Soil-stomata-sky: How forests and shrubs control evaporative partitioning in a subarctic, alpine catchment, Yukon Territory, Canada

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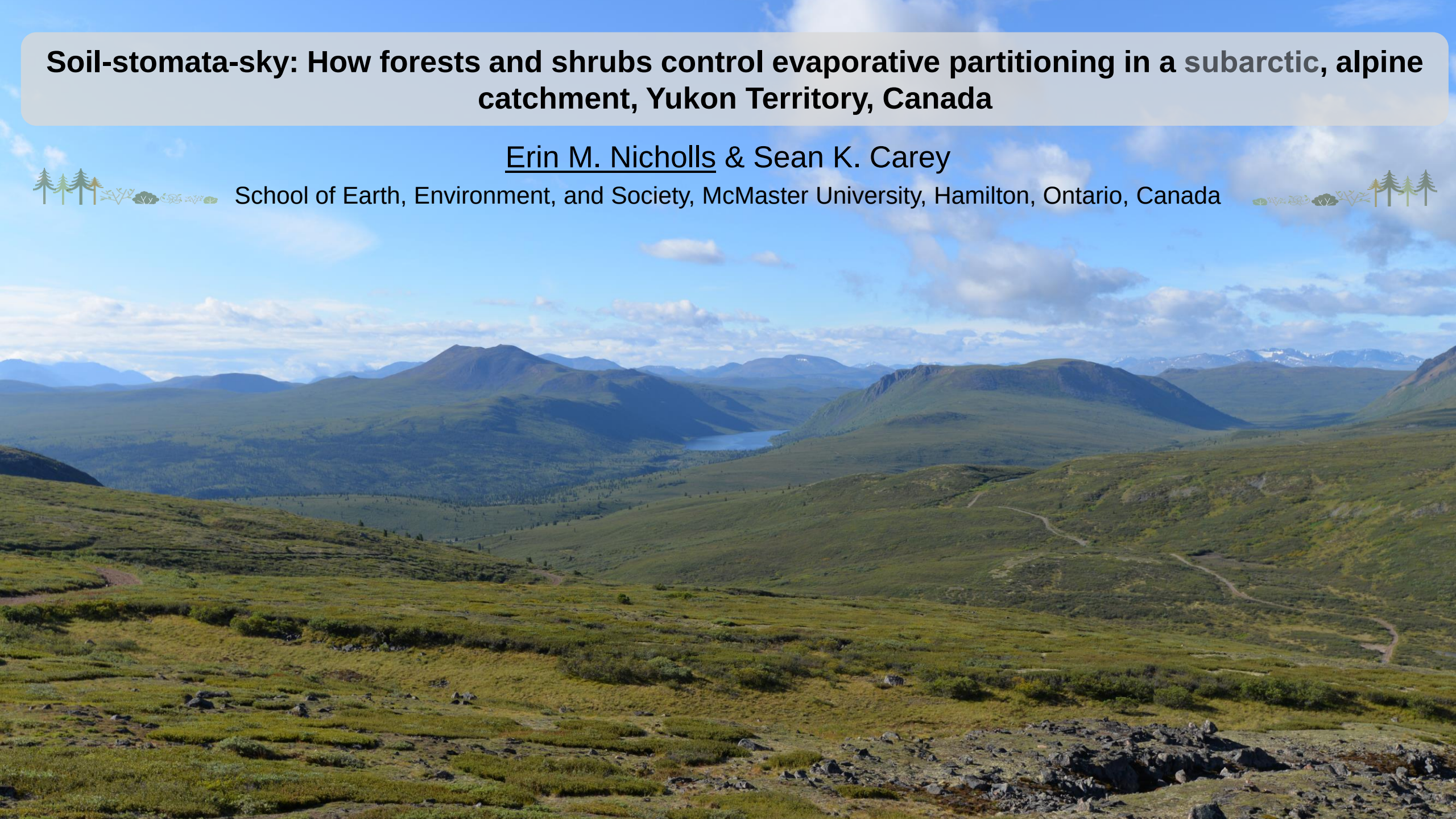

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GWF

Watershed Hydrology Group
McMaster University

Weston Family Foundation

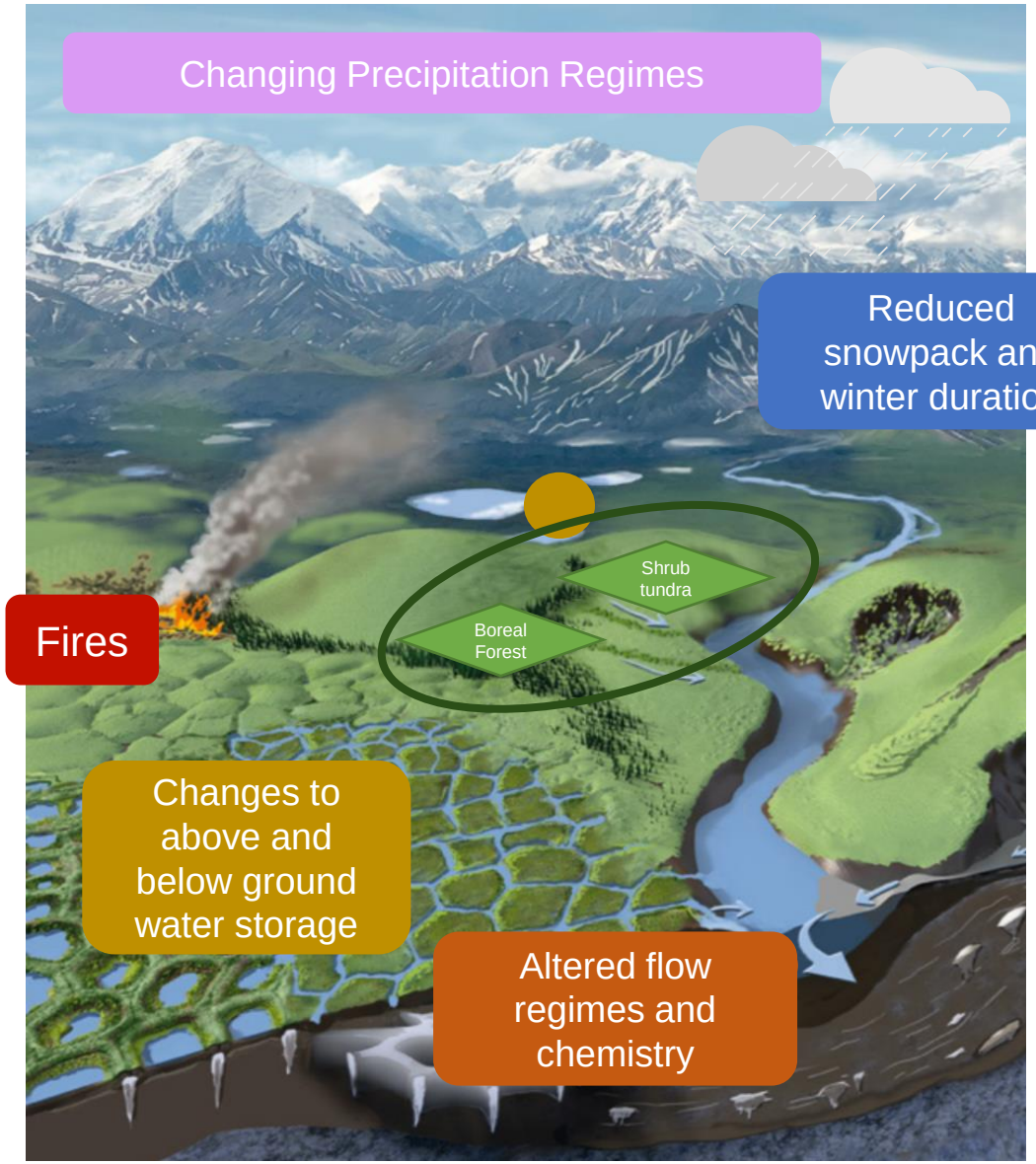
SPOILER ALERT!

Sensitivity to Changes in Growing Season Length

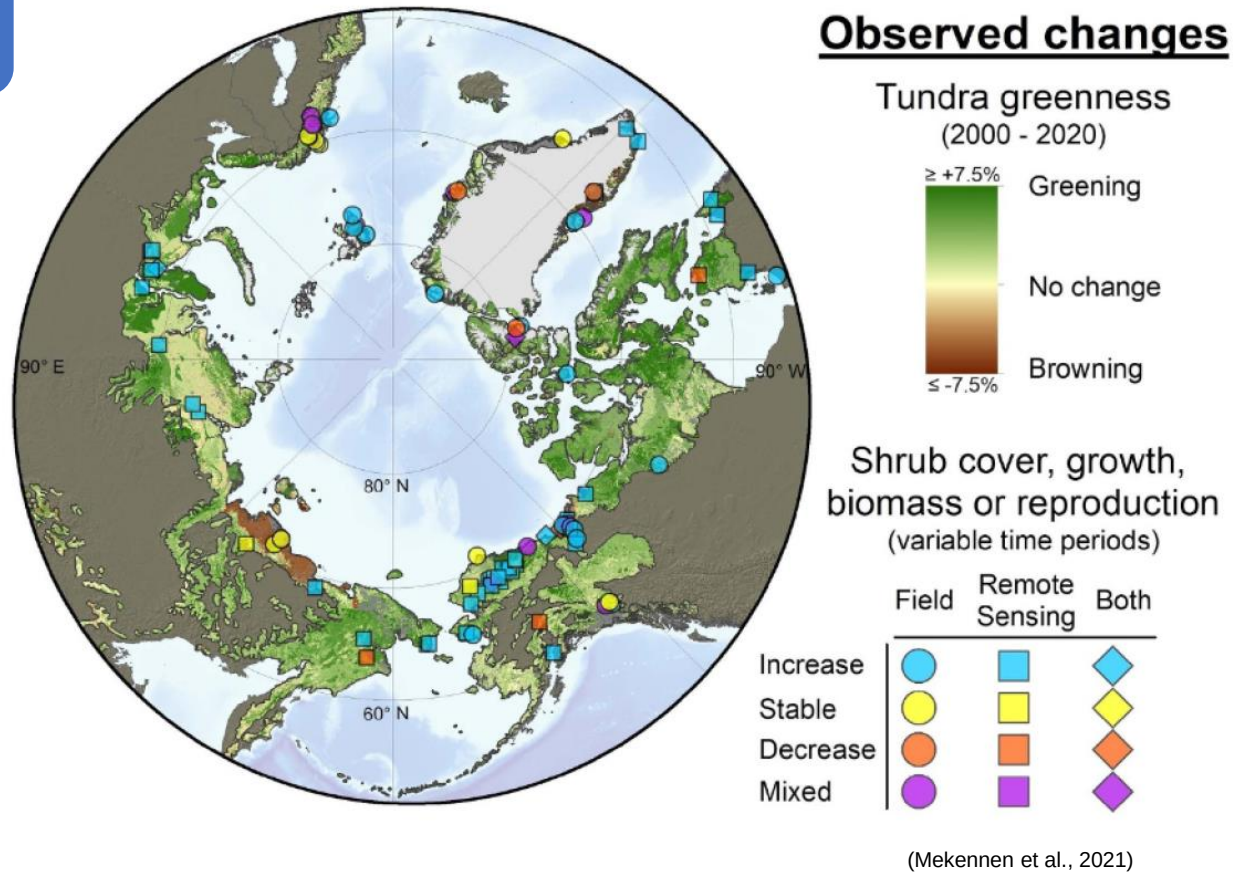
T Birch and Willow Shrubs
Subarctic Taiga

