A new frost-centric snowmelt partitioning framework — with applications to northern Minnesota forests

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Soil frost is known to limit infiltration which influences the partition of snowmelt at the land surface. However, frost's effects on partitioned spring flows might be more complex.

- Plant transpiration increases with reduced soil frost persistence (Anurag, 2022)

- Increases in soil frost can lead to decreases in subsurface flow, but not infiltration (Fuss et al., 2016)

- Studies examining the influence of soil frost on drainage/recharge and evapotranspiration are limited (Ala-aho e al., 2020)

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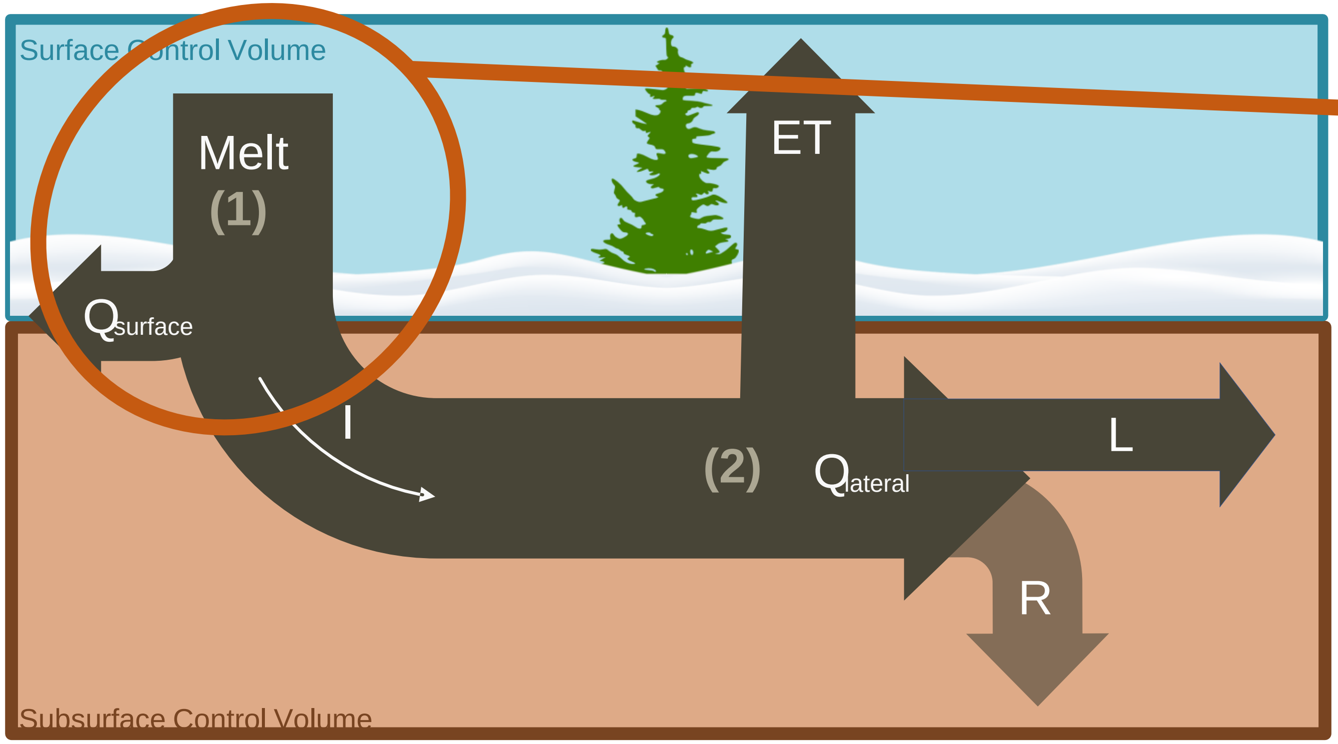
How can we account for the effects of soil frost on spring water flow with the confounding effects of: (1) air temperature, (2) soil water storage capacity, (3) site to site variability

Theory: there are two major partitioning events that influence the flow of snowmelt during the spring season: a surface and a subsurface partition.



P + SWE = Infiltration + Surface Runoff

$$1 = \frac{Q_{Surface}}{P + Melt} + \frac{I}{P + Melt}$$

Infiltration = Subsurface Runoff + Drainage + ET

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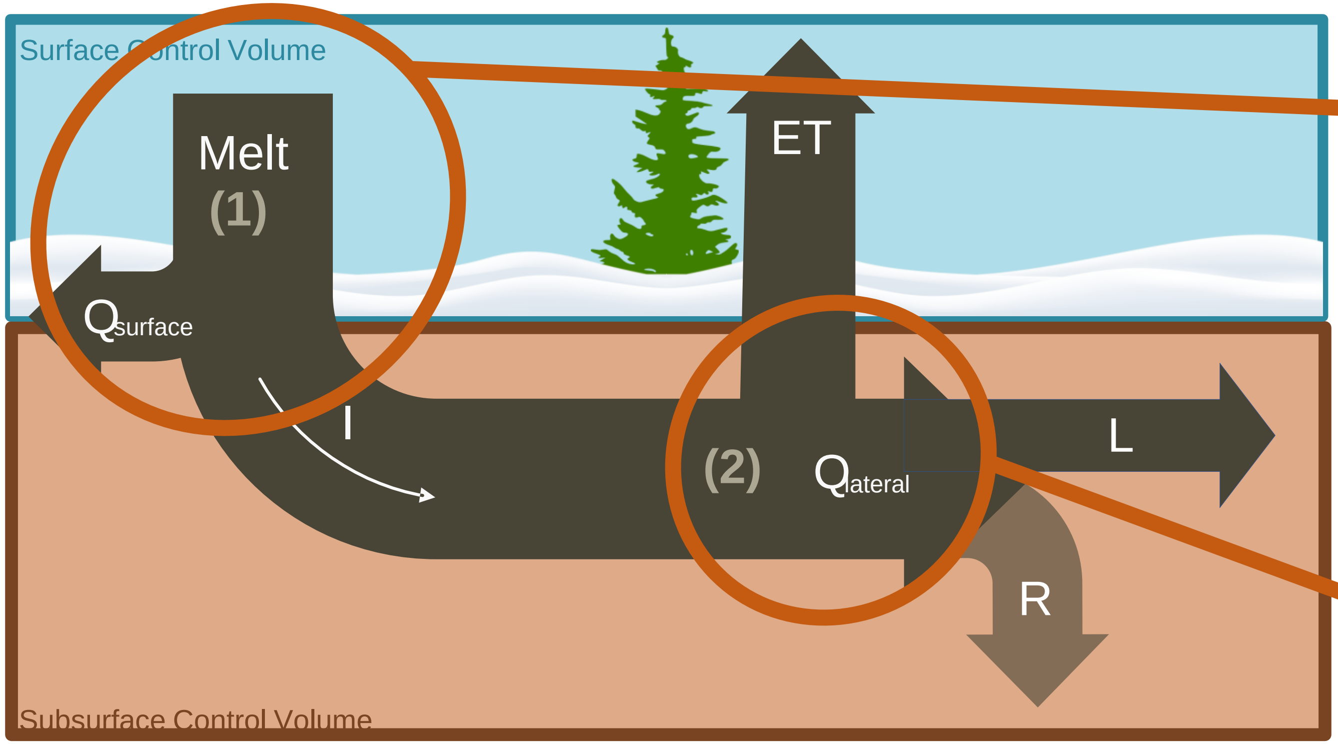

