

How Will Forests Affect Mountain Snow Storage in a Warming Climate?

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Jessica Lundquist – University of Washington

Anne Nolin – Oregon State University

Mark Raleigh – University of Colorado

Julie Vano – UCAR, Boulder, Colorado



Funding:

Northwest Climate Science Center (Dept of Interior)



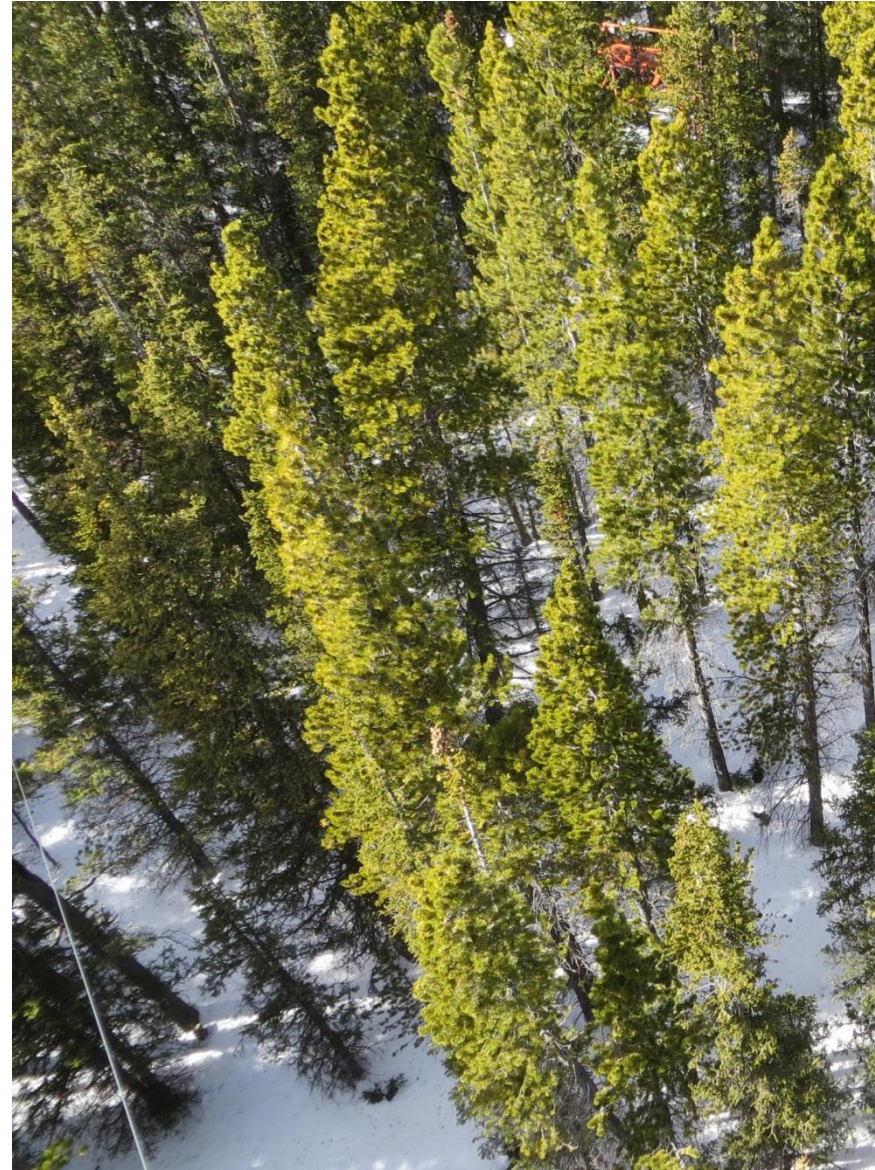
Overview

Motivation: Climate Change and Forest Change

Background: Forest-Snow Processes

