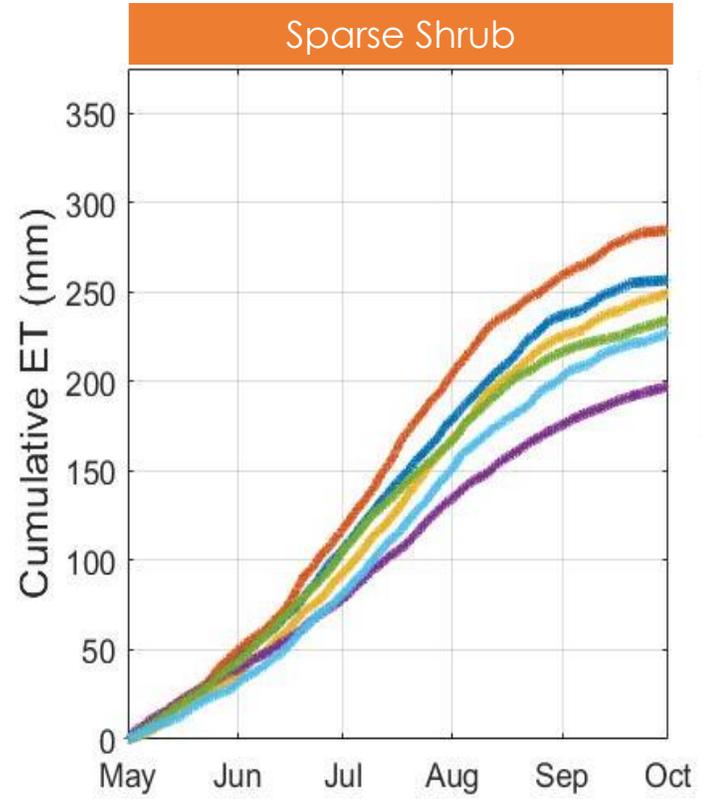
- Annual growing season ET declined with increasing elevation, while interannual variability increased.
- From 2015-2020 at the shrub sites, total growing season ET was highest in 2016, with cumulative ET higher at Sparse Shrub (285 mm) than Buckbrush (261 mm). This year had slightly higher mean May to September air temperature and rainfall.
- Conversely, in the driest year (2018), where the shrub sites only received 182 mm of rainfall, we observed the lowest amount of ET at the Sparse Shrub (192 mm), while ET at Buckbrush was close to the interannual mean of 236 mm. Although 2020 was very wet, receiving 62 mm and 97 mm more rainfall than average from May to September, cumulative ET losses at all sites were close to the mean over the study years.