T White Spruce
Boreal Forest

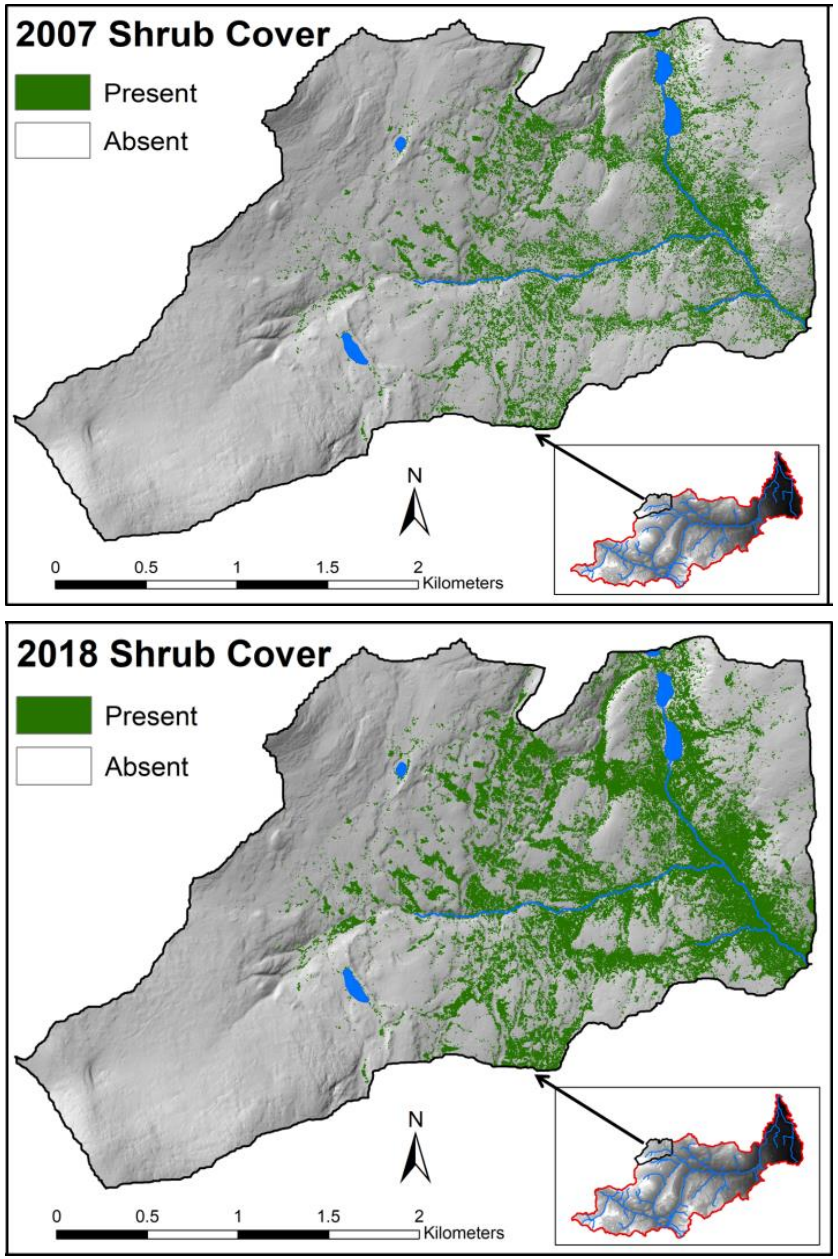
Sensitivity to Air Temperature + VPD



- Tree and shrub migration at increasing altitude and latitude
- Shifts in land classifications
- Increases in shrub height, extent and density



(Mekennen et al., 2021)



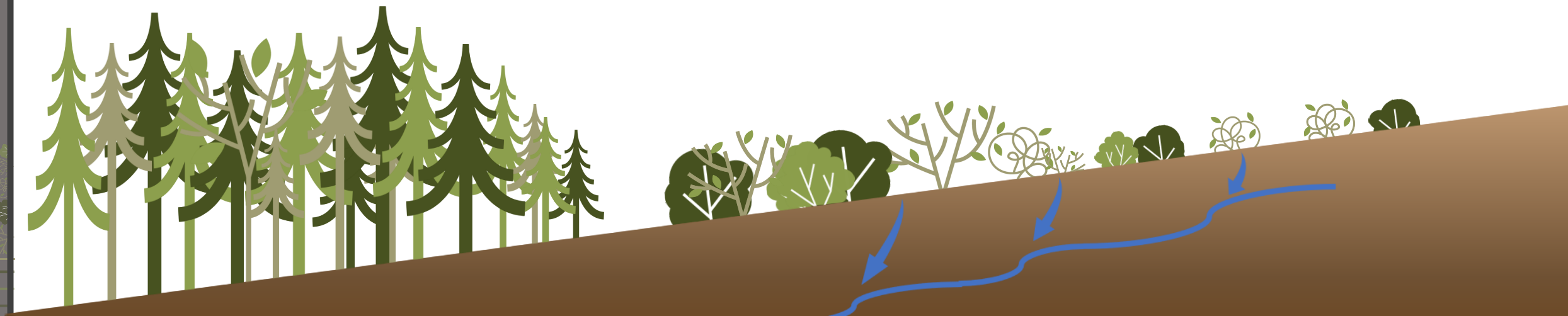
(Leipe and Carey, 2021)

- Tree and shrub migration at increasing altitude and latitude
- Shifts in land classifications
- Increases in shrub height, extent and density

(Credit: NASA's Goddard Space Flight Center/Cindy Starr)

Research Questions

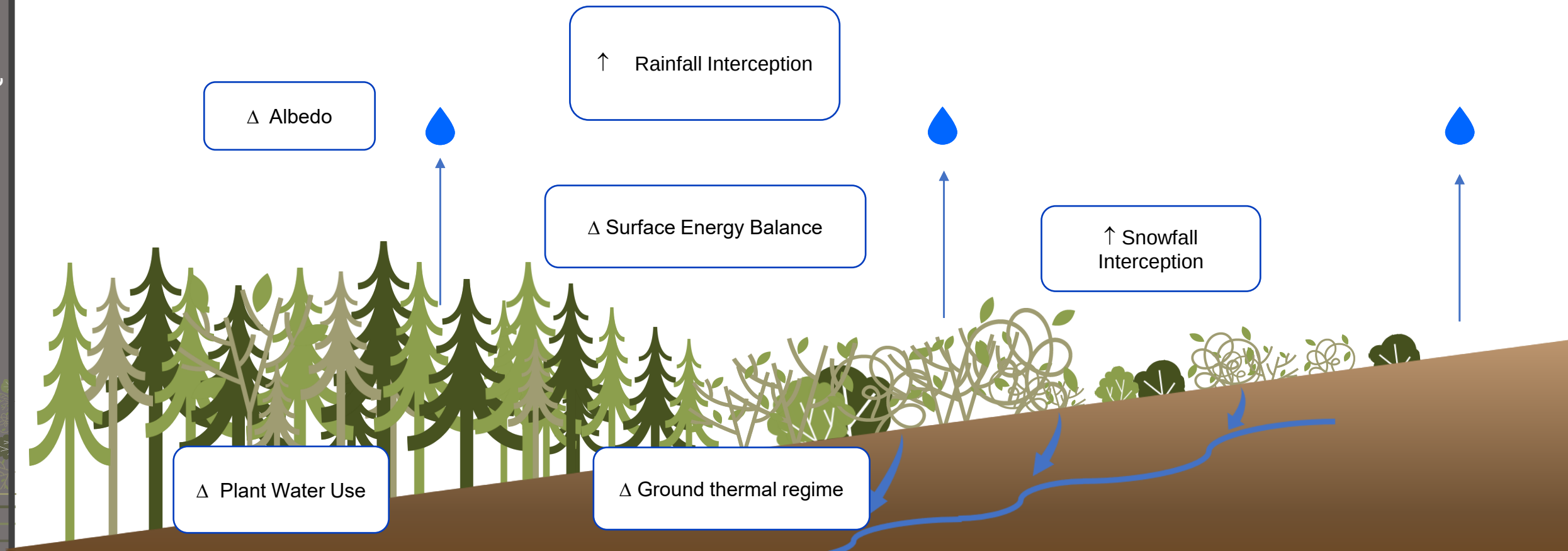
What hydrological changes will occur with a shift in treeline and increased shrub abundance?



Research Questions

What hydrological changes will occur with a shift in treeline and increased shrub abundance?

We need to improve our ability to predict changes in water yield by understanding and numerically representing the role of vegetation on water cycling and storage.



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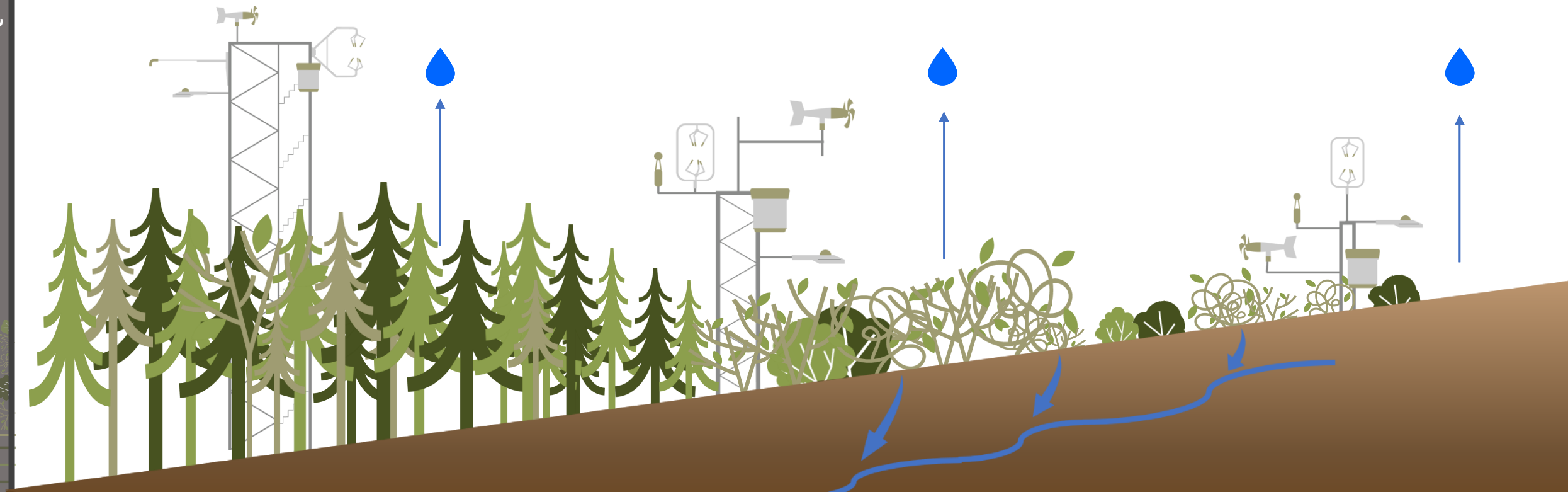
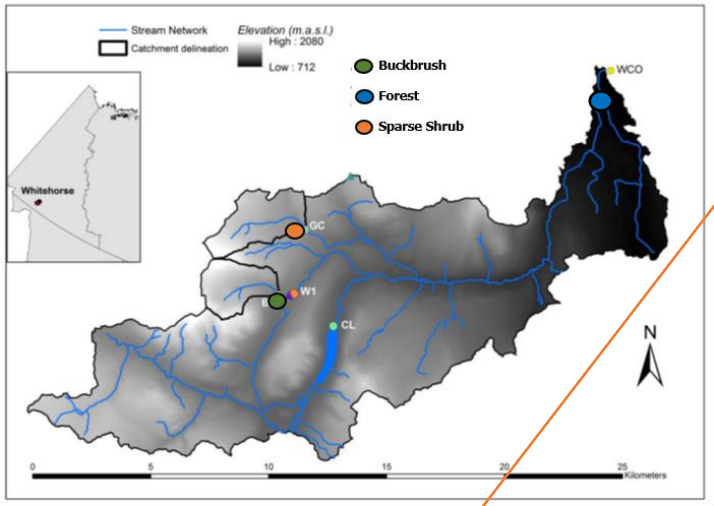
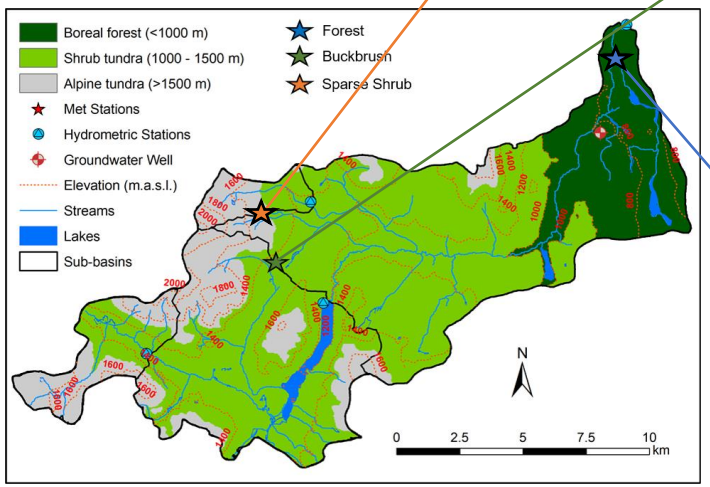