Research: Snow Storage across the PNW

Application: Decision Tree and Examples



Conclusions

Motivation: Climate Change and Forest Change

Combined effects on snow important

Background: Forest-Snow Processes

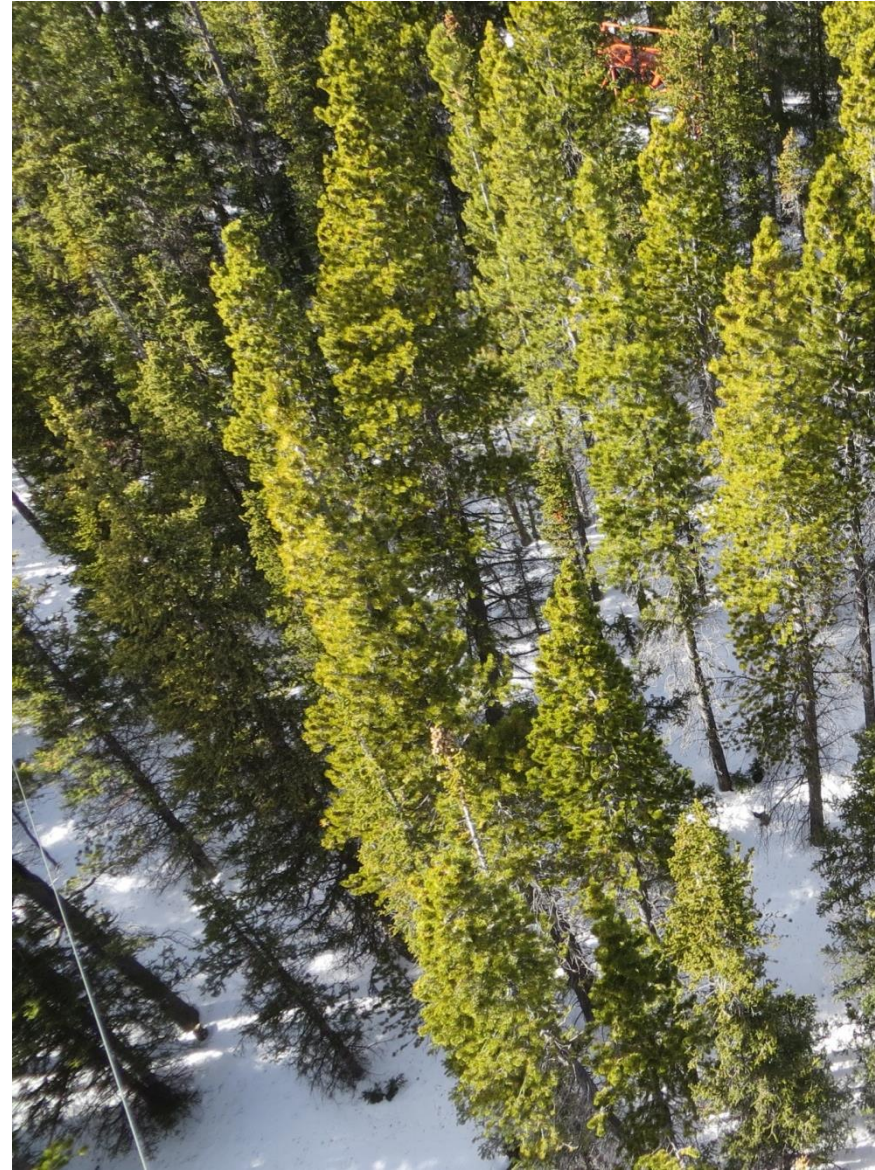
Vary in time and space

Research: Snow Storage across the PNW

Limitations... but there are patterns

Application: Decision Tree and Examples

Actions for today and future



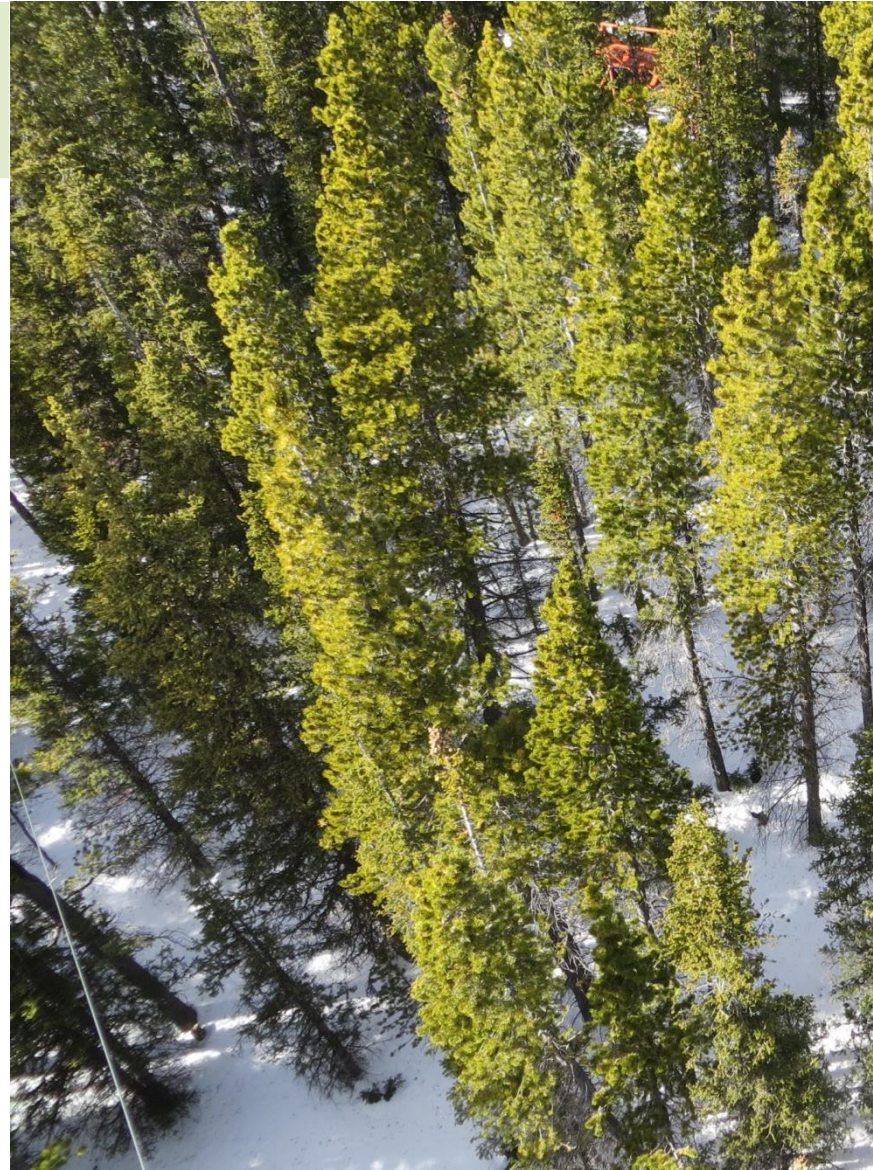