 349 ( $\pm 4$ ) mm  
2.3 mm/day

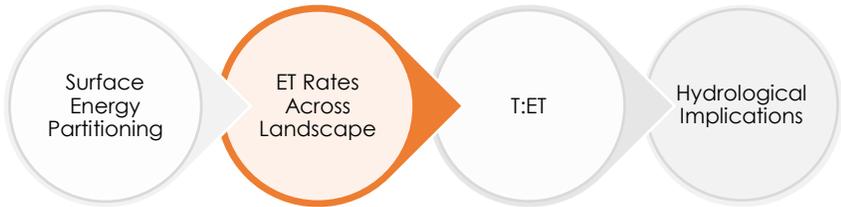


 244 ( $\pm 10$ ) mm  
1.6 mm/day

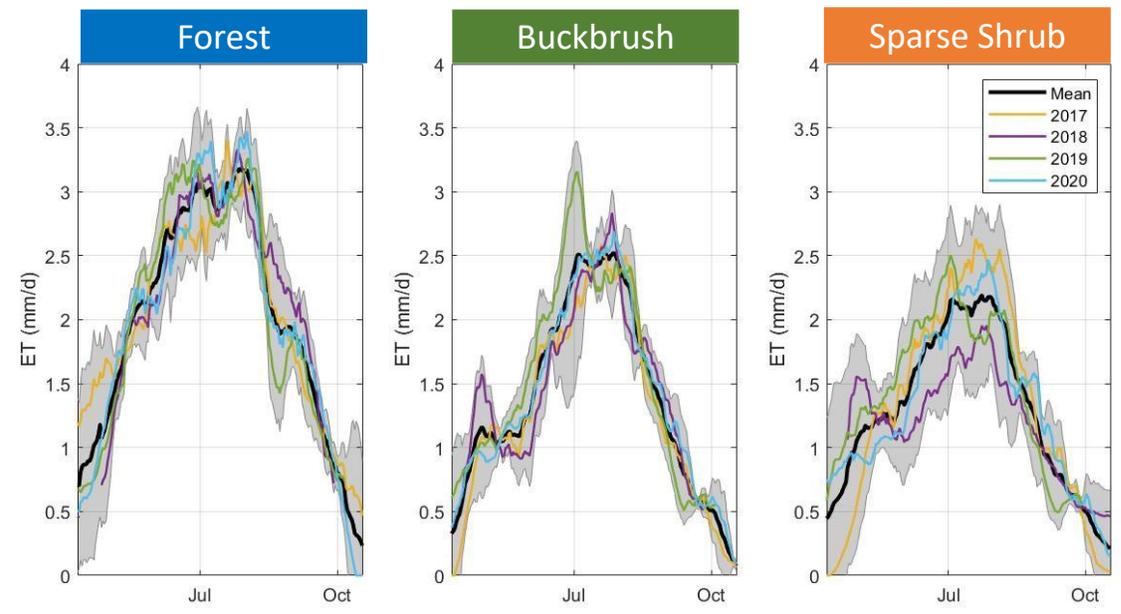
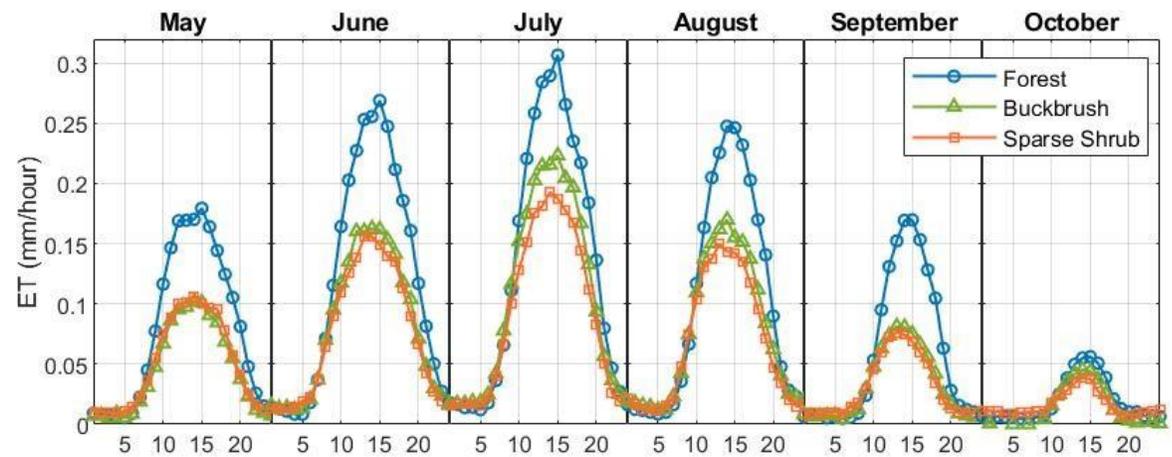