Study Sites

Wolf Creek Research Basin, Yukon Territory





Increasing Elevation

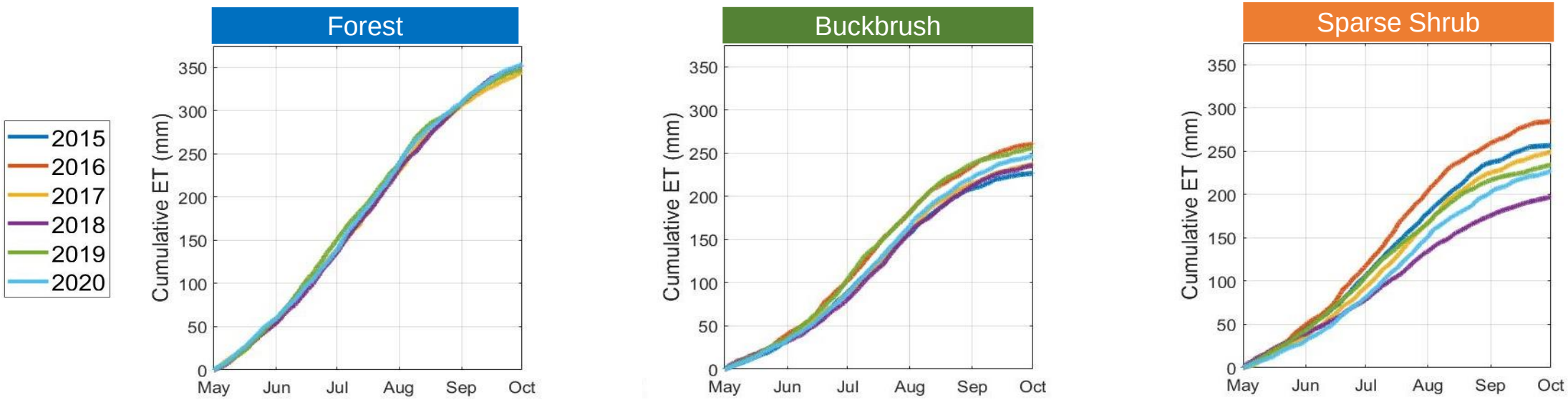
Sparse Shrub
1450 masl
Willow and Birch
Shrubs <~0.5m

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

Forest
750 masl
White Spruce
~12-20 m

Research Questions

What hydrological changes will occur with a shift in treeline and increased shrub abundance?



349 (±4) mm
2.3 mm/day

244 (±10) mm
1.6 mm/day

226 (±22) mm
1.5 mm/day

Increasing interannual variability with decreasing vegetation cover →

Treeline advance:
Increased May to September ET

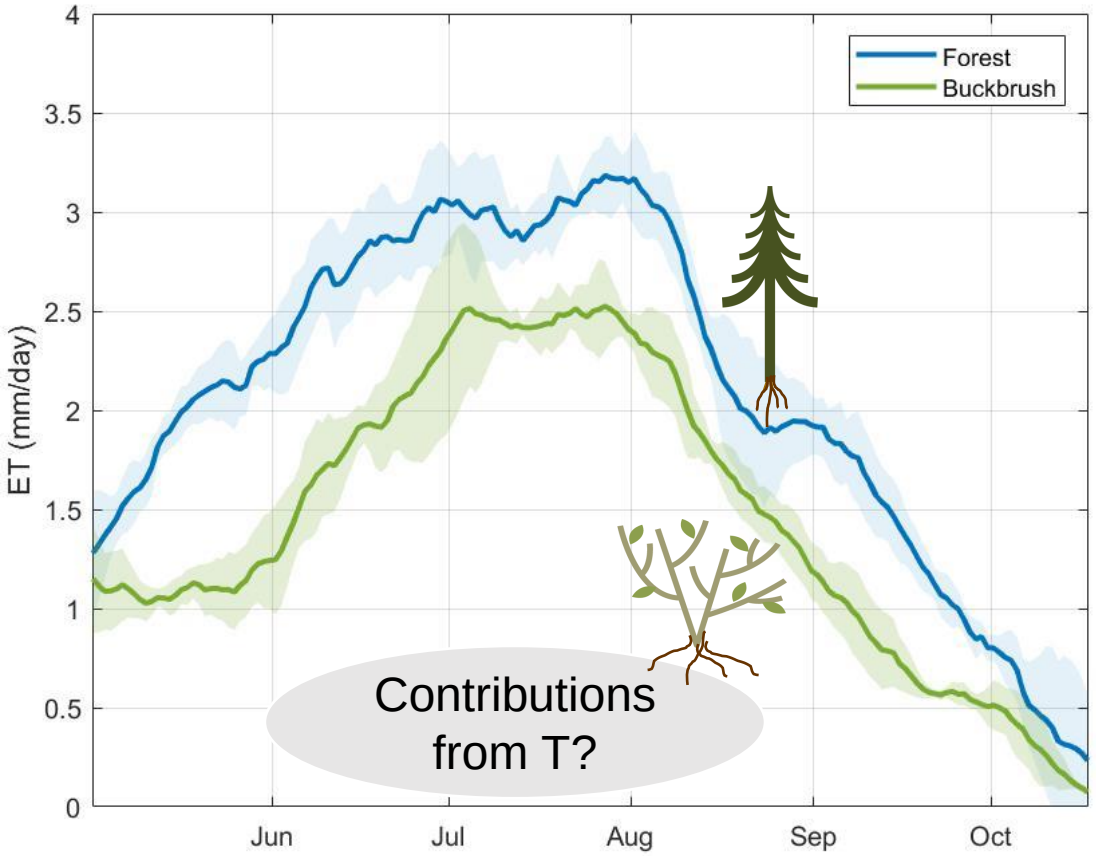
Shrubification:
Similar total May to September ET

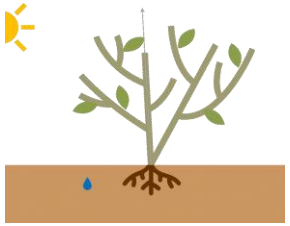
Nicholls and Carey, 2021. Journal of Hydrology.

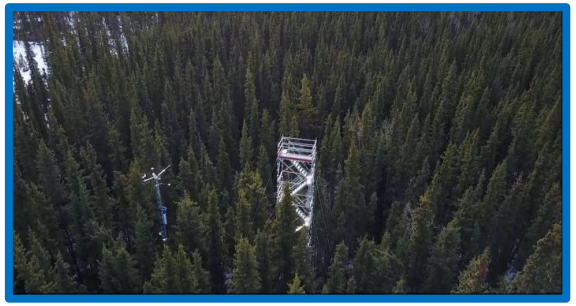
Research Questions

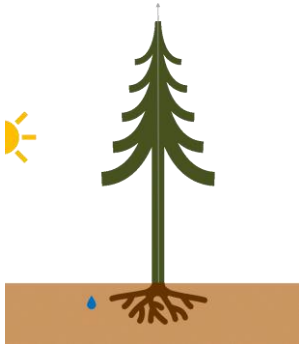
What hydrological changes will occur with a shift in treeline and increased shrub abundance?

What role does vegetation play in regulating these hydrological shifts?



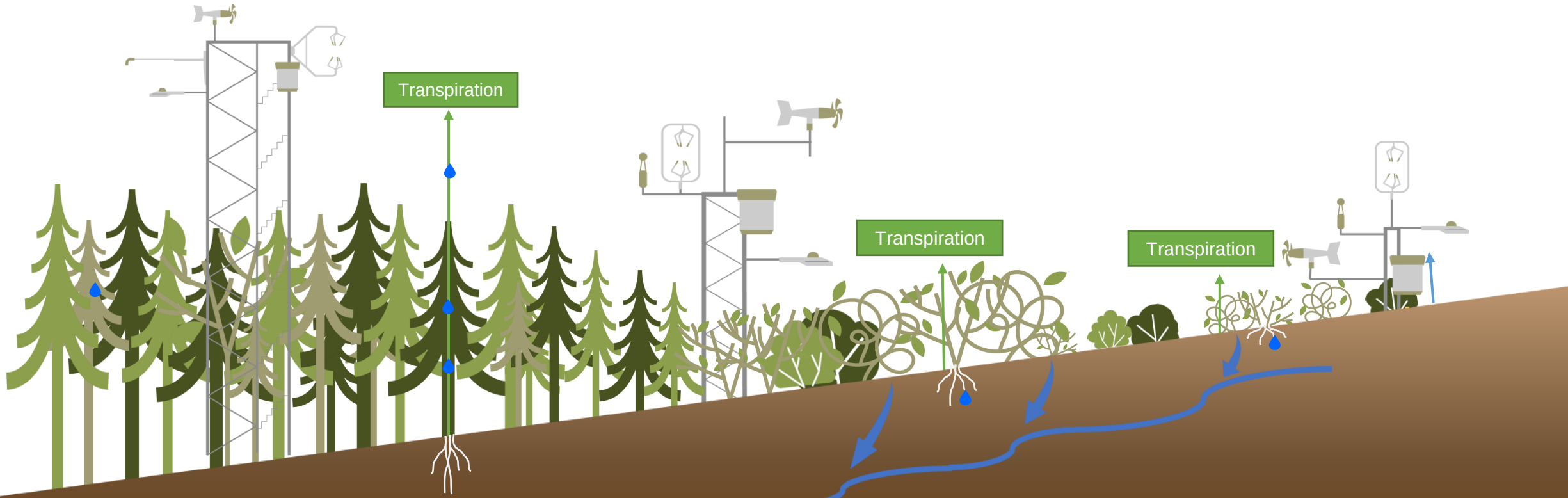






Outline

How do T rates vary across the landscape?



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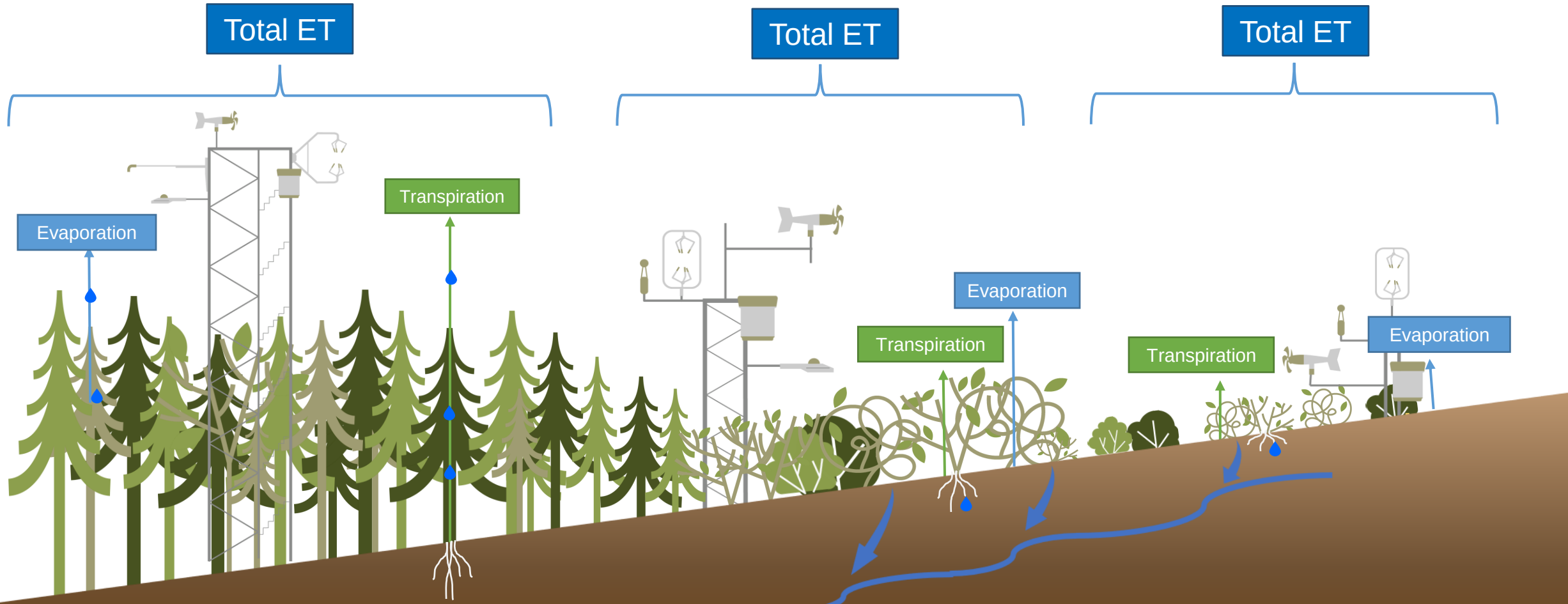
How do T rates vary across the landscape?