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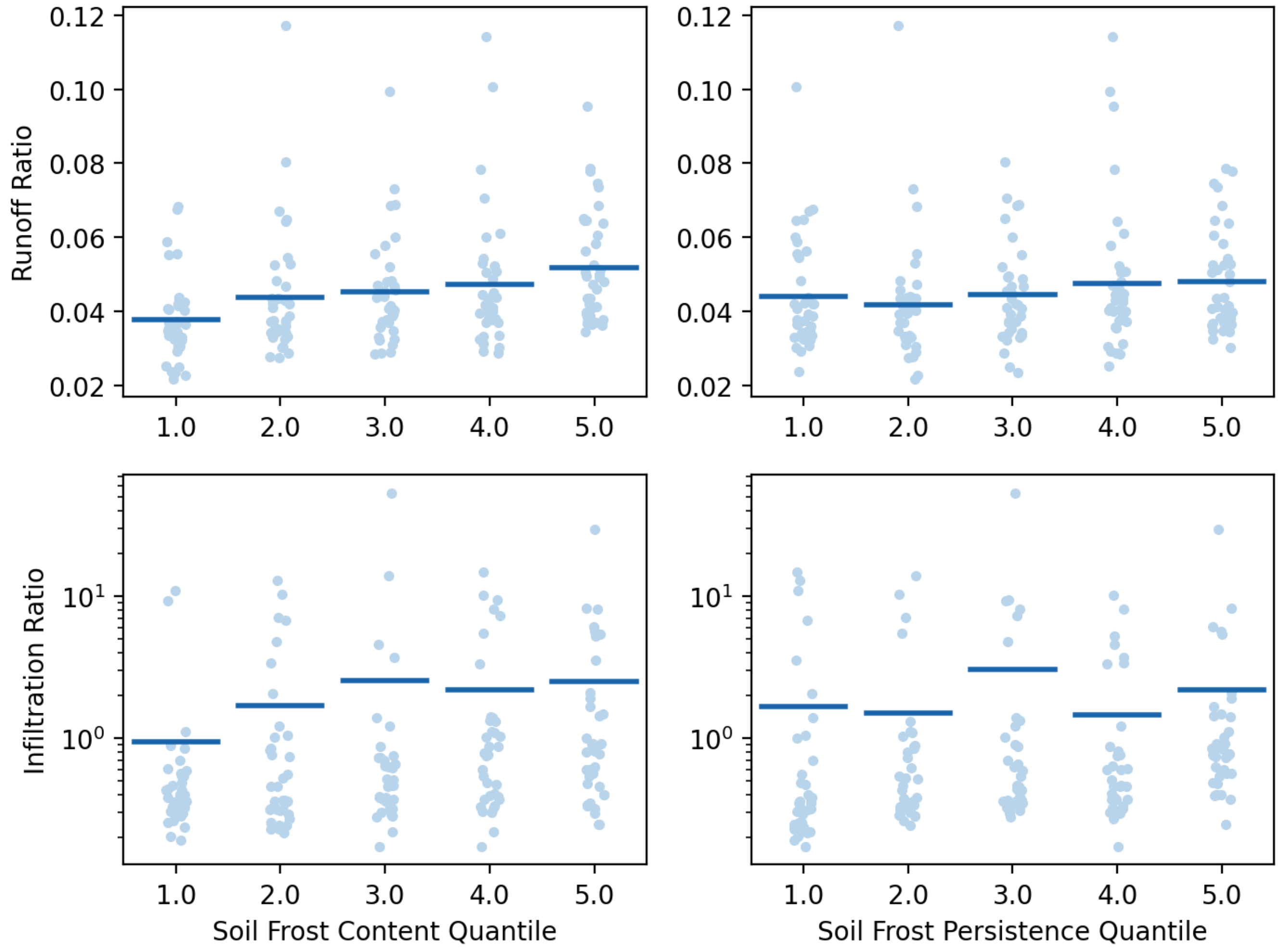
$$1 = \frac{Q_{Lateral}}{I} + \frac{T}{I} + \frac{Drain}{I}$$

Result 1 - At the surface, higher soil frost content in the soil layers leads to increases in both runoff and infiltration ratios



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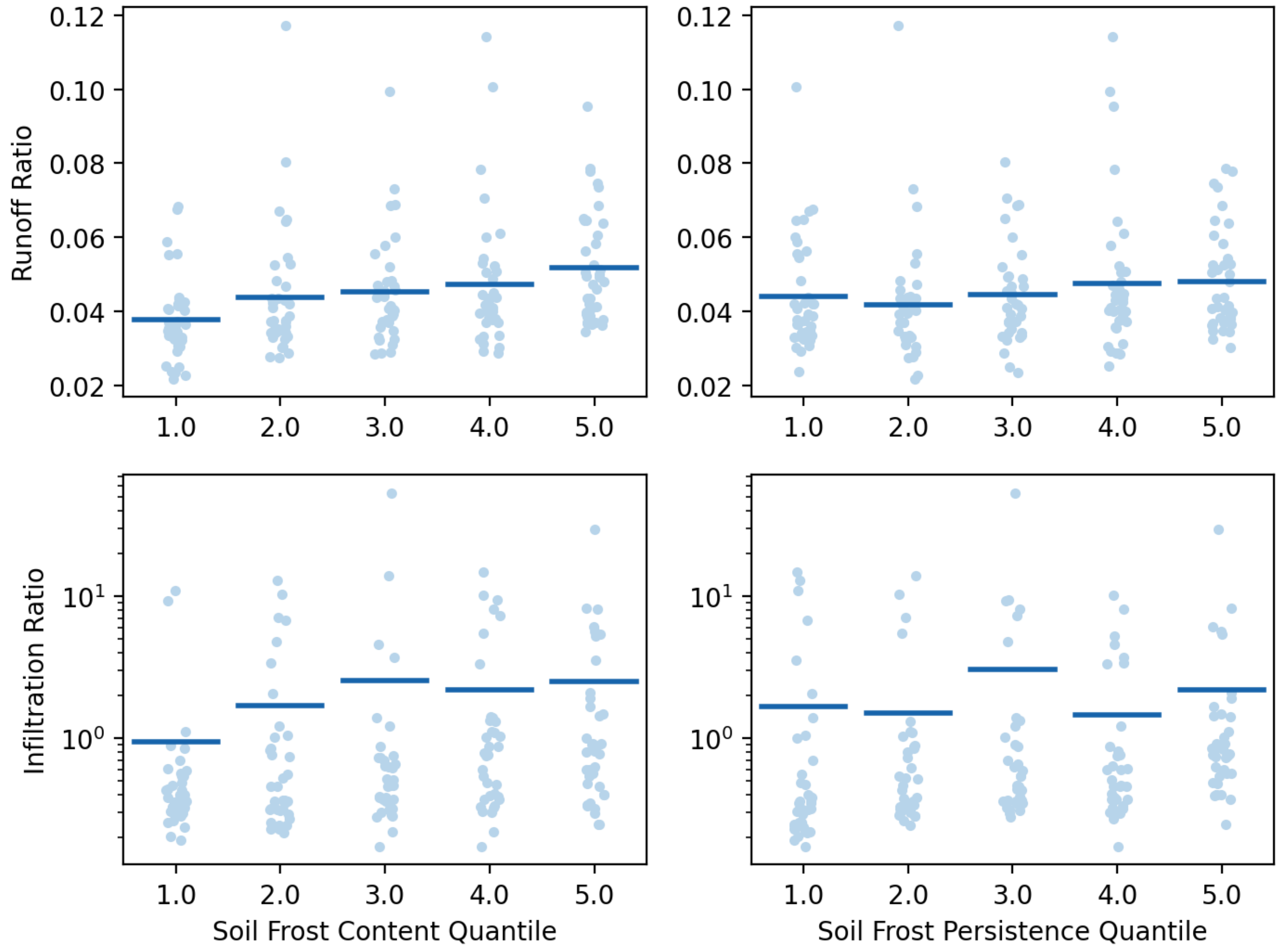