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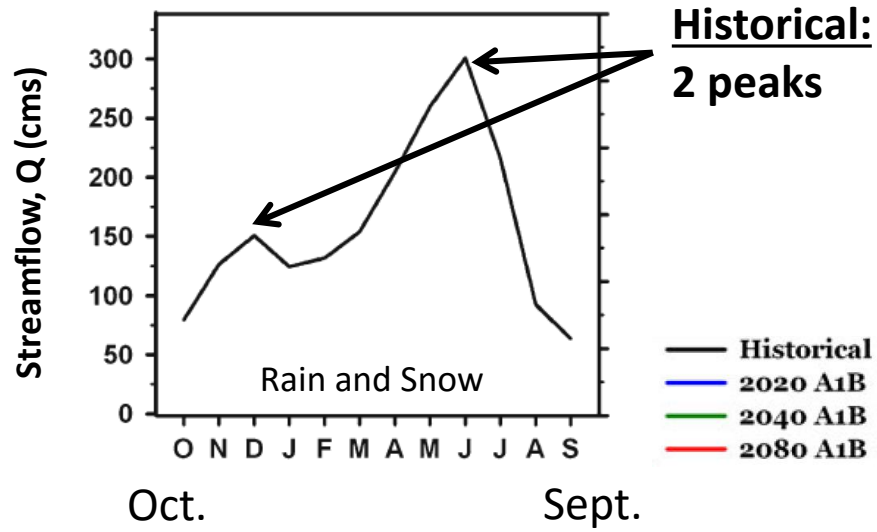
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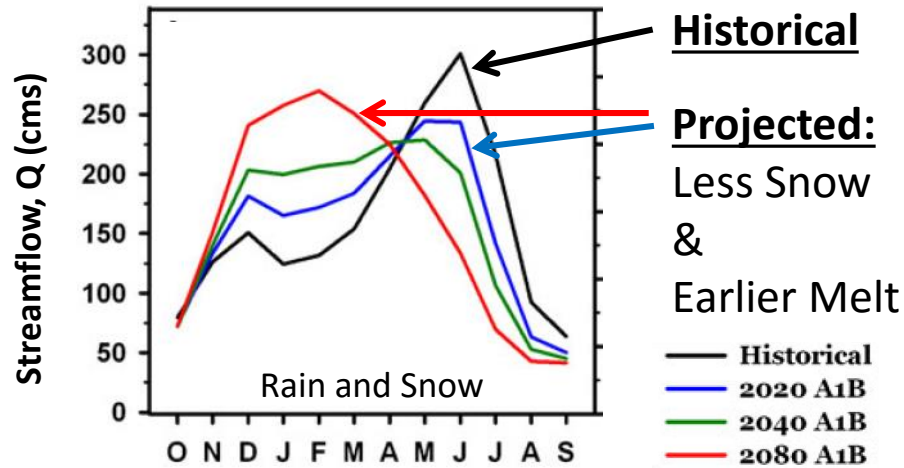
Motivation: Climate Change Effects on Streamflow

Yakima River near Parker



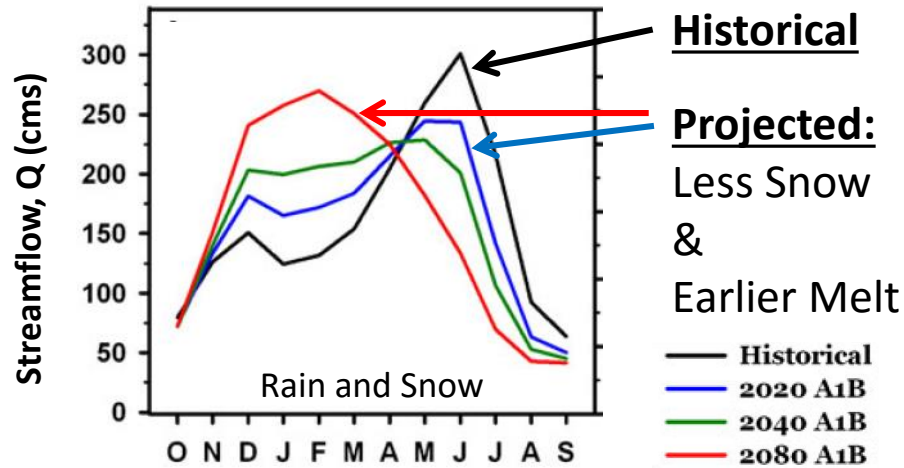
Motivation: Climate Change Effects on Streamflow

Yakima River near Parker



Motivation: Climate Change + Forest Change

Yakima River near Parker



Forest Effects on Snow Storage?

"Does Timber Preserve Snow", 1906

THE OURAY HERALD.