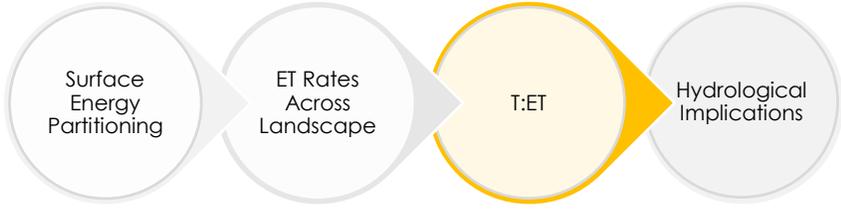
 226 ( $\pm 22$ ) mm  
1.5 mm/day



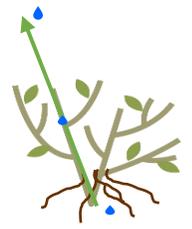
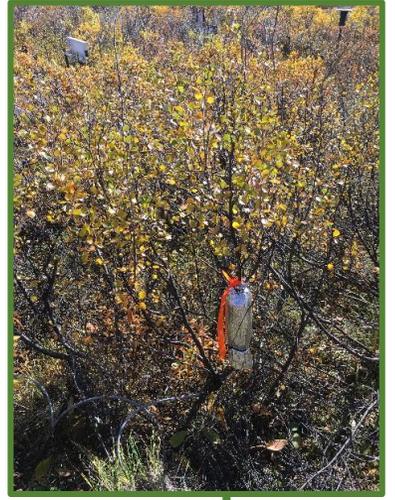
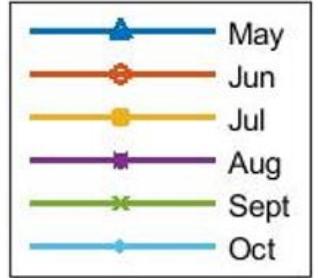
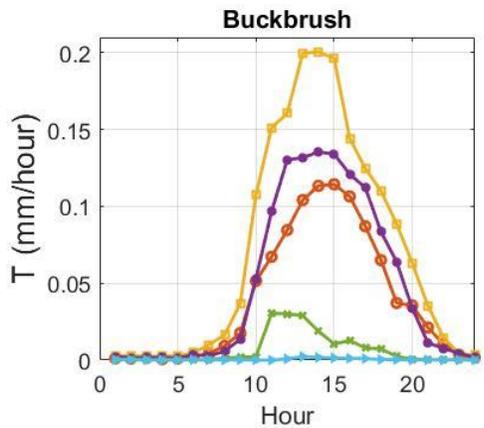
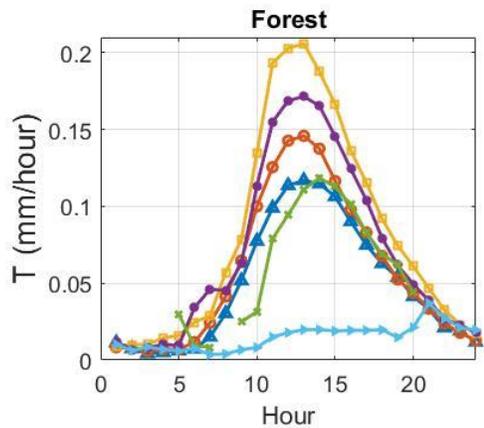
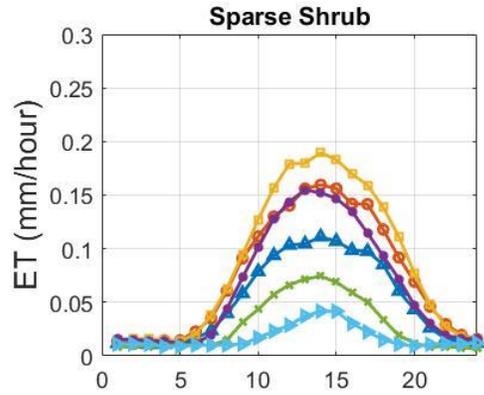
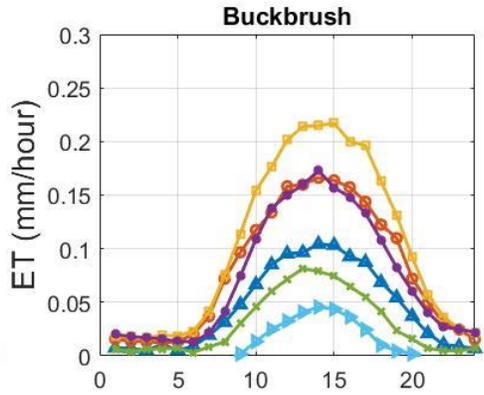
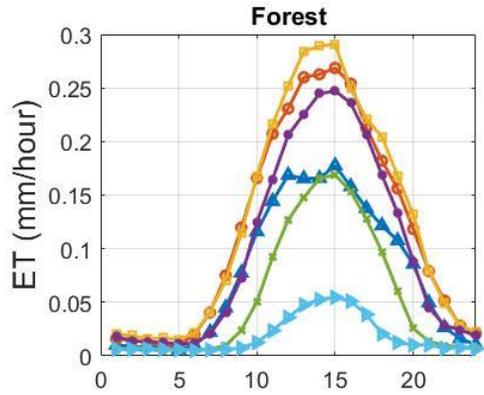