How does T:ET vary across sites and seasons?



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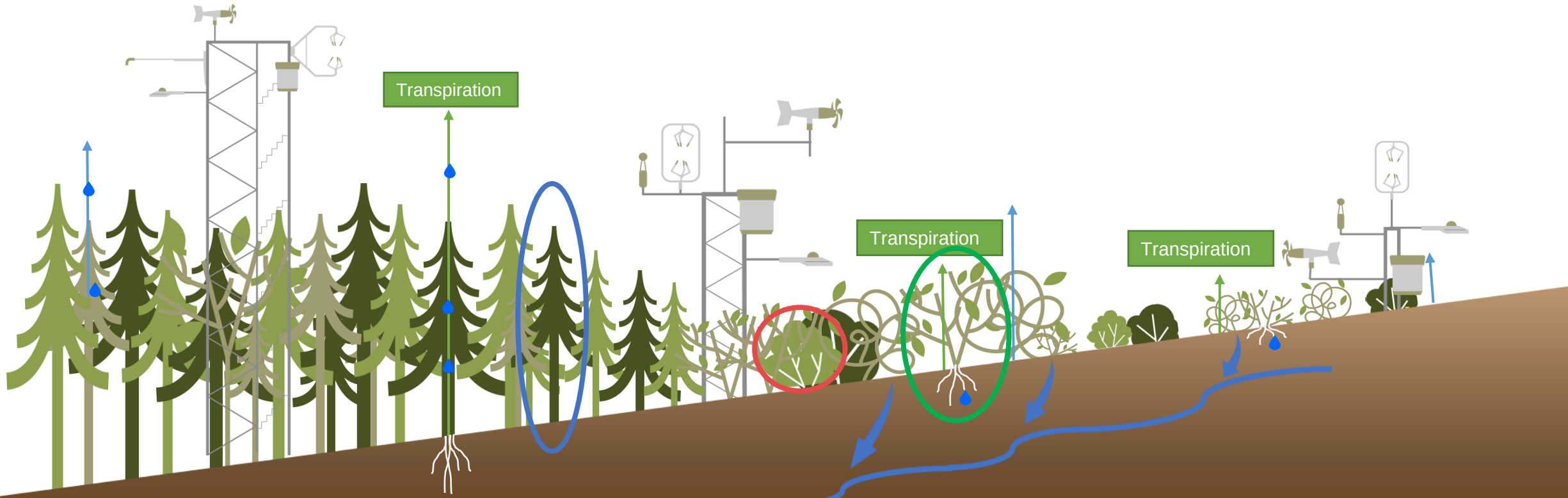

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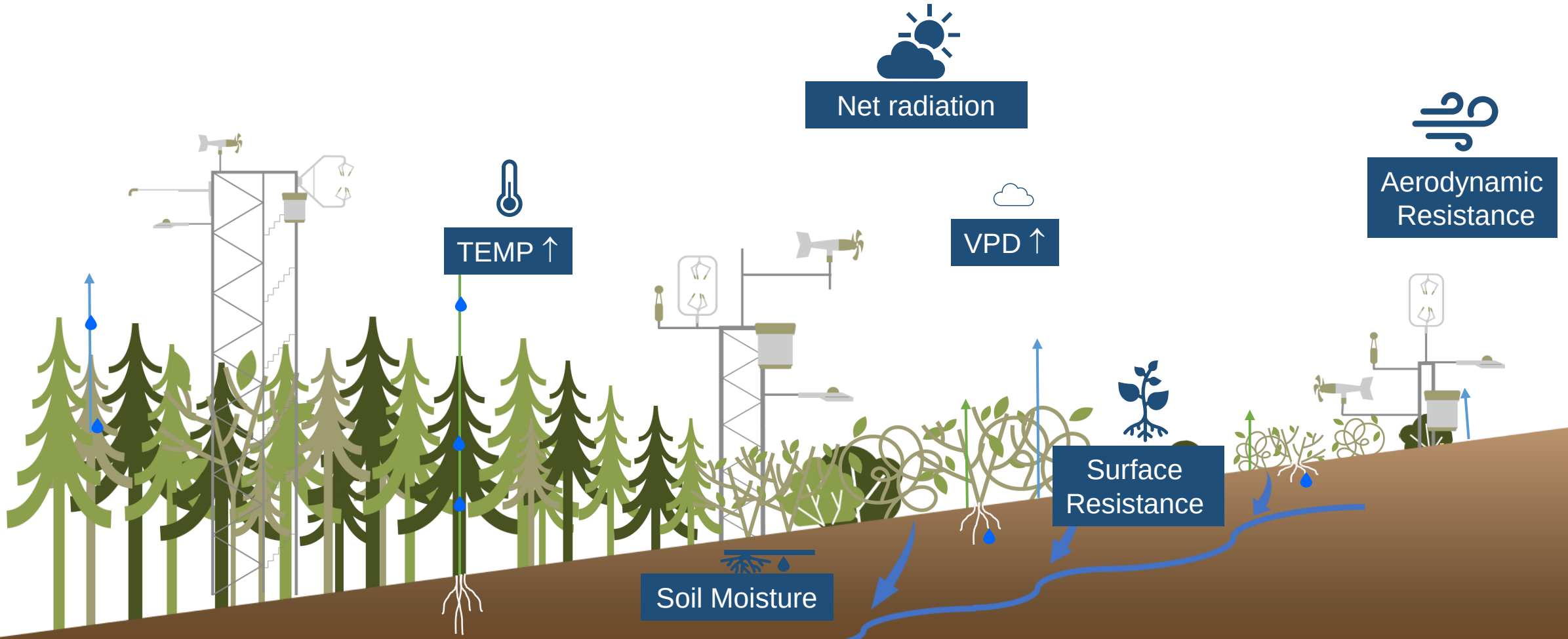

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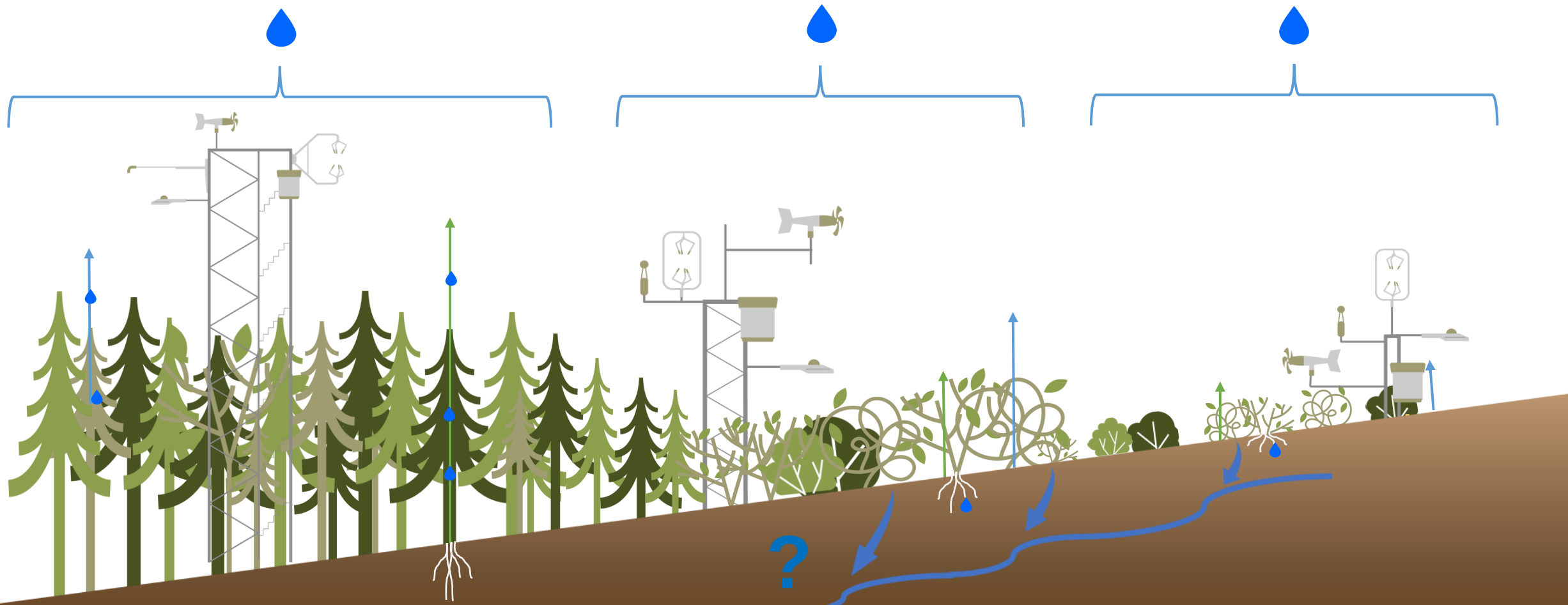
How does water use vary between Forest and shrubs?



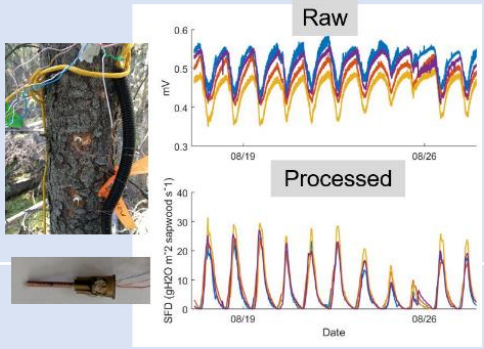
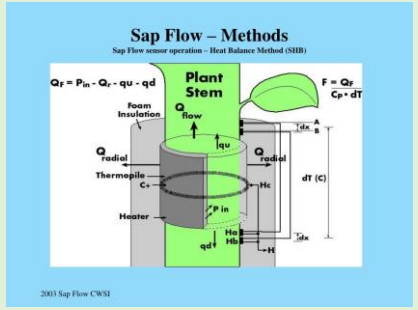
Methodology