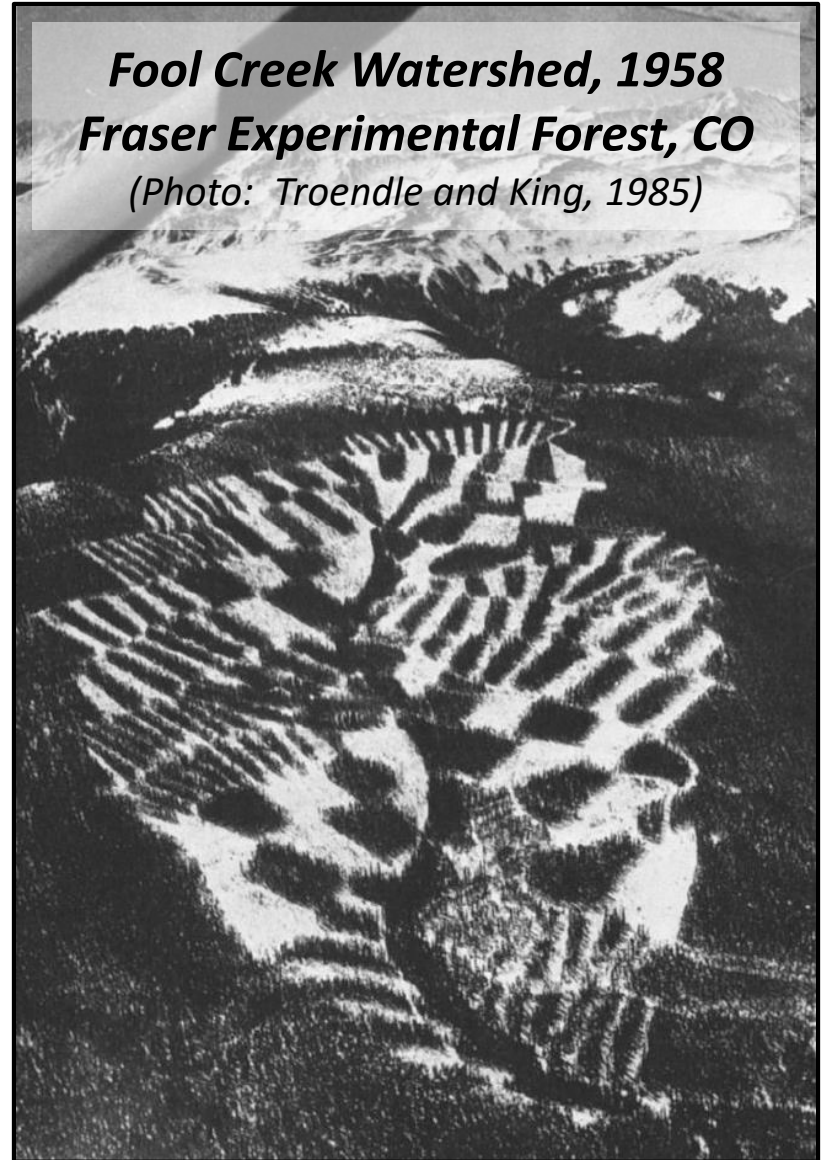
Ouray Second County in Colorado in Gold Production and Third in Aggregate Mineral Output The Herald Prints All of the Reliable Mining News
VOL. XVIII. NO. 19. OURAY, OURAY COUNTY, COLORADO, FRIDAY, AUGUST 3, 1906. PRICE FIVE CENTS

OURAY, OURAY COUNTY, COLORADO, FRIDAY, AUGUST 3, 1906.

<p>we will we will acy. we dem- dem- esy lest d Speer e same before we will l defeat of Mc- Hanna in this looking mocratic</p>	<h3>Does Timber Preserve Snow</h3> <p>Most of us have, without question, concluded that snow will last longer in the timber than in open parks and that the timber in the mountains is the great natural reservoir which retains the snow and consequently the water supply for the late summer. The following from the Gunnison News-Champion on the subject is worthy of consideration:</p> <p>All forestry experts say it does. Experience and observation of hundreds of years in European mountains and the hills of eastern America proves that it does. Prof. Car-</p>	<p>It is nounce the de ty's ol zons, Oakla Martil settler en up died, i memb have l uously was or dustry his fe</p>
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*Fool Creek Watershed, 1958
Fraser Experimental Forest, CO*

(Photo: Troendle and King, 1985)