- The overall pattern of ET was more dynamic on a seasonal basis at the shrub sites, reflecting plant growth and senescence, with notable declines in ET rates between August and September. Comparatively, daily ET at Forest was more consistent between months, increasing in spring with a gradual decline in September.
- The largest difference between mean monthly ET rates between Forest and the two shrub sites occurred in June (Forest rates 1.0 mm/day greater than Buckbrush, and 0.9 mm/day greater than Sparse Shrub), while the largest difference between Buckbrush and Sparse shrub occurred in July during the peak growing season (Buckbrush ET rates greater by 0.35 mm/day).





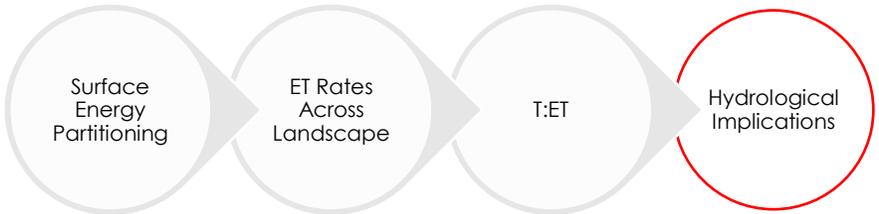
- Contributions of T to ET were lower at the Forest than the shrub sites (55% and 89% respectively). In peak growing season, T at shrub sites reached rates similar to the Forest, however later leaf out and earlier senescence resulted in distinct seasonal patterns.
- Largest difference in ET rates between Buckbrush and Sparse Shrub was in July, when T rates at Buckbrush were high.