Soil frost content	Soil frost persistence
↑	—
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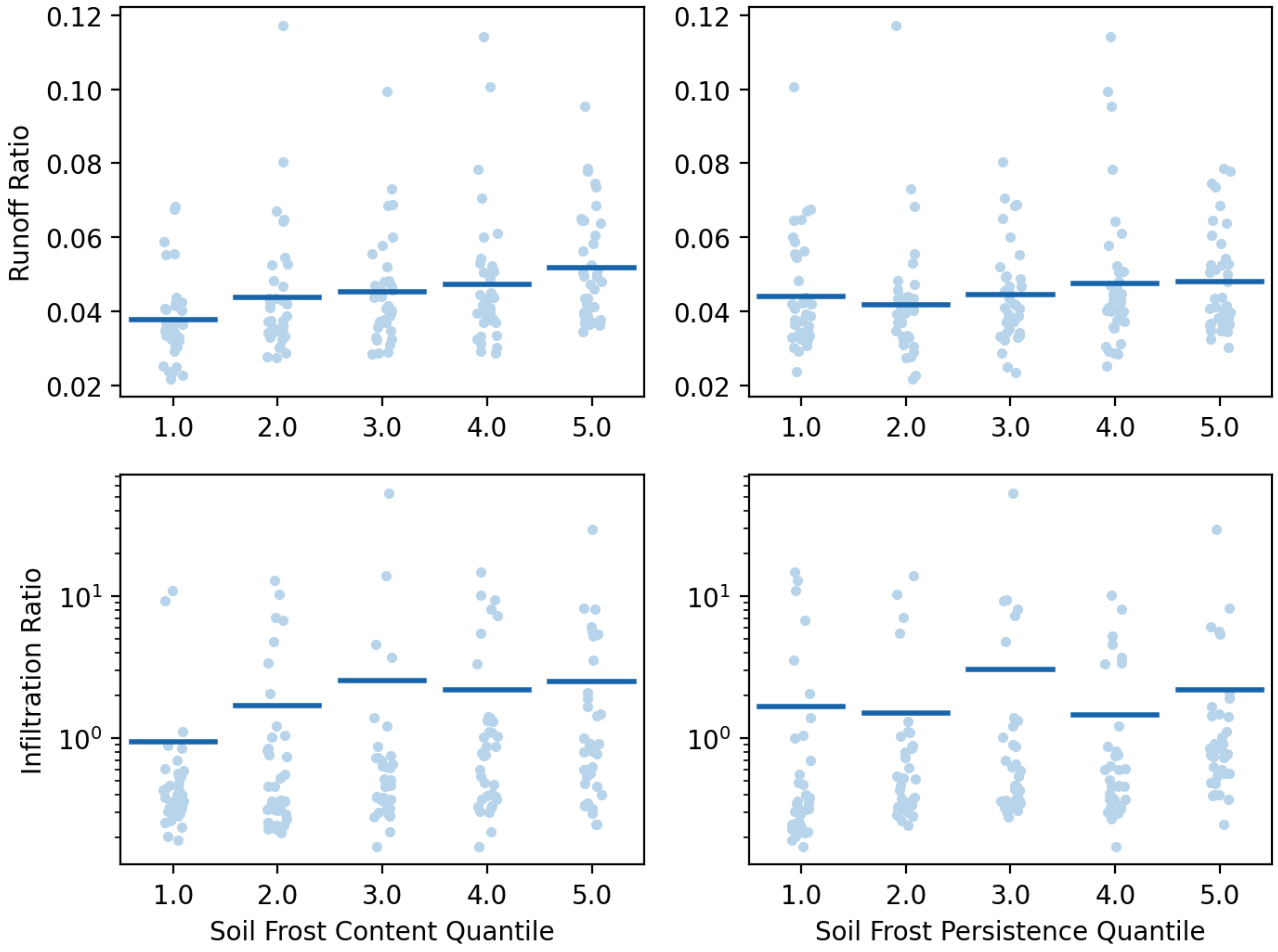

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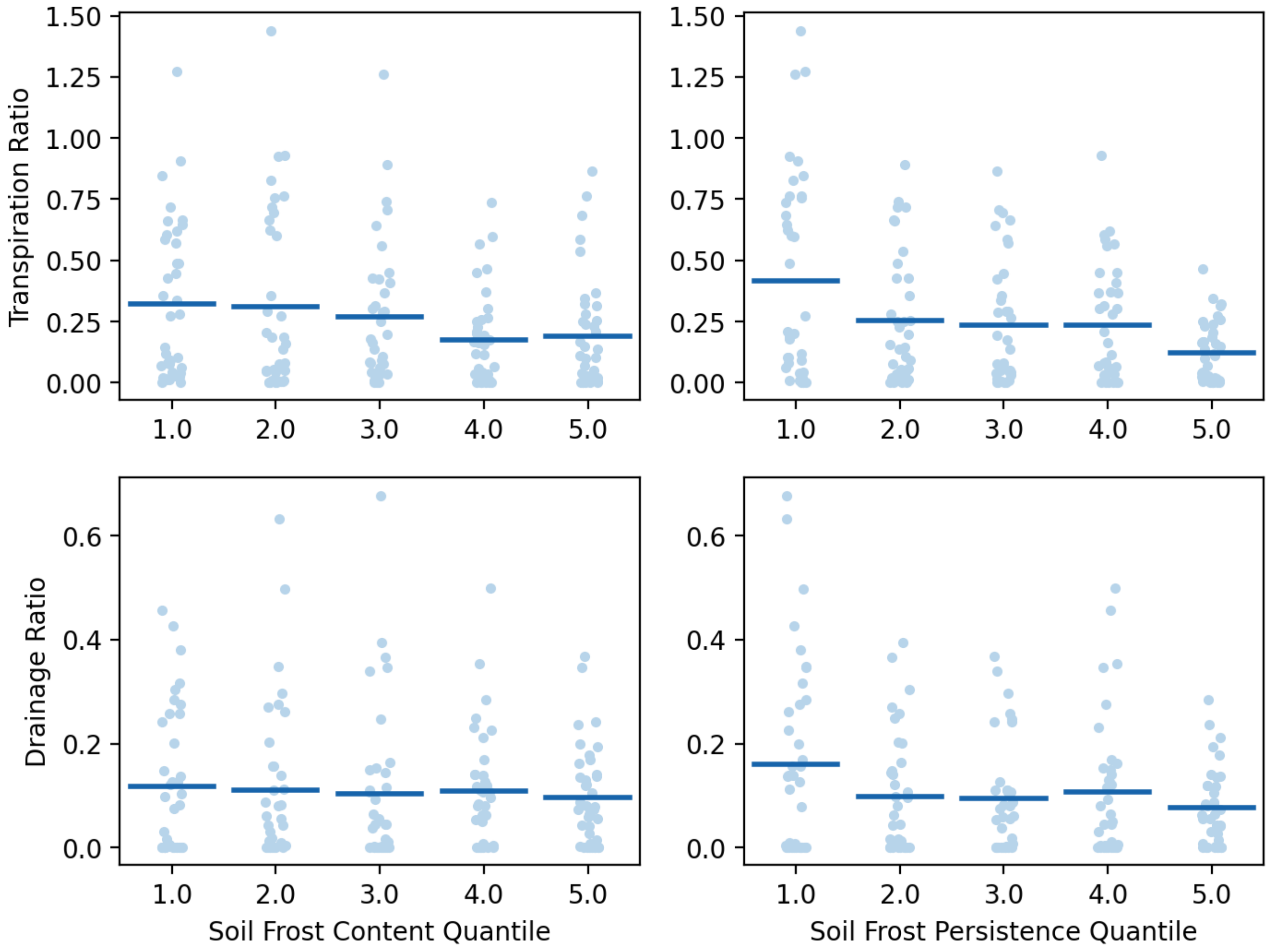
Maximum soil frost **content** is responsible for determining the **surface** partition