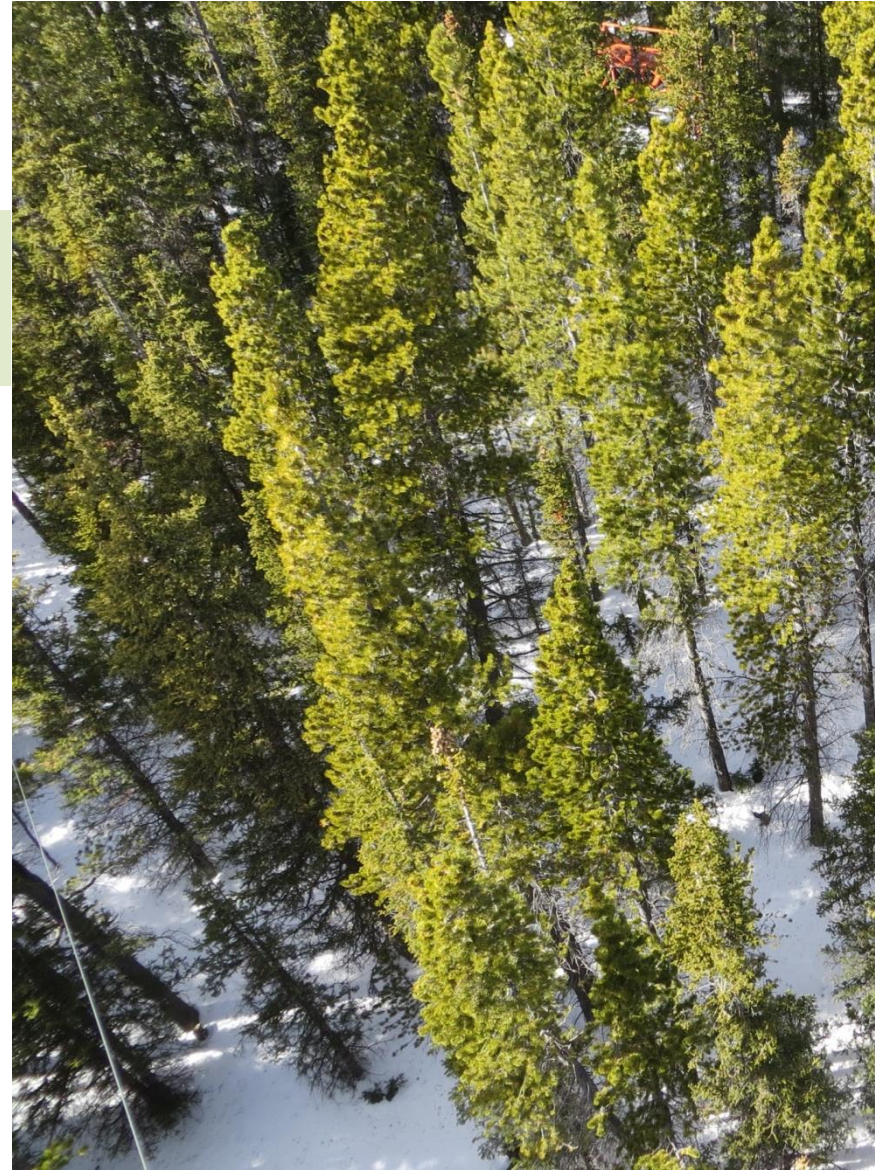
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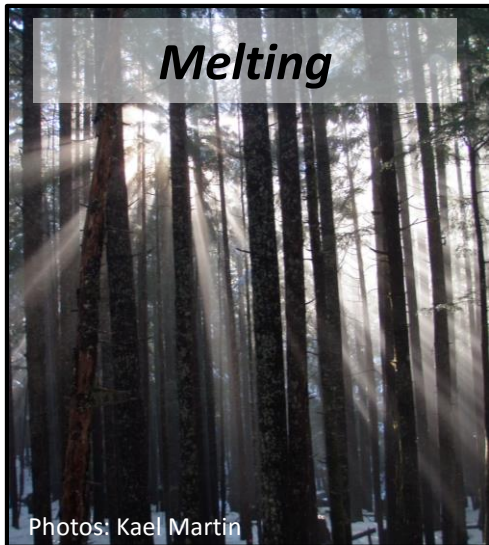
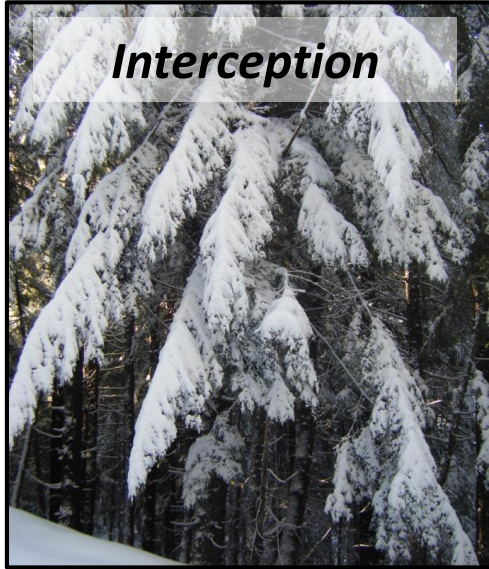
Research: Snow Storage across the PNW