Sap Flow Sensors

Data Processing

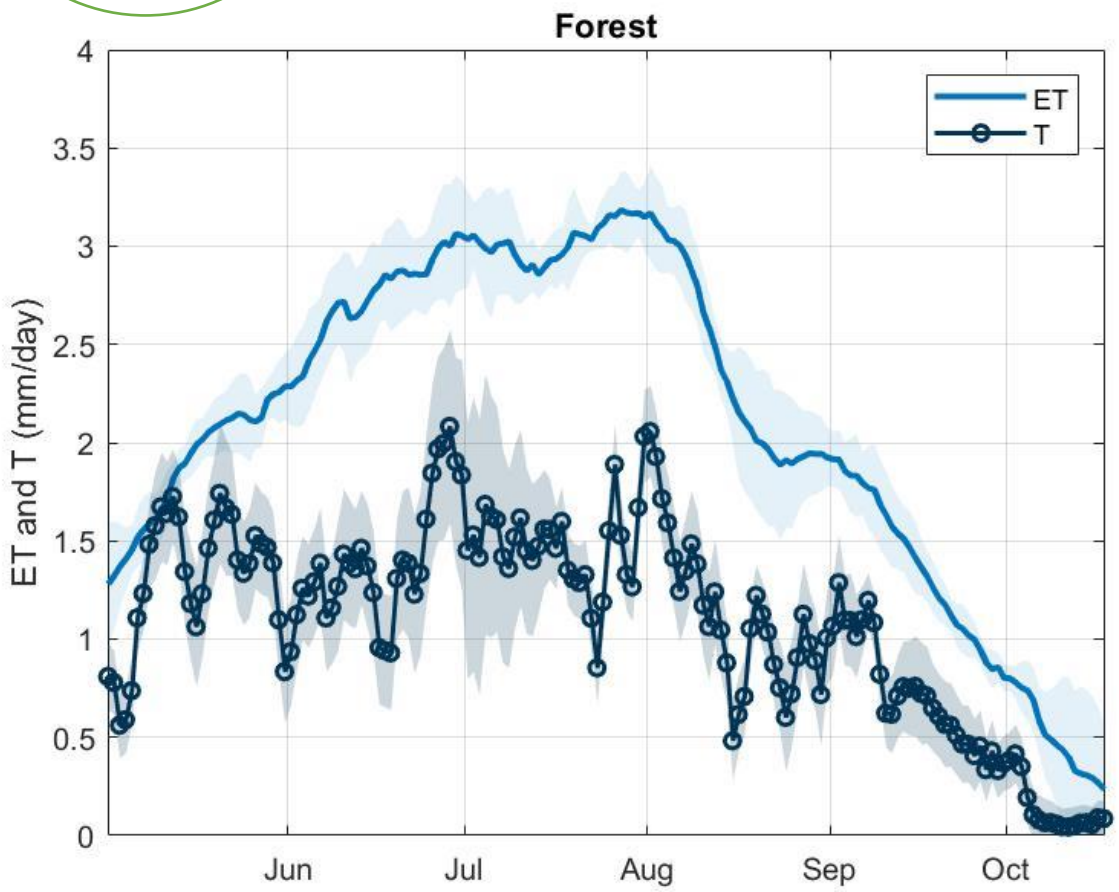
Upscaling

Gap-filling

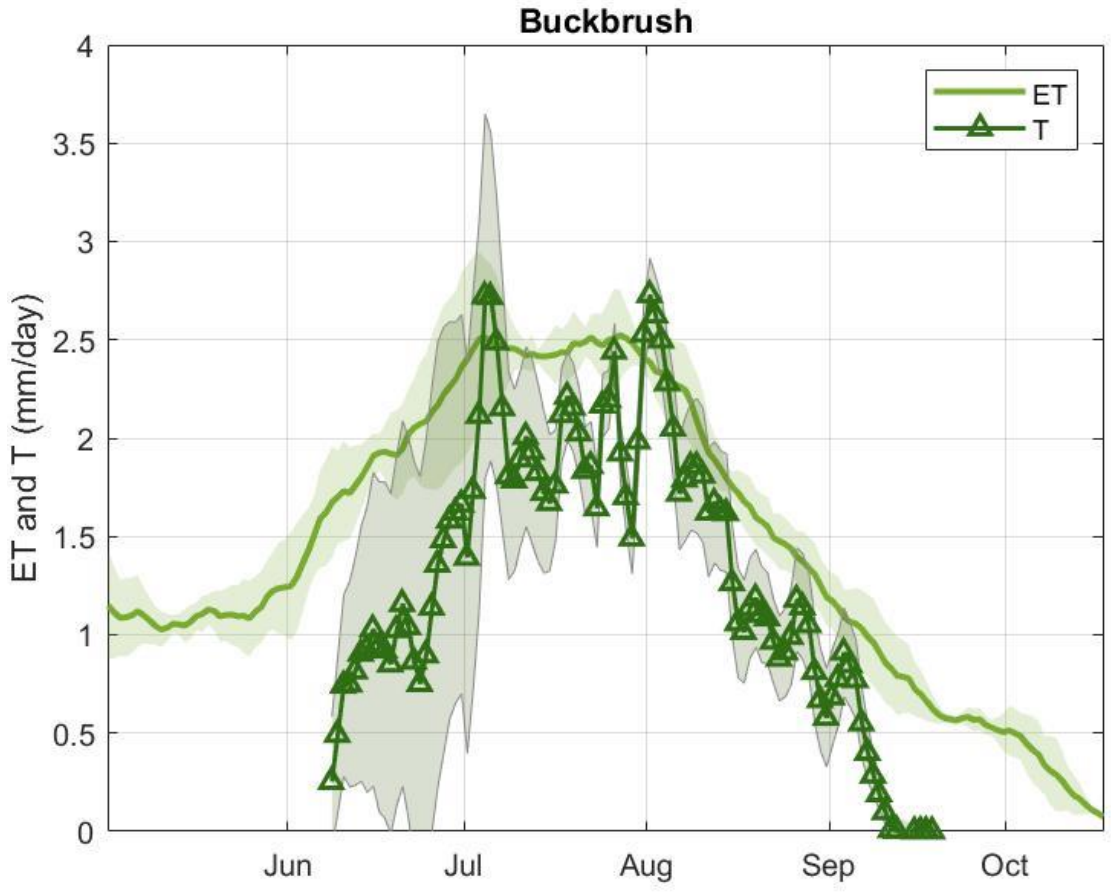
	Forest	Buckbrush
Sap Flow Sensors	**Granier Style Thermal Dissipation Probes** • **22 White Spruce** Year round (2019-2020) 20 mm depth 	**Dynamax EXO Skin Sensors (13-16 mm) diameter** • **3 Willow** • **5 Birch** ~June to October (2019-2020) 
Data Processing	TREX (R) package • Coniferous calibration • Pre-dawn determination of T_{max} • Clearwater et al.(1999) correction applied for sapwood depth • Assume 0 T during < 10 W/m^2 K↓ and rainfall >0.2 mm $J_s = a(\frac{\Delta T_{max}}{\Delta T} - 1)^b$	• SFD determined by heat balance method • Assume 0 T during < 10 W/m^2 K↓ and rainfall >0.2 mm 
Upscaling	• Mean J_s x sapwood density • Allometric equation (DBH vs. sapwood area) from Quiñonez-Piñón and Valeo (2017)	• Mean J_s x sapwood density • Sapwood area determined by plot measurements
Gap-filling	• Mean diurnal variation (3-day) and artificial neural network (K↓, T_{air}, VPD)	• Mean diurnal variation (3-day) and artificial neural network (K↓, T_{air}, VPD)

How do T rates vary across the landscape?

- Mean T rates higher in willow and birch shrubs than white spruce forest
- Forest T follows a more seasonal trend with net radiation, beginning earlier in the spring and sustained later in the Fall
- Interannual and seasonal variability in T higher at Buckbrush than Forest



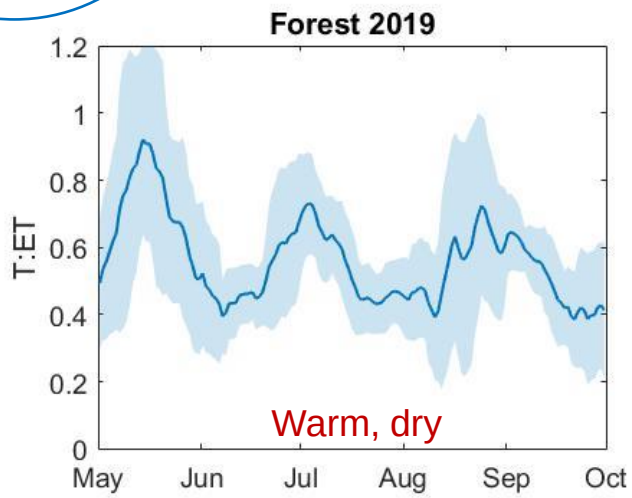
July to Sept T:
1.1 (± 0.58) mm/day

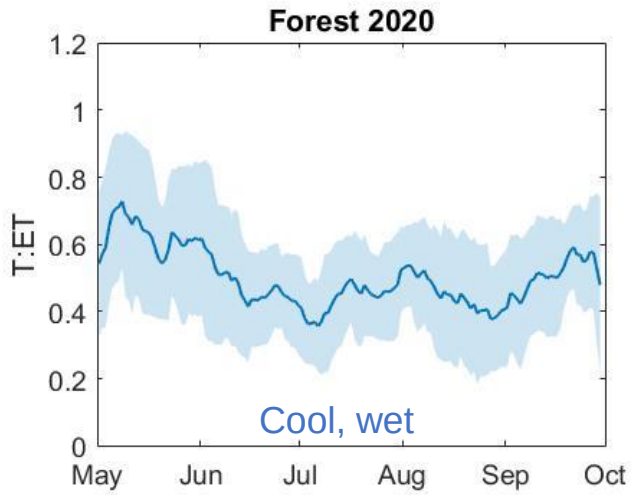


July to Sept T:
1.65 (± 1) mm/day

How does T:ET vary across sites and seasons?

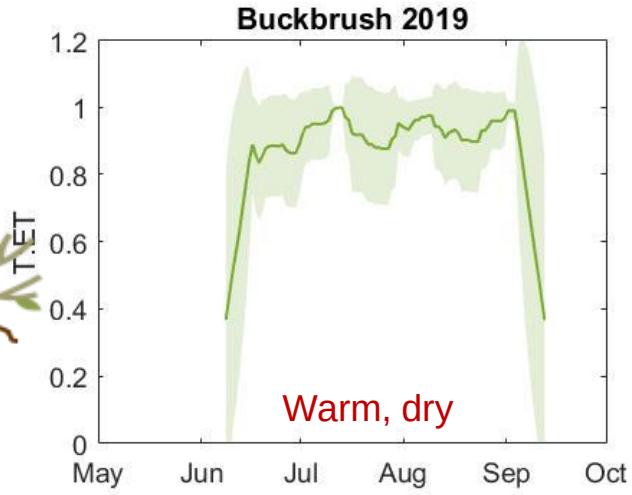
- **Forest**: T:ET was highest in the early season, when T had started but ET was still low
- **Buckbrush**: T:ET was high in the mid-growing season, with distinct shoulder season thresholds
- During the warm, dry growing season of 2019, T:ET was controlled by rainfall (moisture deficit)

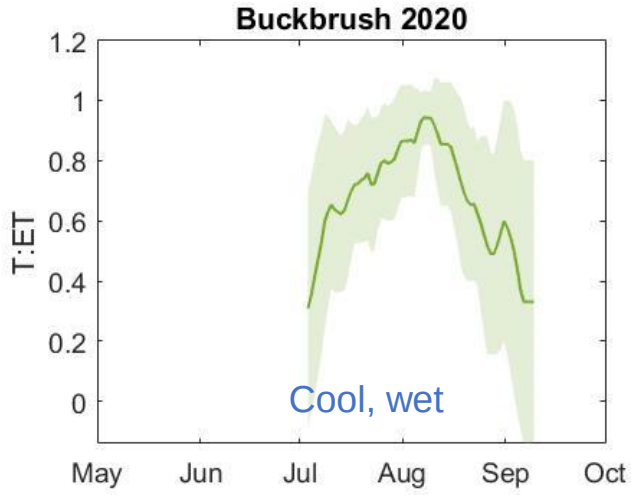




Forest:

- Peak growing season (July), T:ET =
  - 53% (2019)
  - 43% (2020)





Buckbrush:

- Peak growing season (July), T:ET =
  - 92% (2019)
  - 68% (2020)

Species-specific response: Does plant composition matter?