Result 2 - In the subsurface, shorter soil frost persistence leads to increased transpiration and drainage ratios.



$$\frac{T}{I}$$

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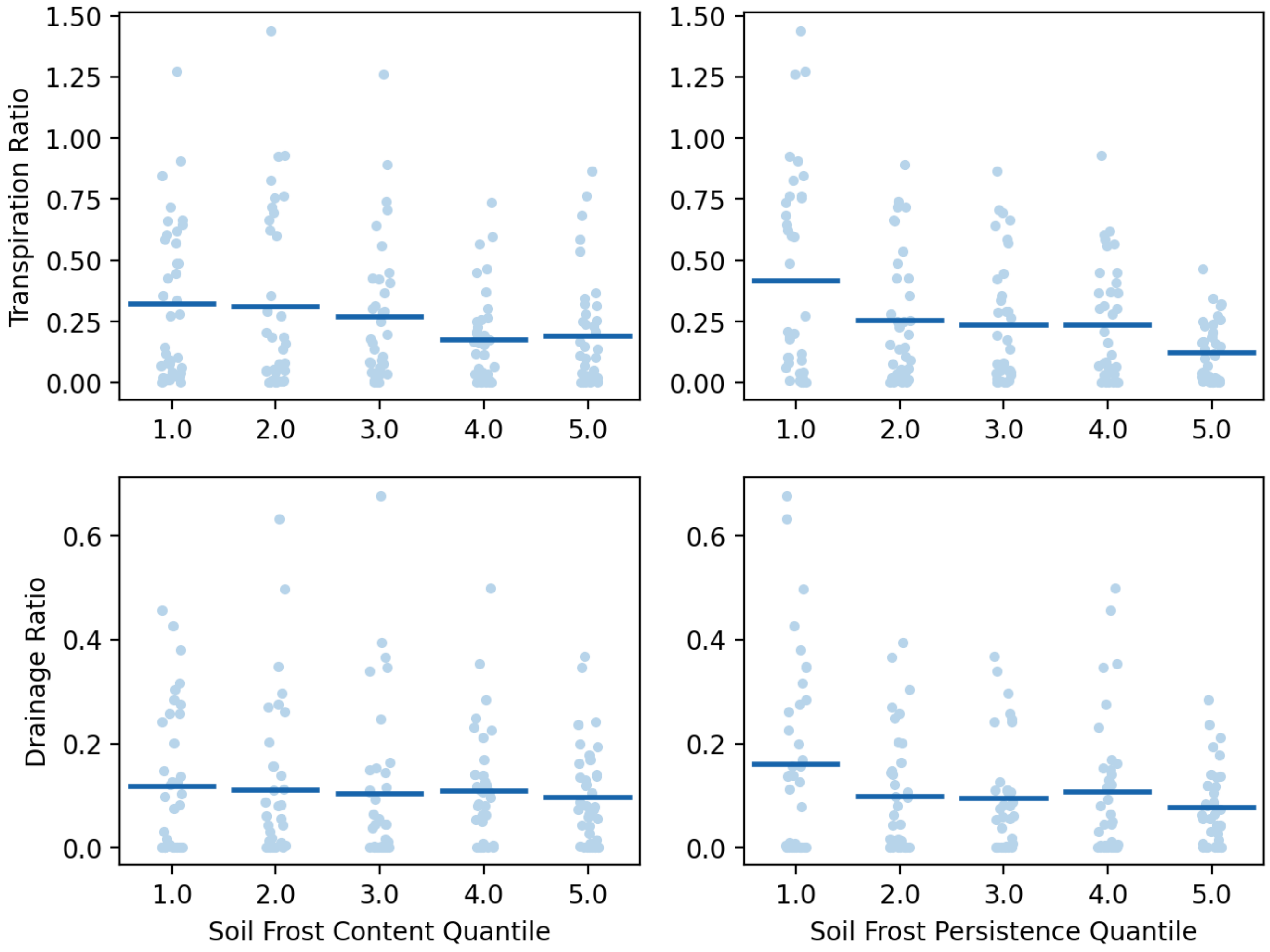

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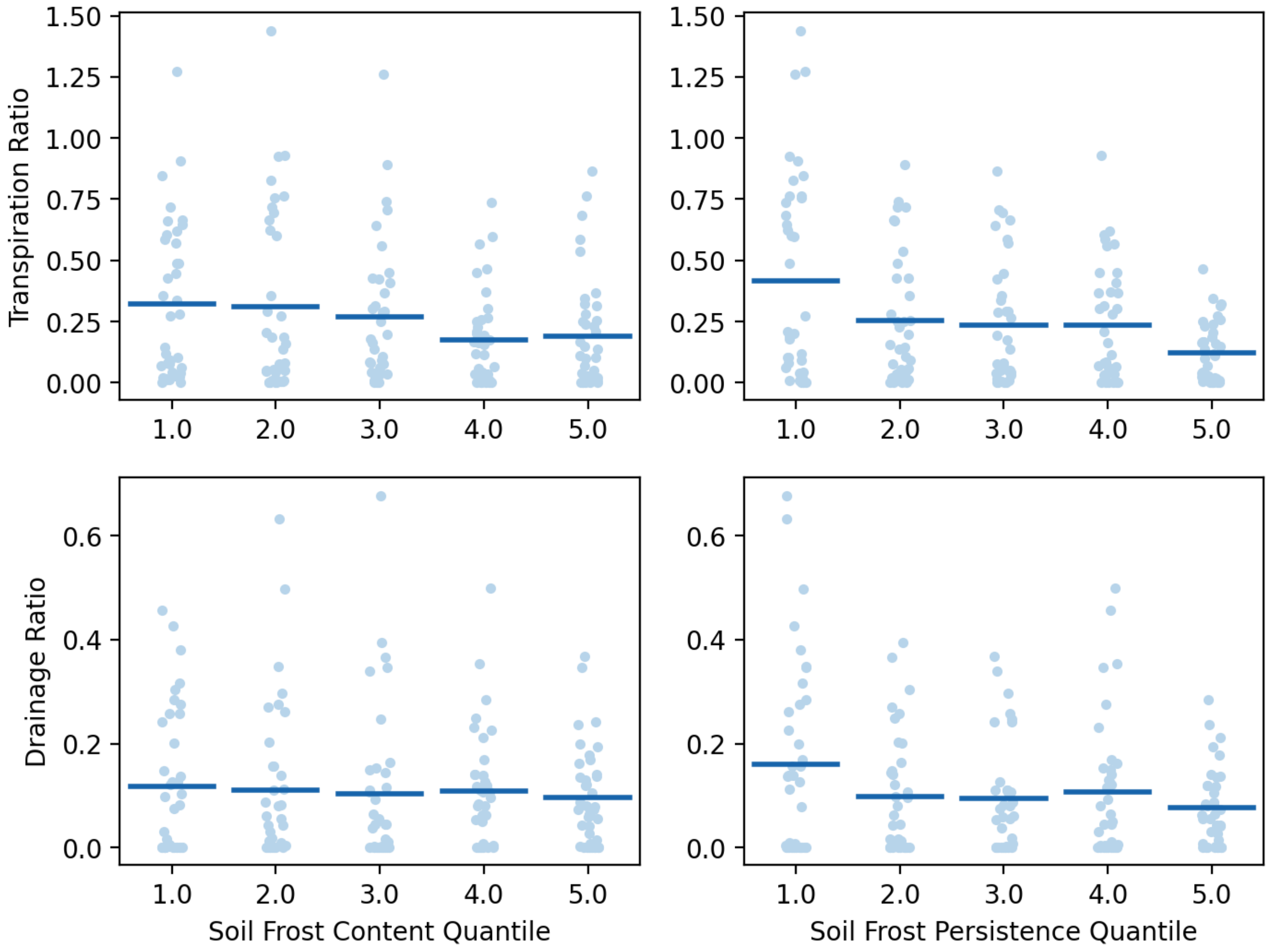