Application: Decision Tree and Examples



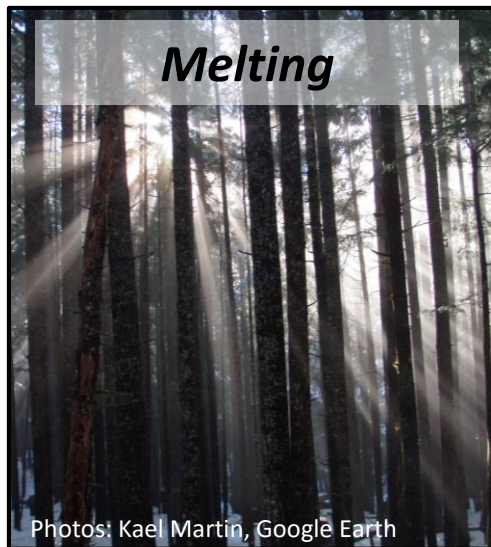
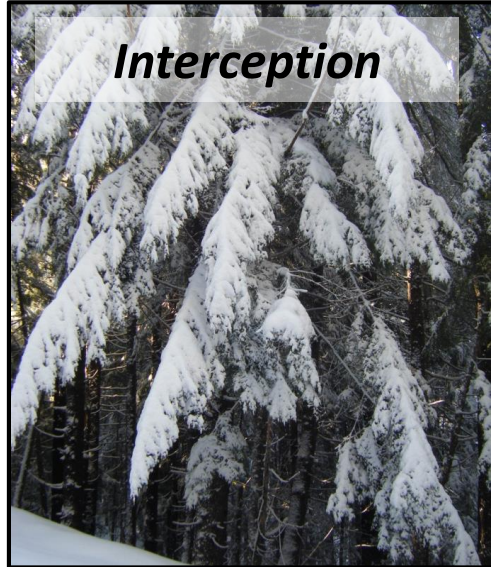
Background: Forest-Snow Processes

Processes

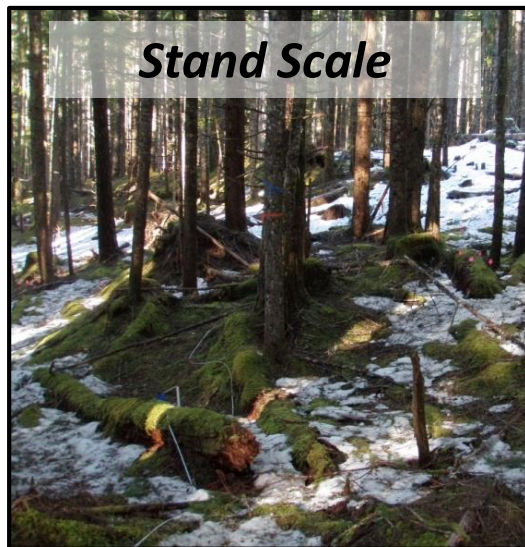


Background: Forest-Snow Processes

Processes

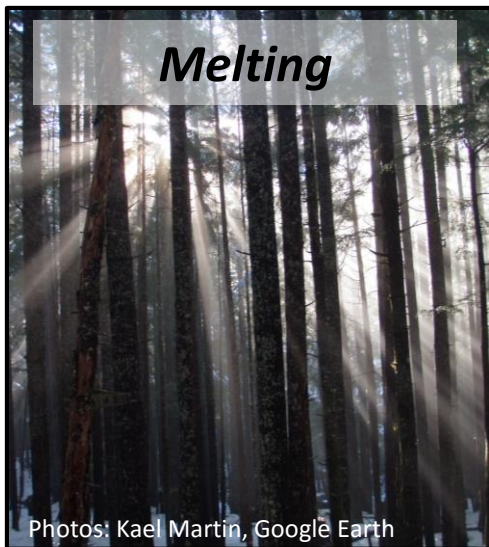
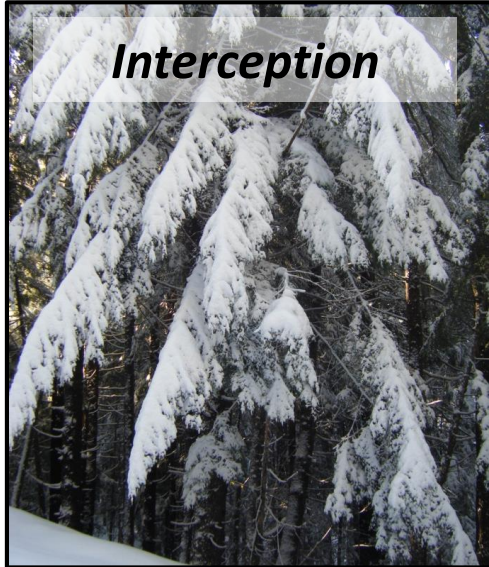