- At Buckbrush, sapwood area of birch (m^2/m^2) was more than double sapwood area of willow

Buckbrush

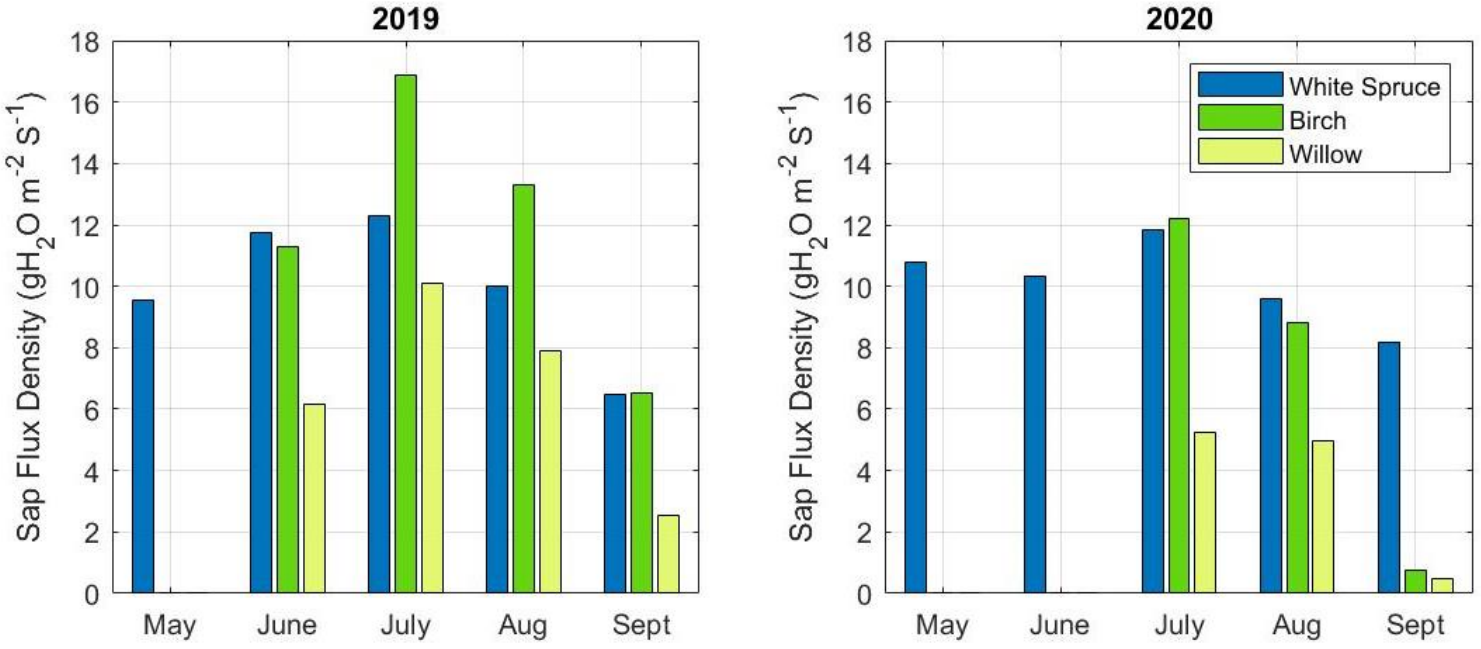
Species	Sapwood Area
Forest	
White Spruce	2.4×10^{-3} (m^2/m^2)

Buckbrush	
Birch	2.3×10^{-3} (m^2/m^2)
Willow	1.1×10^{-3} (m^2/m^2)
Total:	3.4×10^{-3} (m^2/m^2)

Results: Species specific sap flux densities

Species-specific response: Does plant composition matter?

- At Buckbrush, sapwood area of birch (m^2/m^2) was more than double sapwood area of willow
- Mean sap flux density ($gH_2O\ m^2\ s^{-1}$) was almost 2 times greater in birch than willows
- *Yes - Plant composition and density matters*



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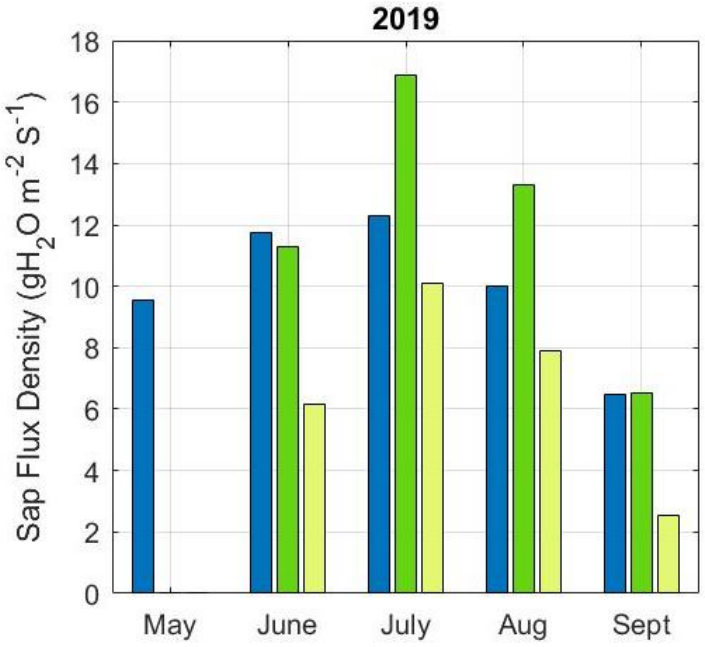
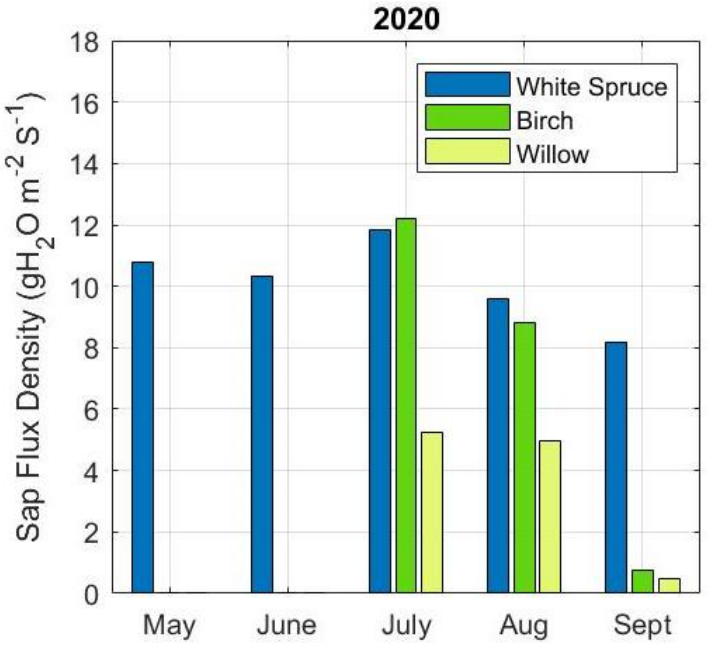


Warm, dry



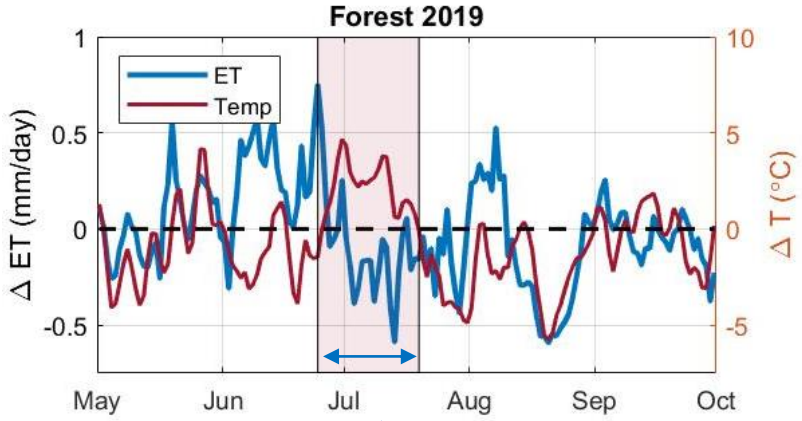
Cool, wet

Forest SFD remains similar between years, while SFD Is suppressed in 2020

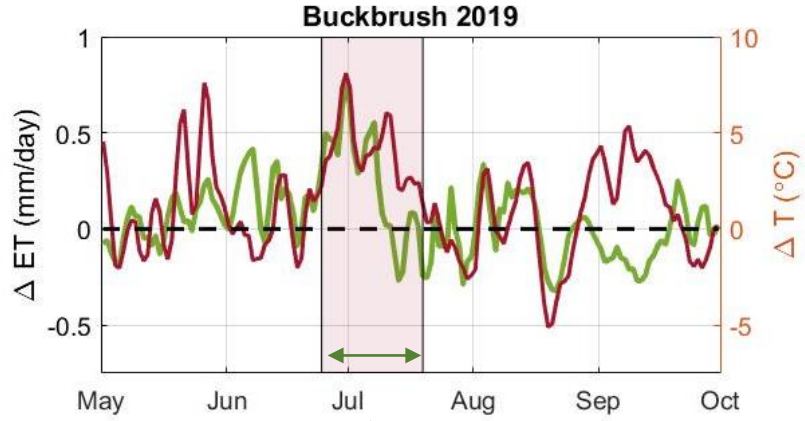
What environmental and physiological drivers are these systems sensitive to?

What environmental factors are ET and T most sensitive to?

- Sensitivity of ΔT_{air} on total ET differs between forest and shrubs throughout the year



NOT sensitive to changes in air temperature



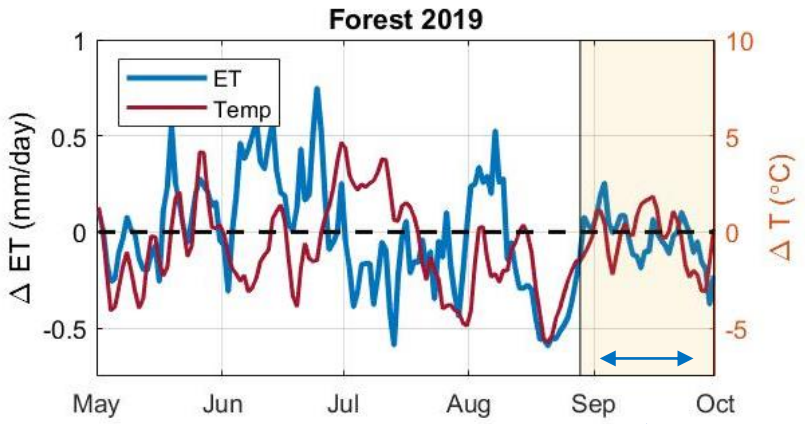
Sensitive to changes in air temperature

In the warm, dry July of 2019:

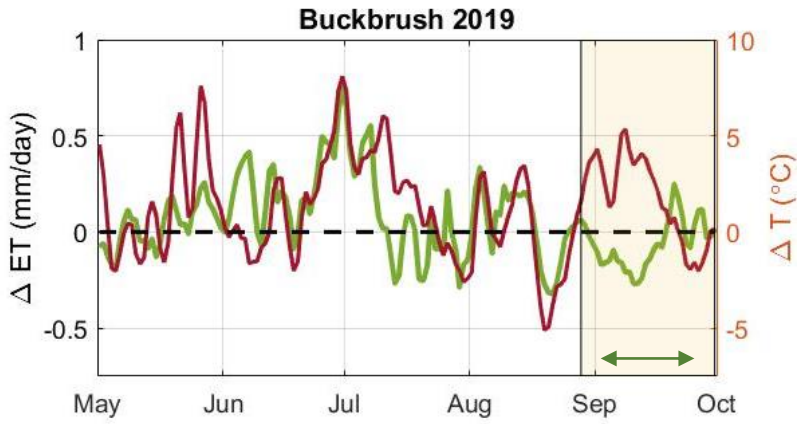
- At Forest: ET was lower than the mean
- At Buckbrush: ET was higher than mean and followed changes in temperature

What environmental factors are ET and T most sensitive to?

- Sensitivity of ΔT_{air} on total ET differs between forest and shrubs throughout the year



ET sensitive to changes in air temperature

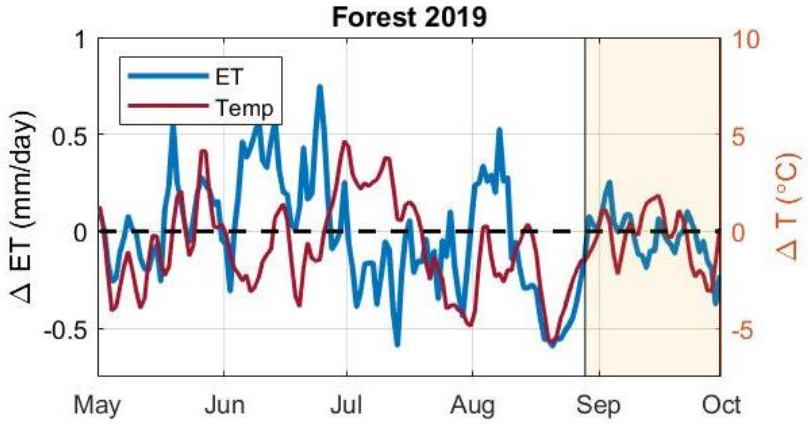


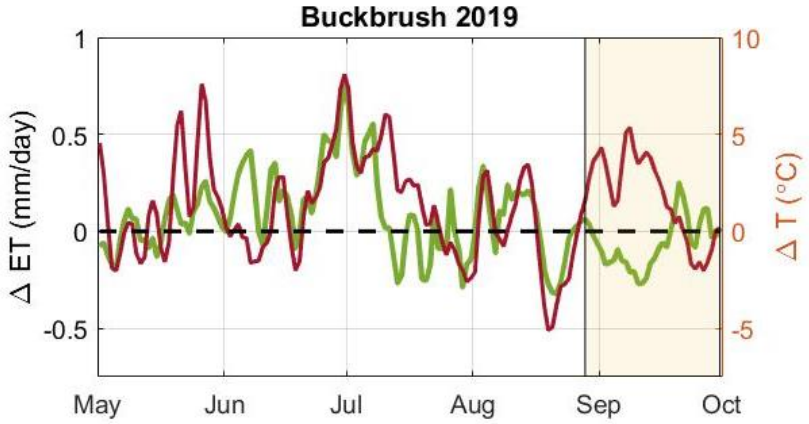
ET NOT sensitive to changes in air temperature