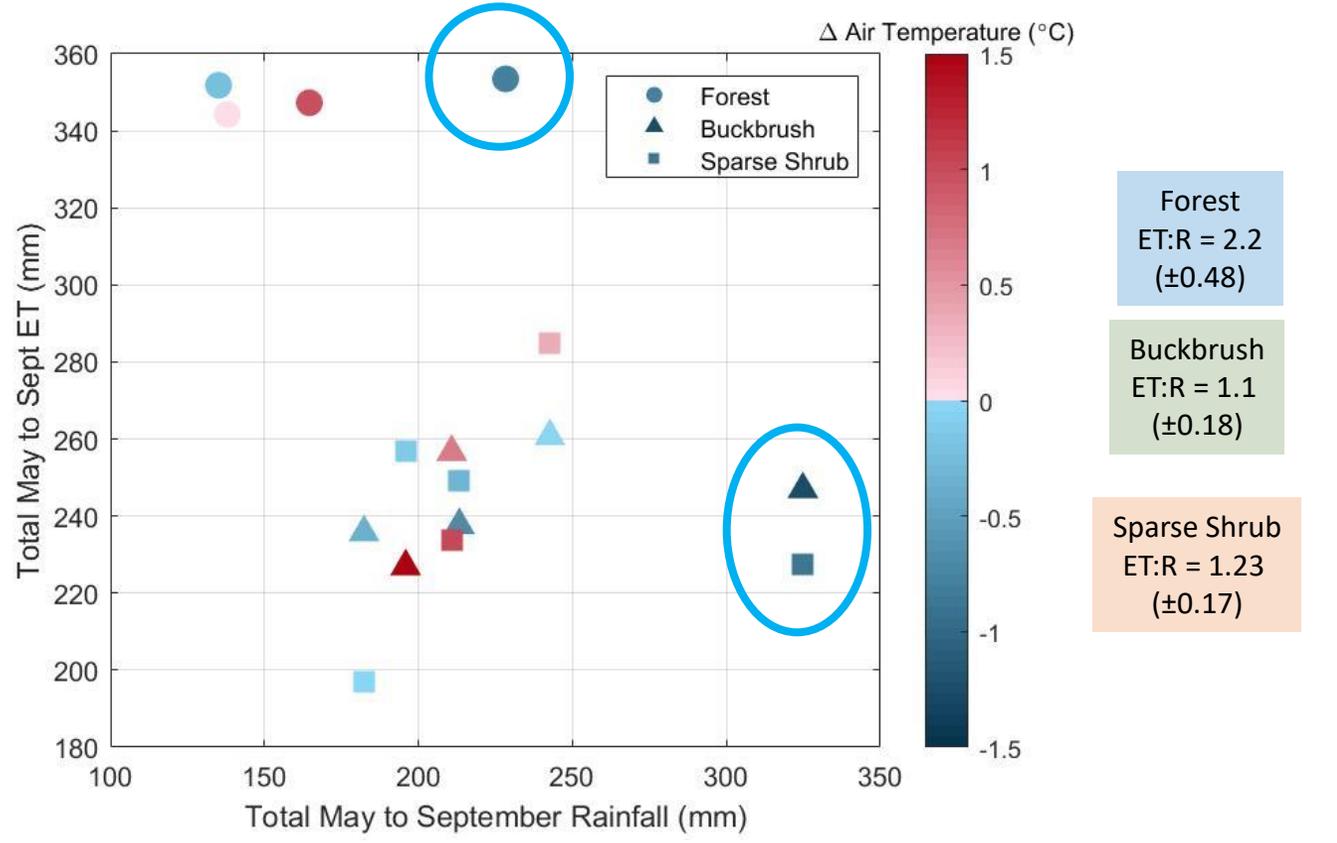
White Spruce  
T:ET = 55%

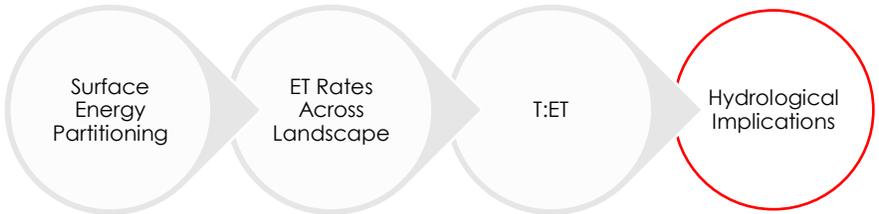
Birch and Willow  
T:ET = 89%

[Back to Menu](#)