Effects

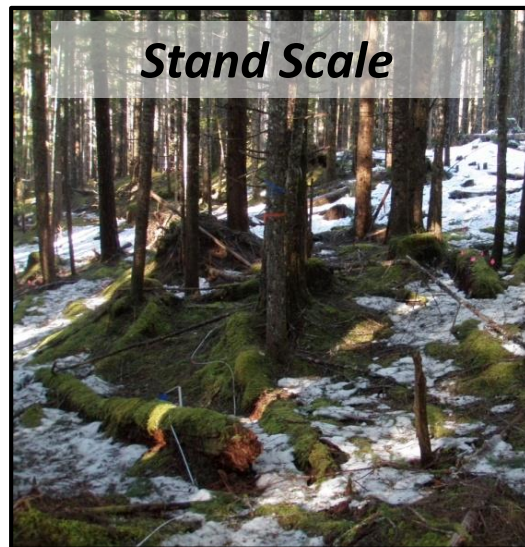


Background: Forest-Snow Processes

Processes



Effects

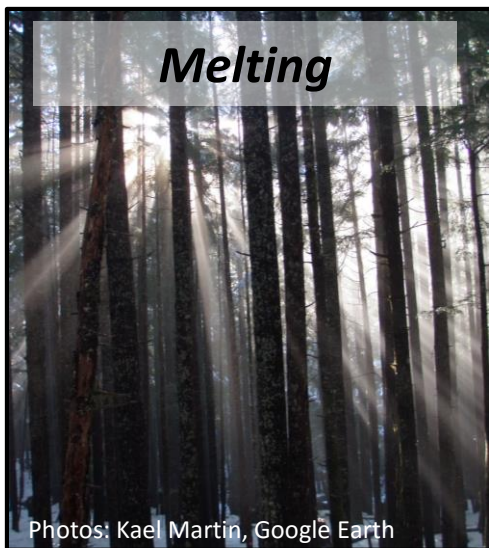
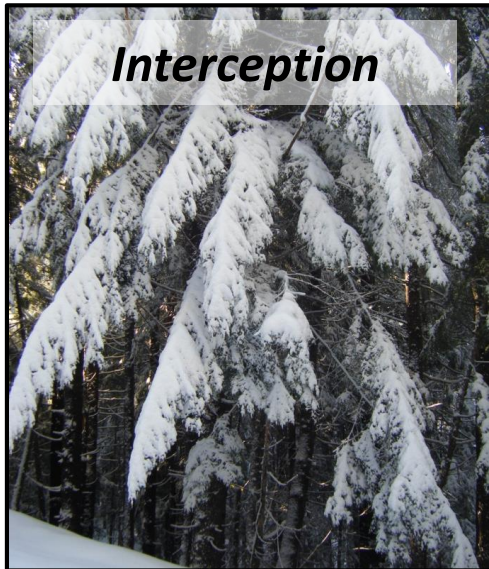


Watershed Impacts

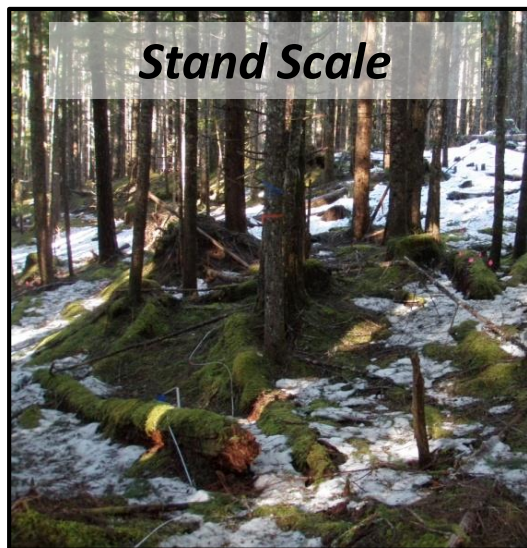
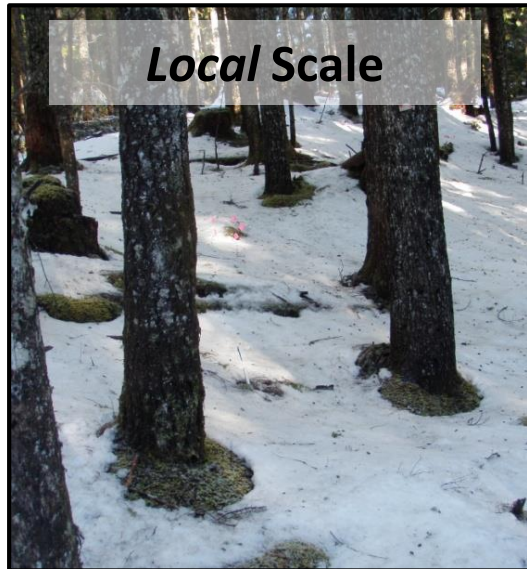


Background: Forest-Snow Processes

Processes



Effects



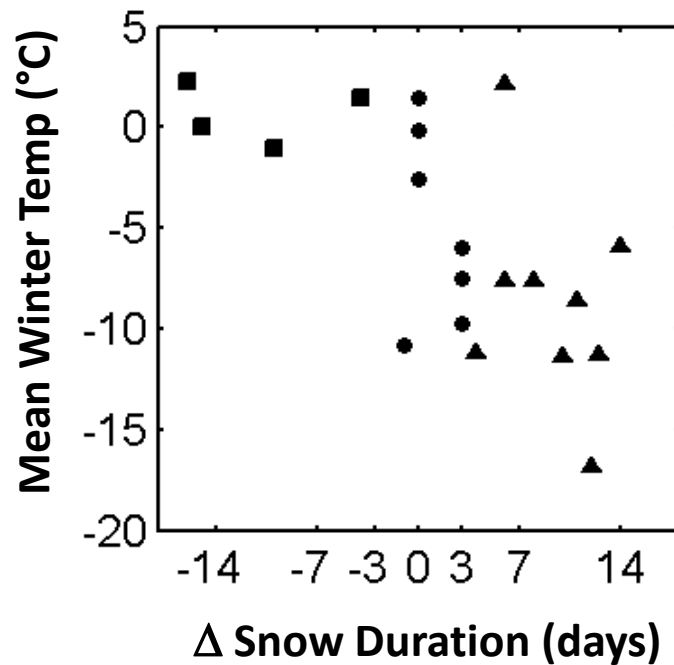
Watershed Impacts



Background: Forest-Snow Processes



Snow Storage Differences Relate to Temperature



4 week difference
between forested and open areas!