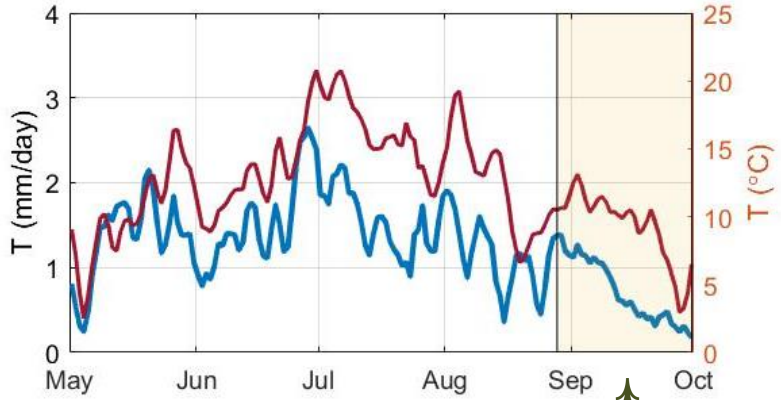
In the Fall at Buckbrush sensitivity of ET to air temperature decreases when T is low (senescence)

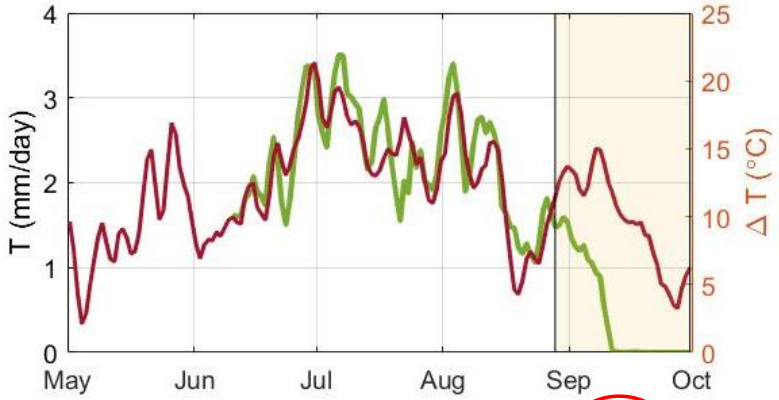
What environmental factors are ET and T most sensitive to?

- Sensitivity of ΔT_{air} on total ET differs between forest and shrubs throughout the year









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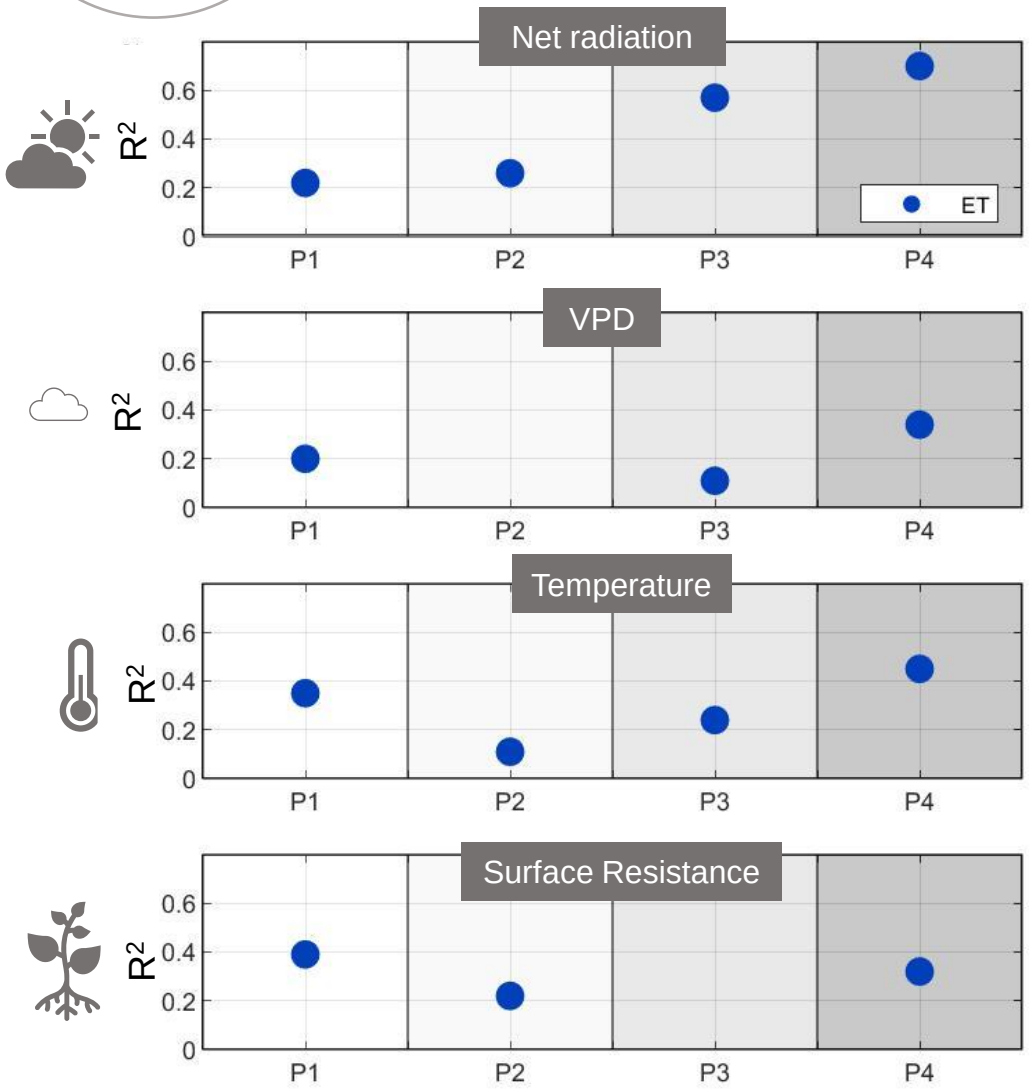
What drives ET?

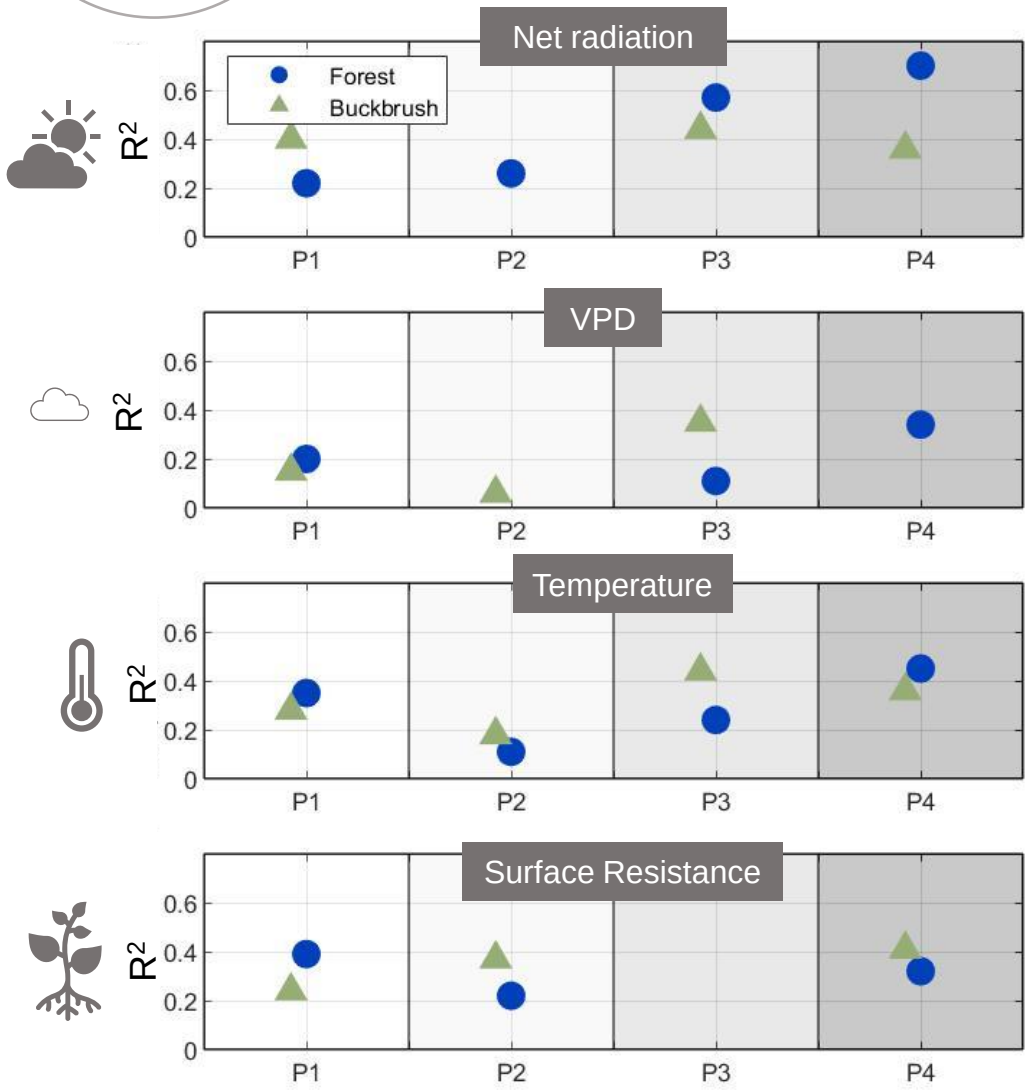
What controls ET at Forest?



- Net radiation increasingly important throughout year
- T_{air} controls ET in shoulder seasons

What drives ET?

What controls ET at Forest and Buckbrush?



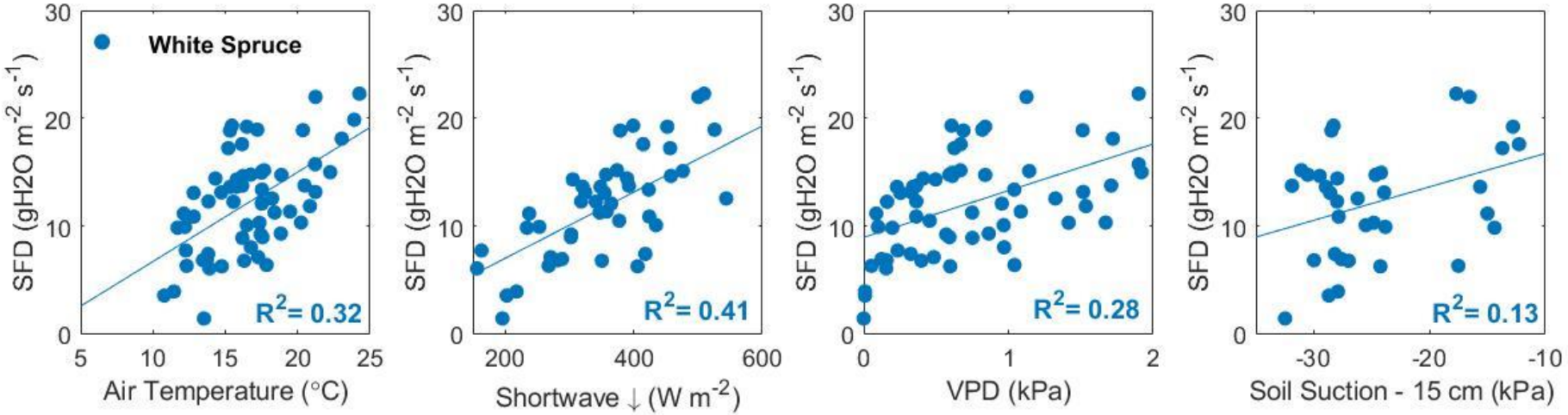
- Net radiation increasingly important throughout year
- T_{air} controls ET in shoulder seasons