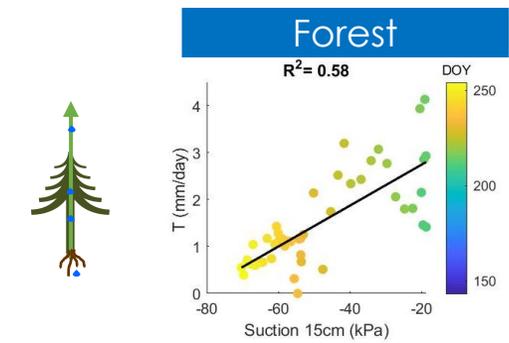
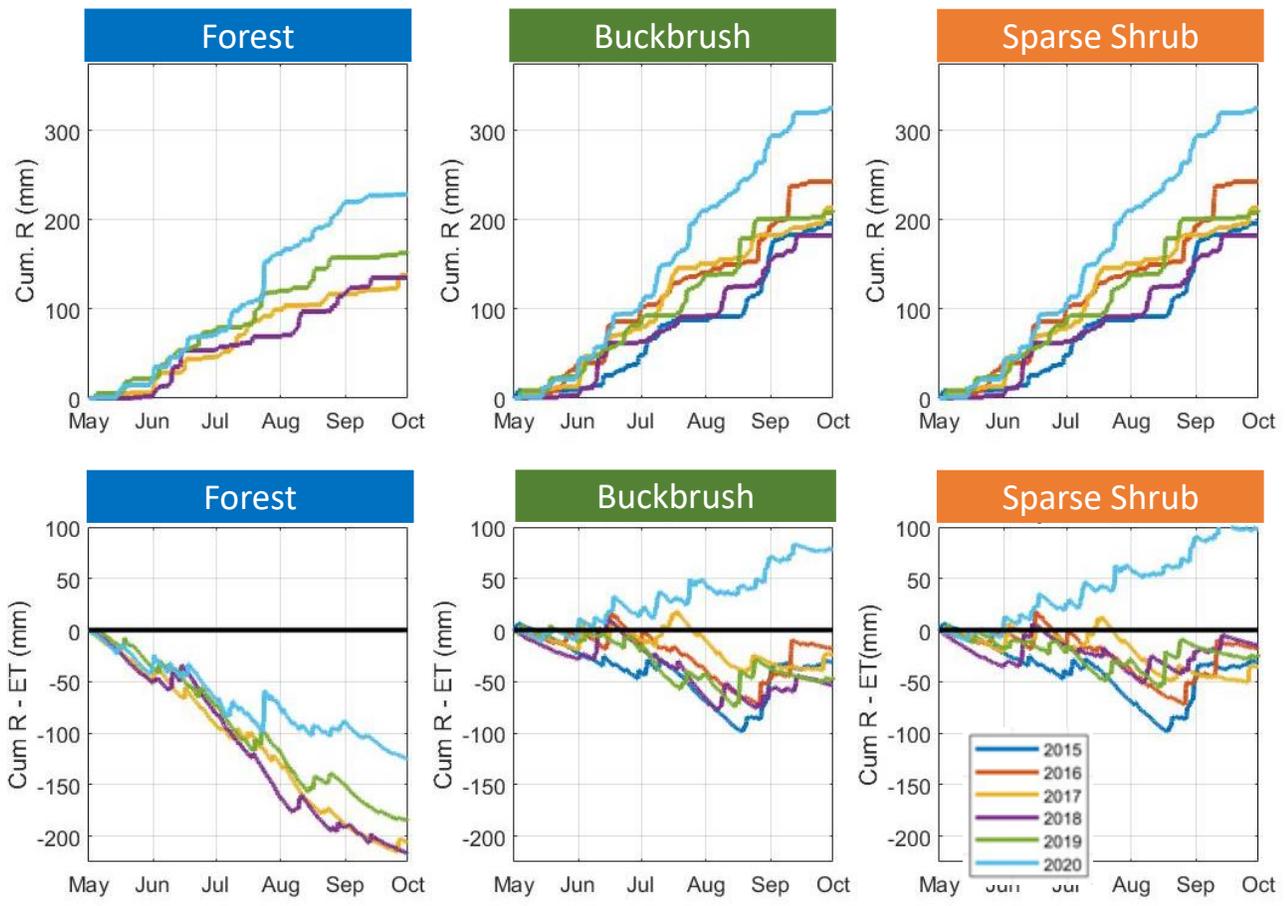
- Total May to September ET and rainfall (R) are shown in the figure below. Forest ET was consistent among years, despite differences in rainfall. This resulted in the highest and most variable ET:R.
- At the shrub sites, ET increases with increasing R (lower and less variable ET:R); however, 2020 was a wet summer (shown in blue circles), and ET is lower at the shrub sites, due to cooler temperatures.



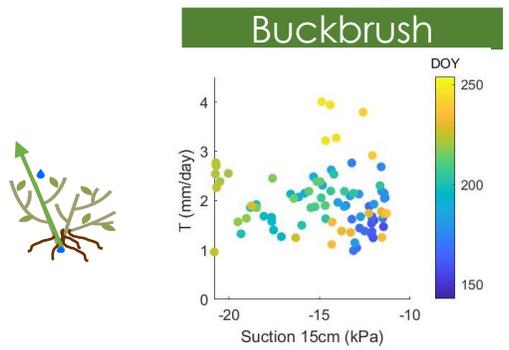


Over the growing season each year, the Forest was in a water deficit (even in 2020 with large amounts of rainfall). At Buckbrush and Sparse Shrub, ET is lower, and rainfall (R) is higher and therefore less moisture stressed.

Soil moisture is a primary control over T at Forest, but is not a control of T at Buckbrush, due to wetter conditions maintained throughout the year.