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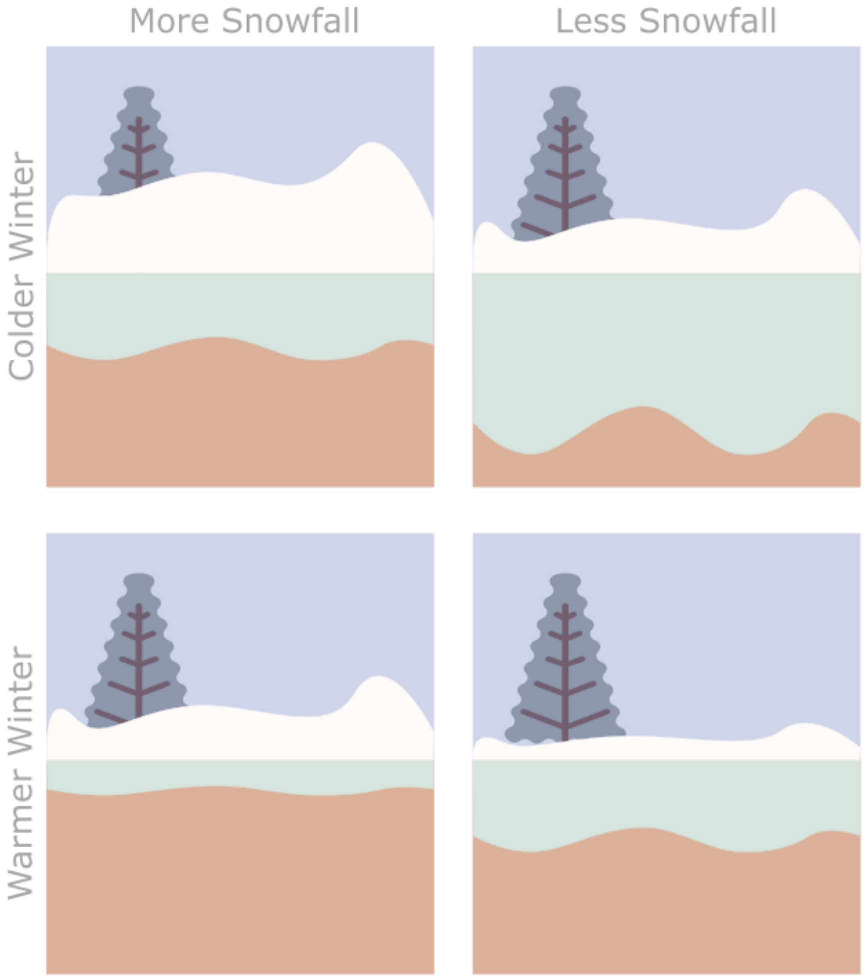
Soil frost **persistence** is responsible for determining the **subsurface** partition

Under four alternative winter climate scenarios, this framework can used to explain changes in spring flows