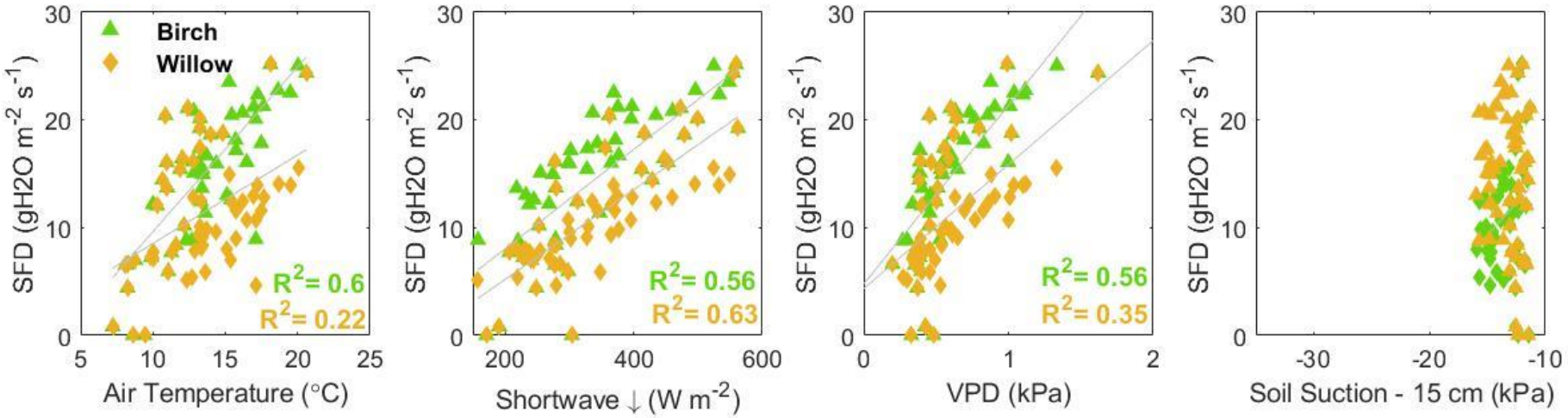
- T_{air} drives ET in mid-growing season
- Surface resistance controls ET in shoulder seasons

What drives T?

Species-specific response: Does plant composition matter?

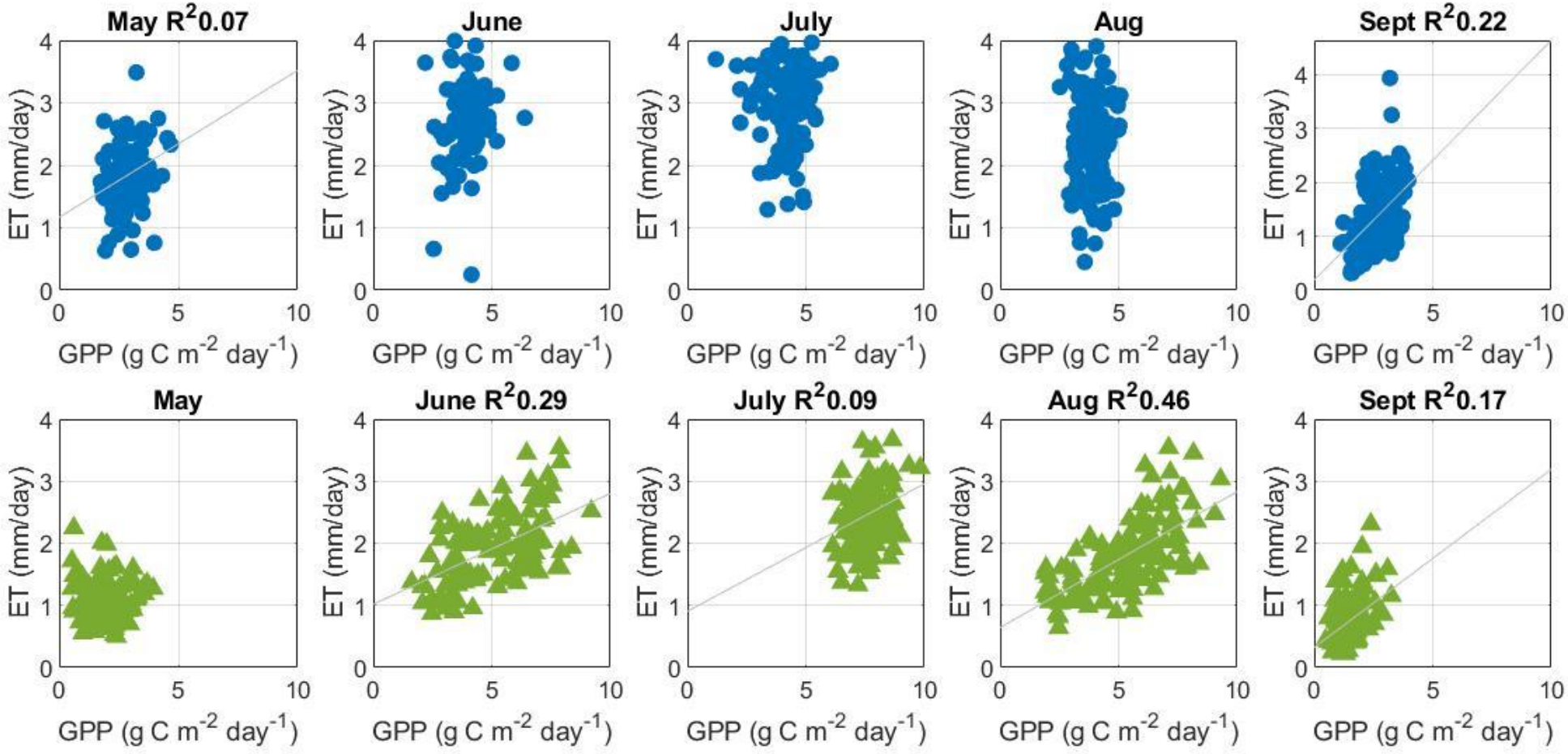
- Forest T controlled by net radiation
- Buckbrush T controlled by T_{air} and VPD
- Willow and birch have different sensitivities to air temperature and VPD





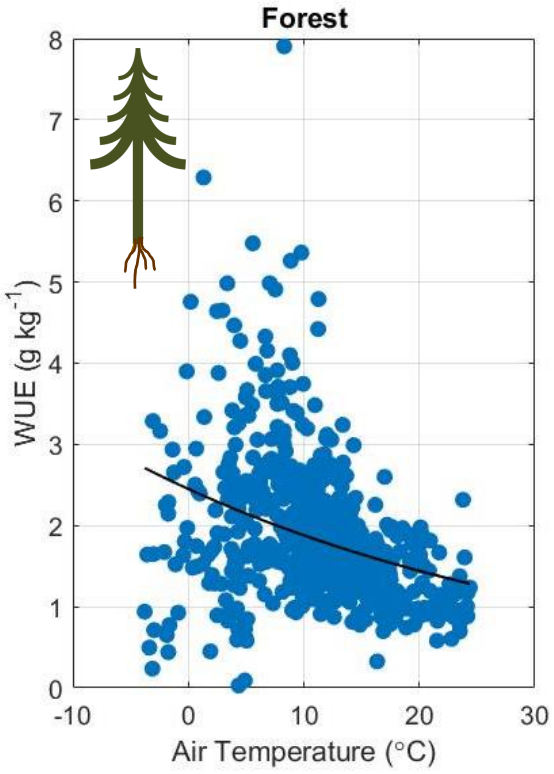
How does water use vary between Forest and shrubs?

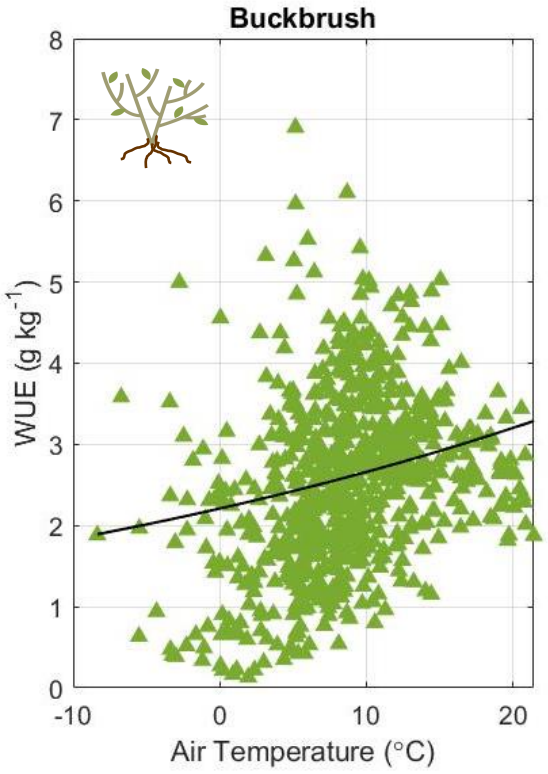
- Forest: ET not well coupled to GPP → ET is not physiologically controlled in growing season
- Buckbrush: ET and GPP coupled in June and August when T is a large component of ET

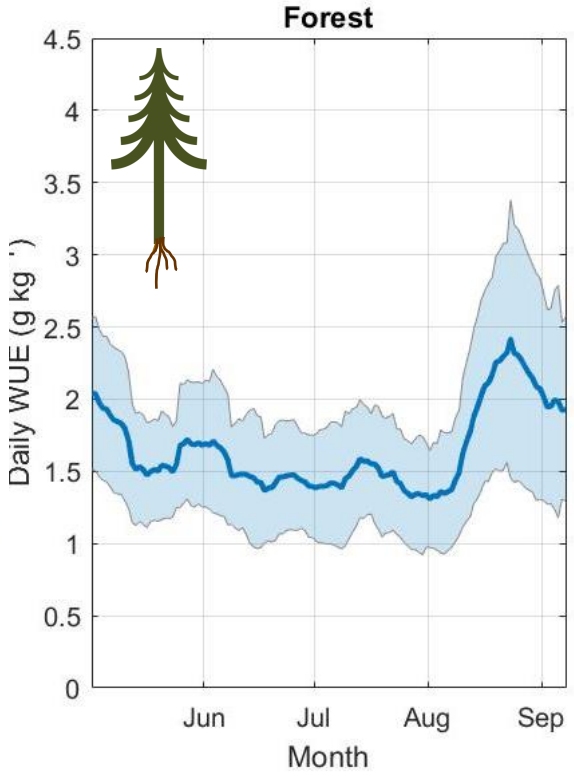


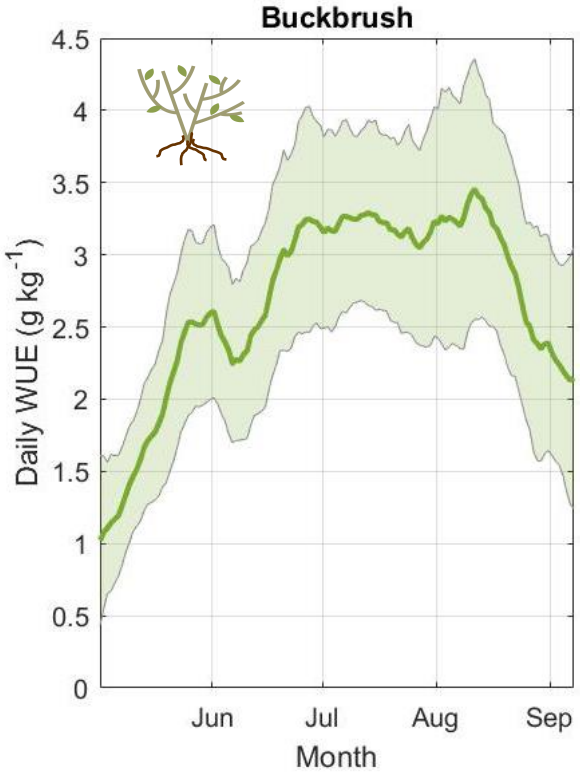
How does water use vary between Forest and shrubs?

- Mid-season WUE higher at Buckbrush than Forest
- Opposite relationship between WUE and air temperature at Forest and Buckbrush









Response to climate change will differ across ecosystems:

- Net radiation controls T and ET
- ET dynamics less variable interannually
- T:ET ~50%
- T less sensitive to changes in air temperature and growing season length
- Timing and magnitude of rainfall influence ET

- T and ET sensitive to change in air temperature and VPD during the growing season
- T:ET ~80% but sensitive to weather conditions
- Changes to length of growing season will impact ET losses

Thank you!

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