↓ P and ↑ ET:  
Risk of drought

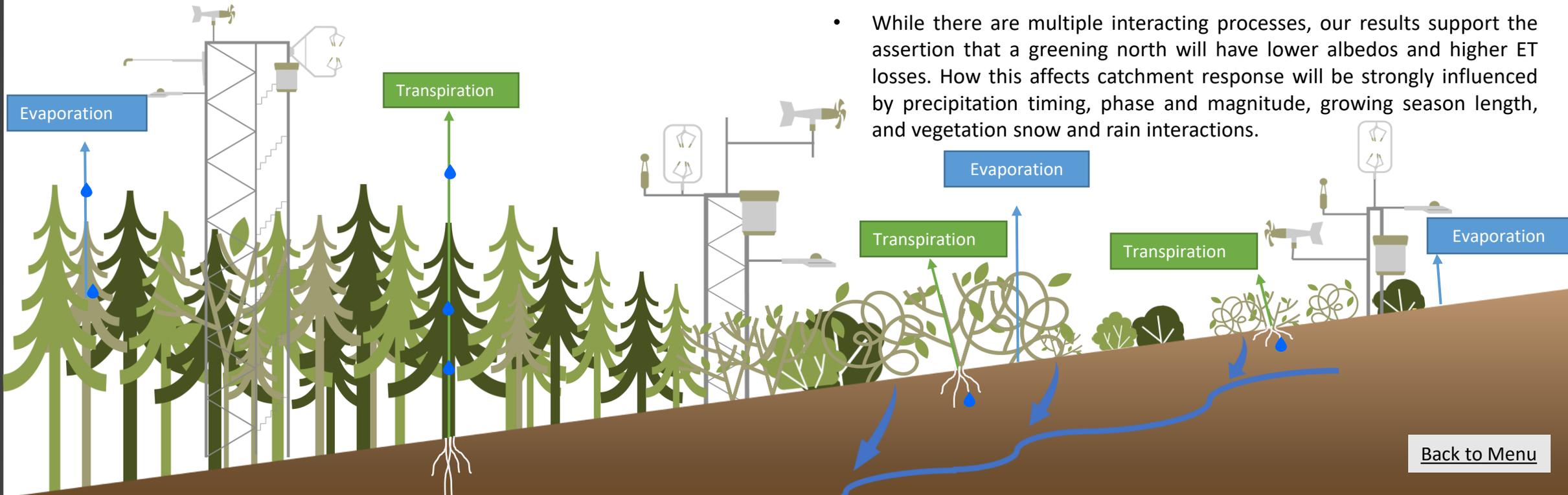


↑ P and ↓ ET:  
Not moisture stressed

Results: Conclusions

Treeline Advance		Shrubification	
Large ↑ total ET	↑ Total ET	Small ↑, July only	
↓ Albedo			
Strong reliance on snow inputs (large deficit)		Not moisture limited (small deficit)	
White Spruce ~50% T:ET		Shrubs > 80% T:ET	
Slow – susceptible to disturbance		Rapid – susceptible to changes in temp	

- Results indicate that the greatest change in water and energy fluxes will occur from changes in treeline compared with shrubification across all seasons as they have distinct regimes.
- ET was greatest at the Forest site compared with the shrub sites, and varied little over 4 years despite differences in meteorology and a considerable growing season water deficit. In contrast, ET was considerably less at the cooler higher elevation shrub sites, which exhibited similar ET losses over 6 years despite differences in shrub height and abundance.
- While the observation of limited differences in ET has been reported before for a single year, our results indicate that ET variance is much greater at the short, sparse shrub site compared with the tall, dense shrub site due the reduced influence of vegetation controls on total ET.
- While there are multiple interacting processes, our results support the assertion that a greening north will have lower albedos and higher ET losses. How this affects catchment response will be strongly influenced by precipitation timing, phase and magnitude, growing season length, and vegetation snow and rain interactions.



[Back to Menu](#)

Thank you for your interest.  
We welcome all questions and comments:



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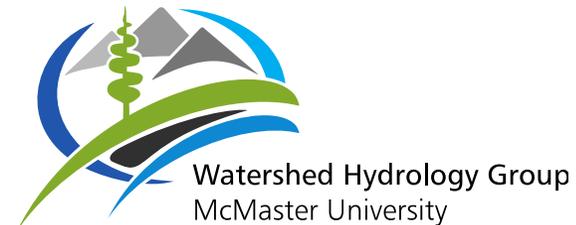
[nicholem@mcmaster.ca](mailto:nicholem@mcmaster.ca)

Upcoming Paper  
under Review:



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