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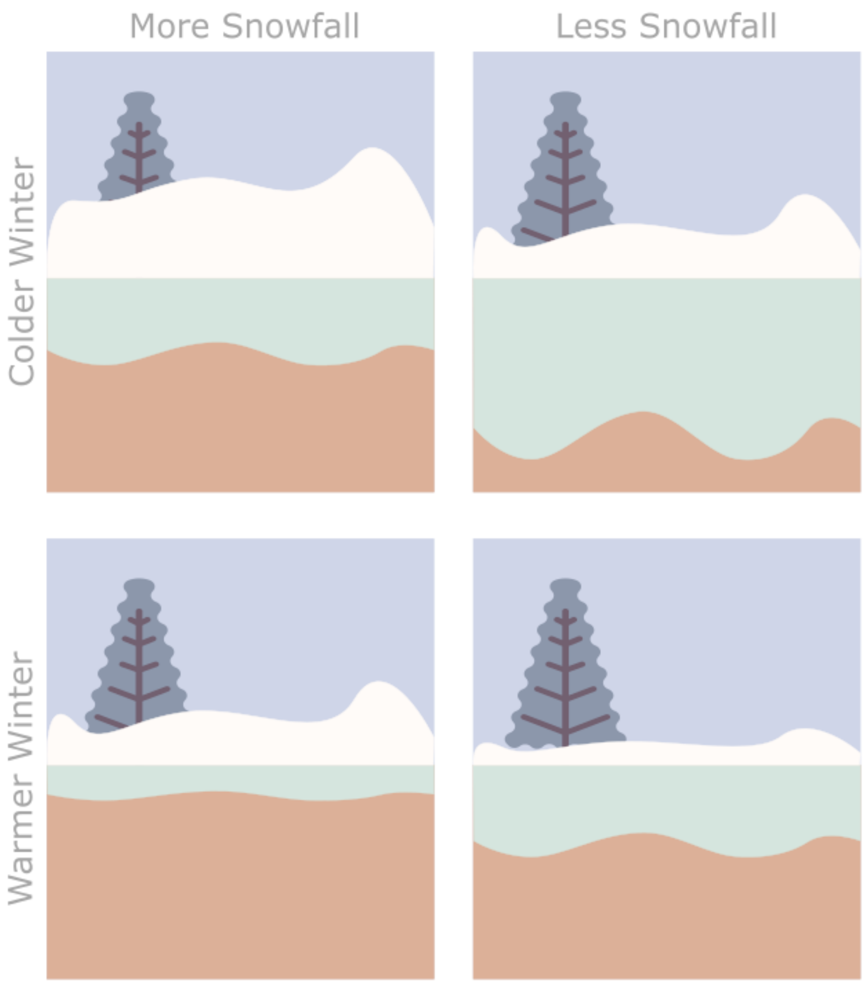
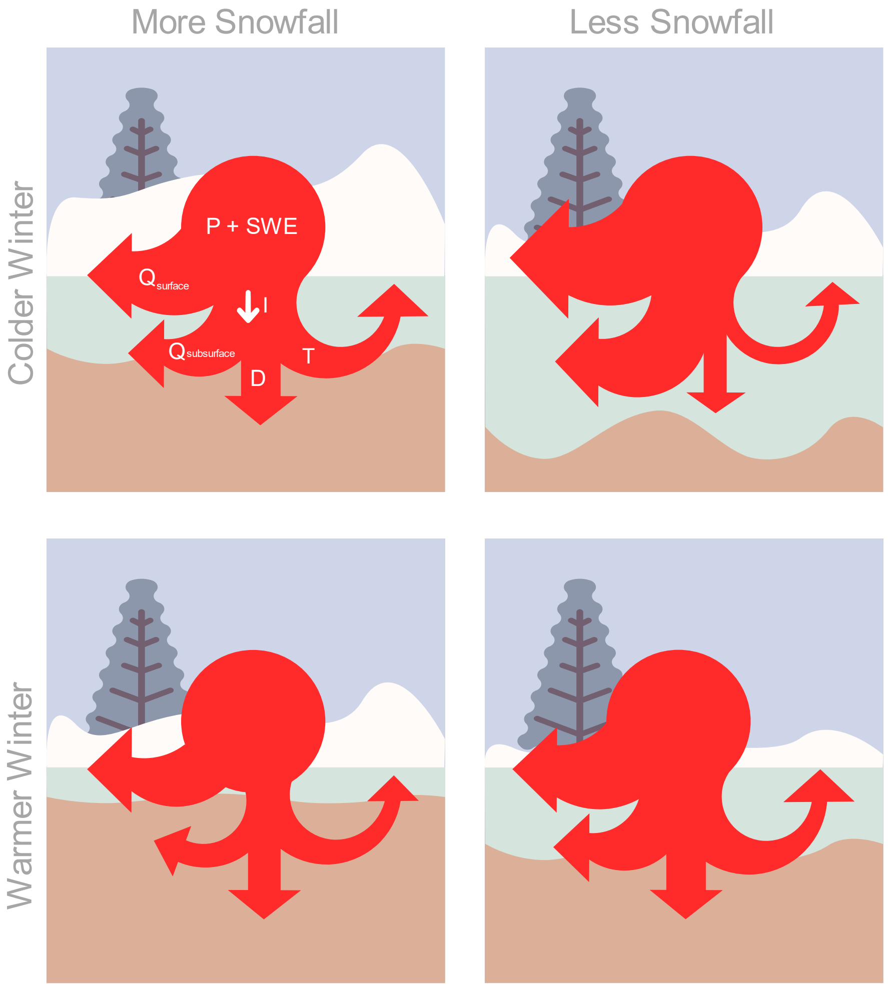
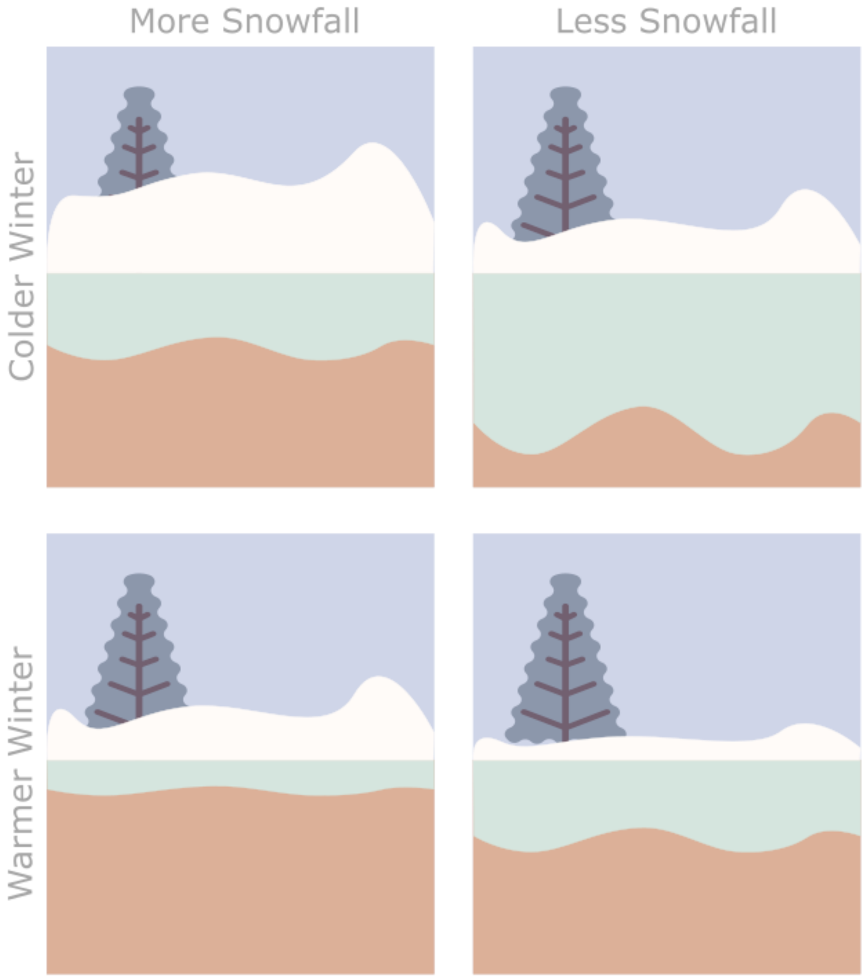
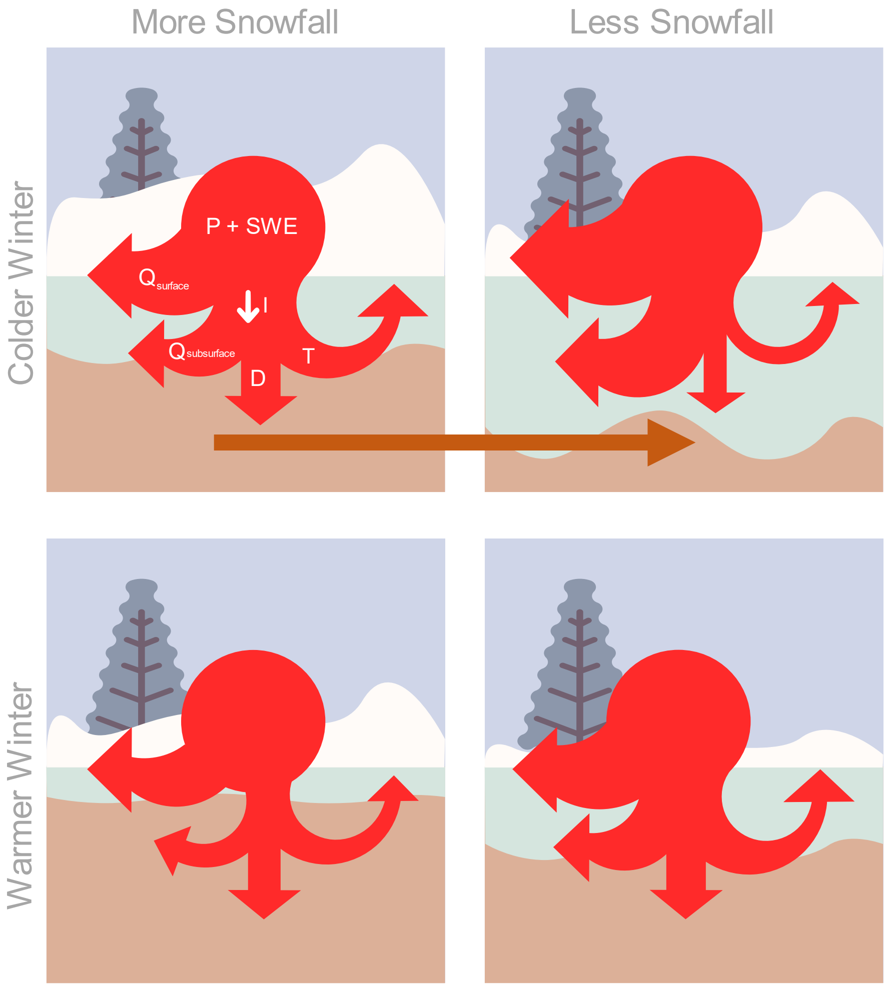


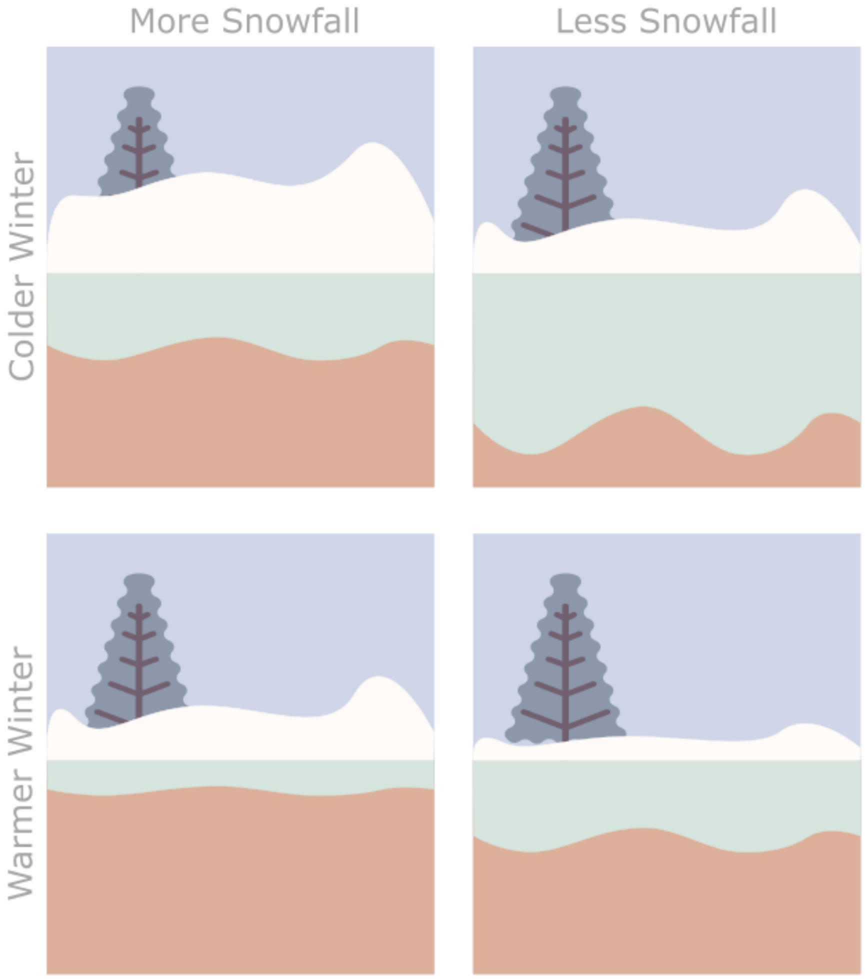


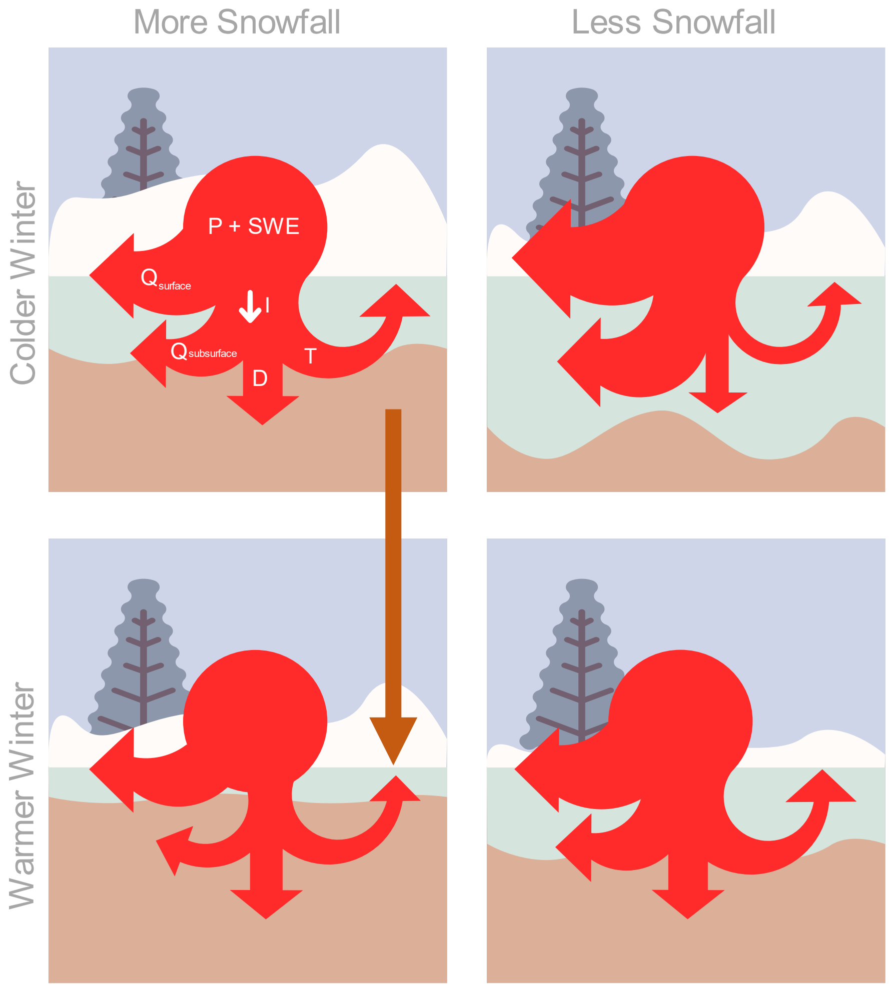
Shifting from high to low snow winters will lead to an increase in both surface and subsurface runoff ratios and decreases in transpiration and drainage ratios.

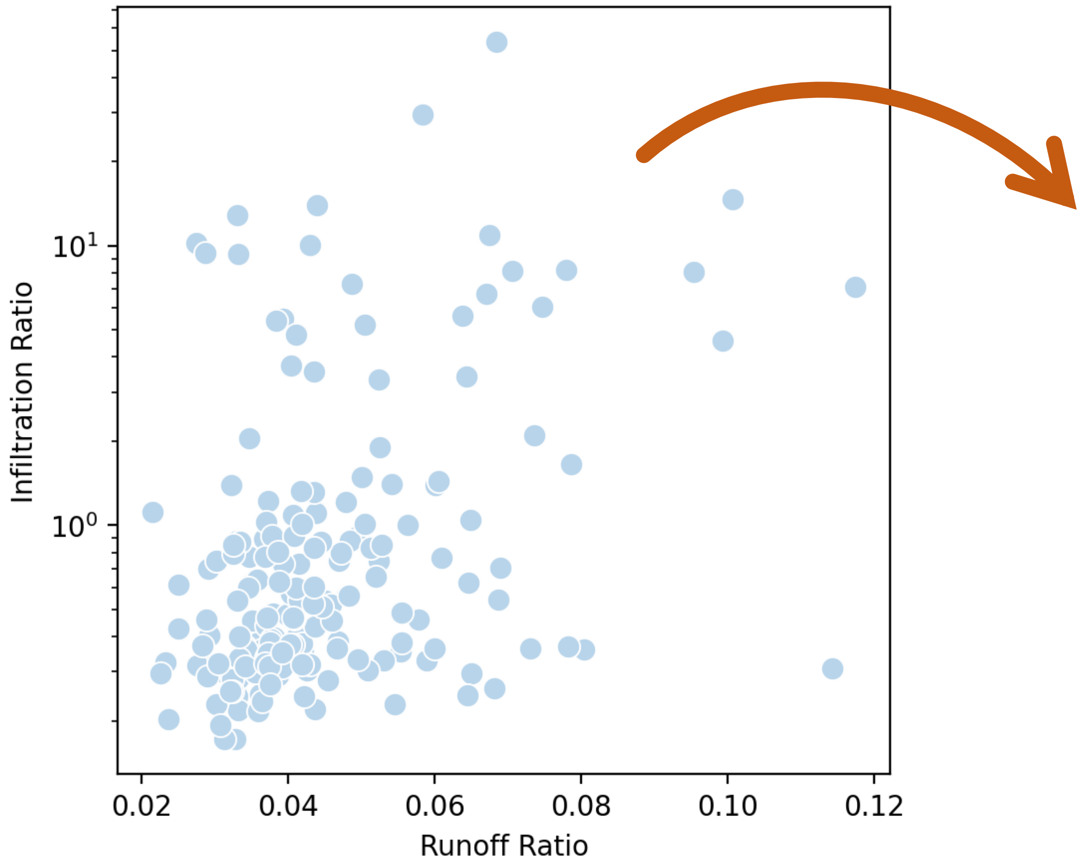




Shifting from colder to warmer springs will lead to a decreases in both surface and subsurface runoff ratios and increases in transpiration and drainage ratios.



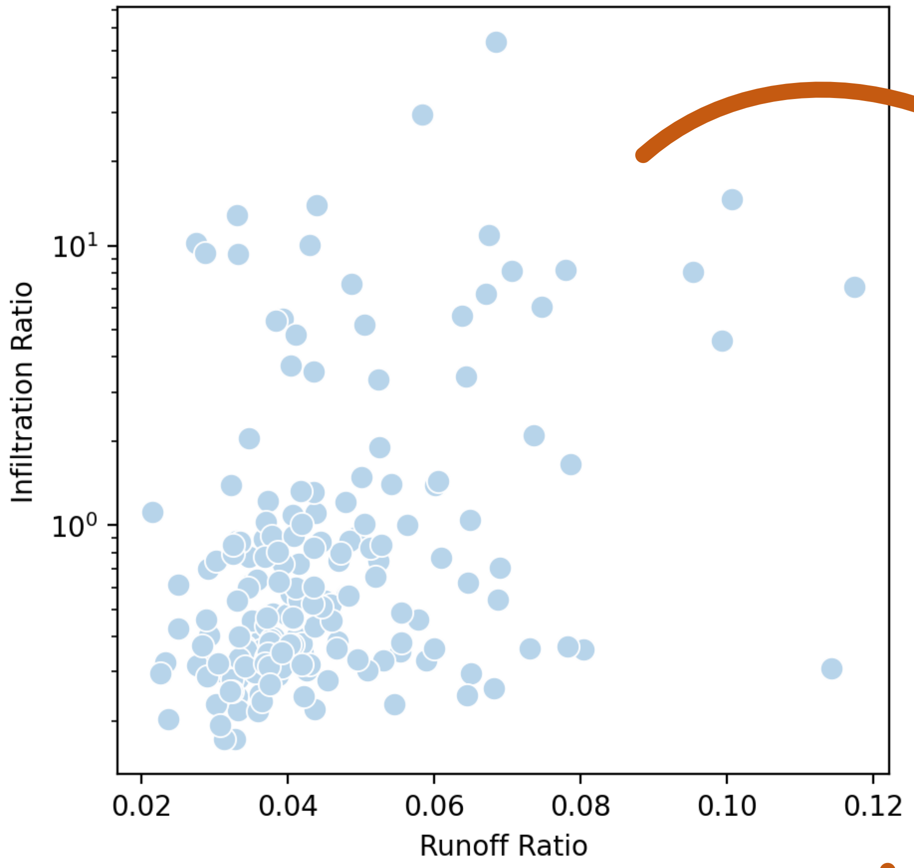




Additional Considerations

Antecedent Soil Moisture

Our data shows that there is no tradeoff between runoff fraction and infiltration fraction (as expected) – either due to sublimation flux or carry over effects of soil water storage from the fall.



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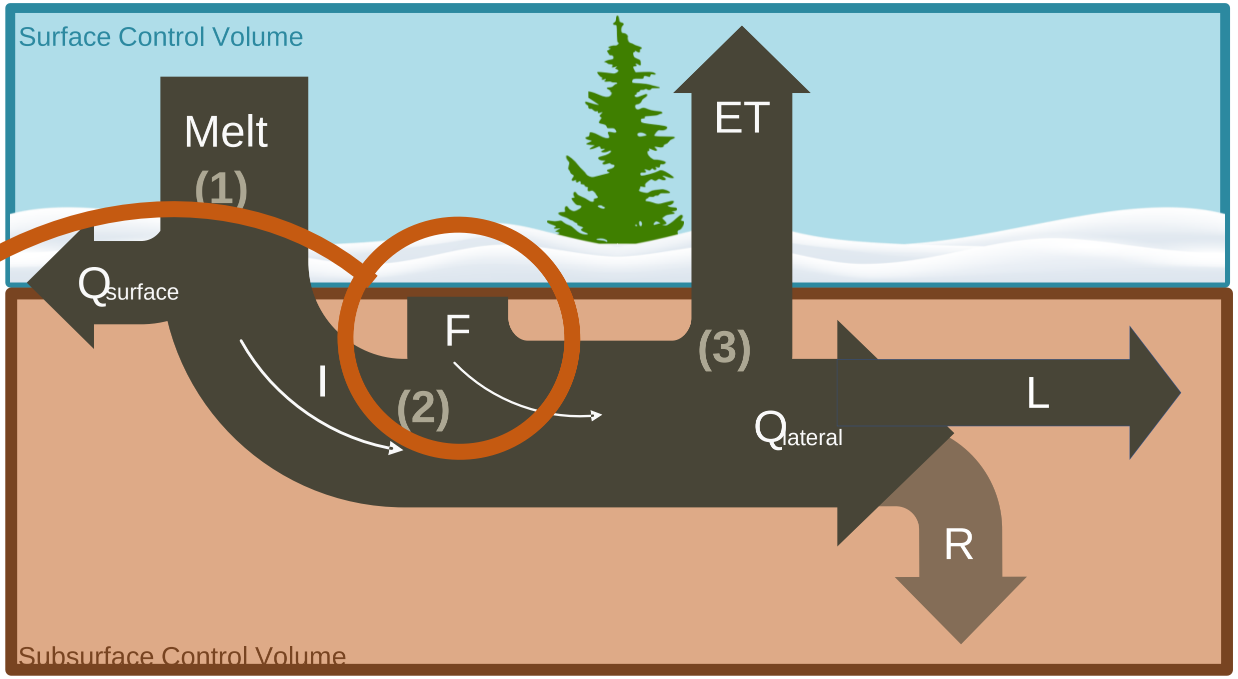

Frost melt

The melting of soil frost in the spring may also affect soil moisture– likely providing additional available water for partitioning into ET, drainage, and runoff.

1. Separating the snowmelt into surface and subsurface partitions can help disentangle the effects of soil frost on spring water availability

2. Soil frost presence determines the surface partition between spring surface runoff and infiltration, whereas soil frost persistence controls the subsurface partition between spring transpiration, lateral flow, and deep drainage

3. Additional water fluxes (sublimation) and stores (carry over fall soil moisture, frost) need to be accounted for.

Do you have any questions?

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