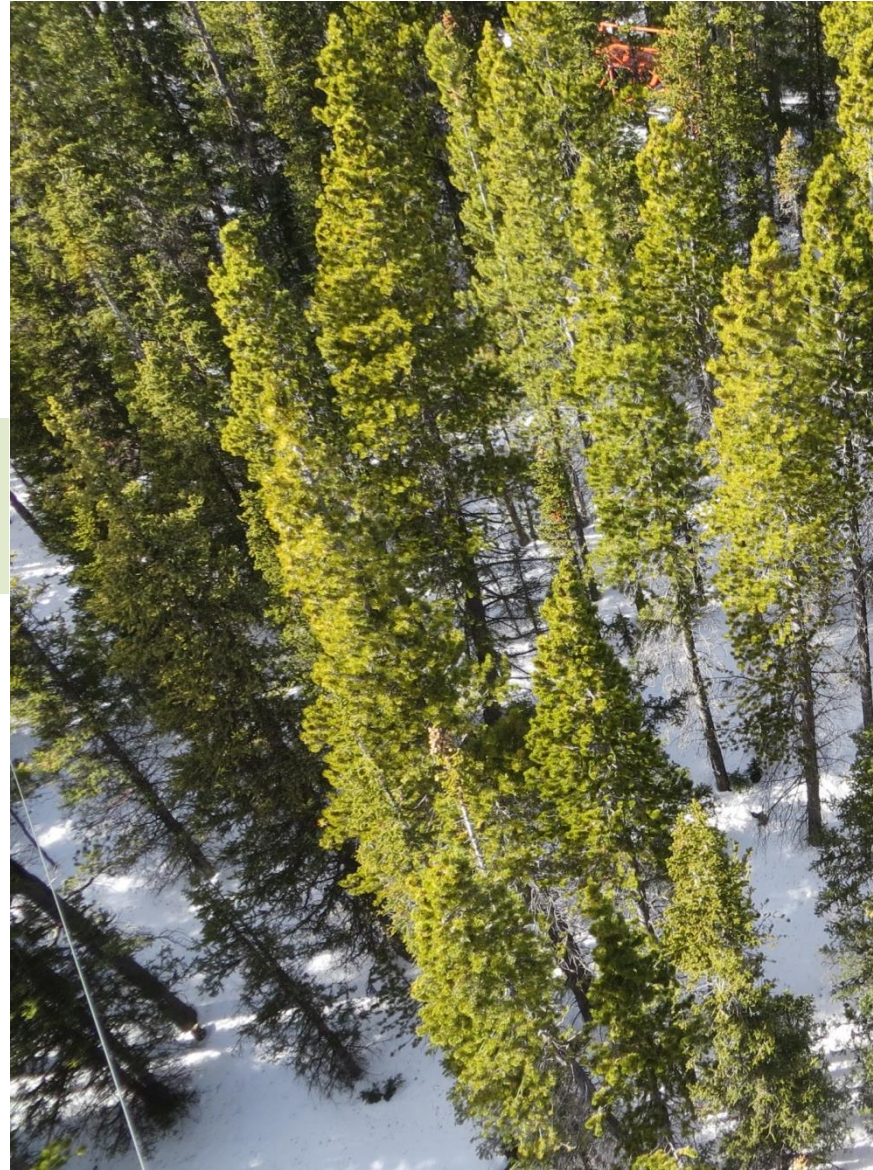
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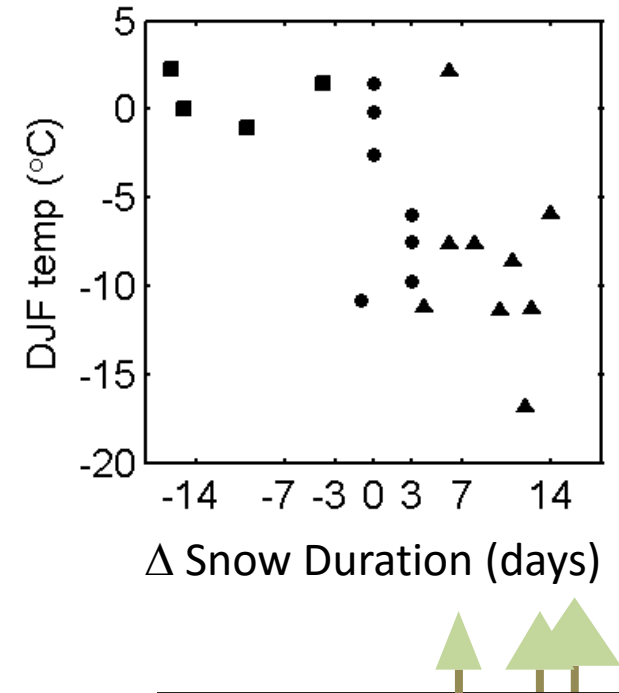
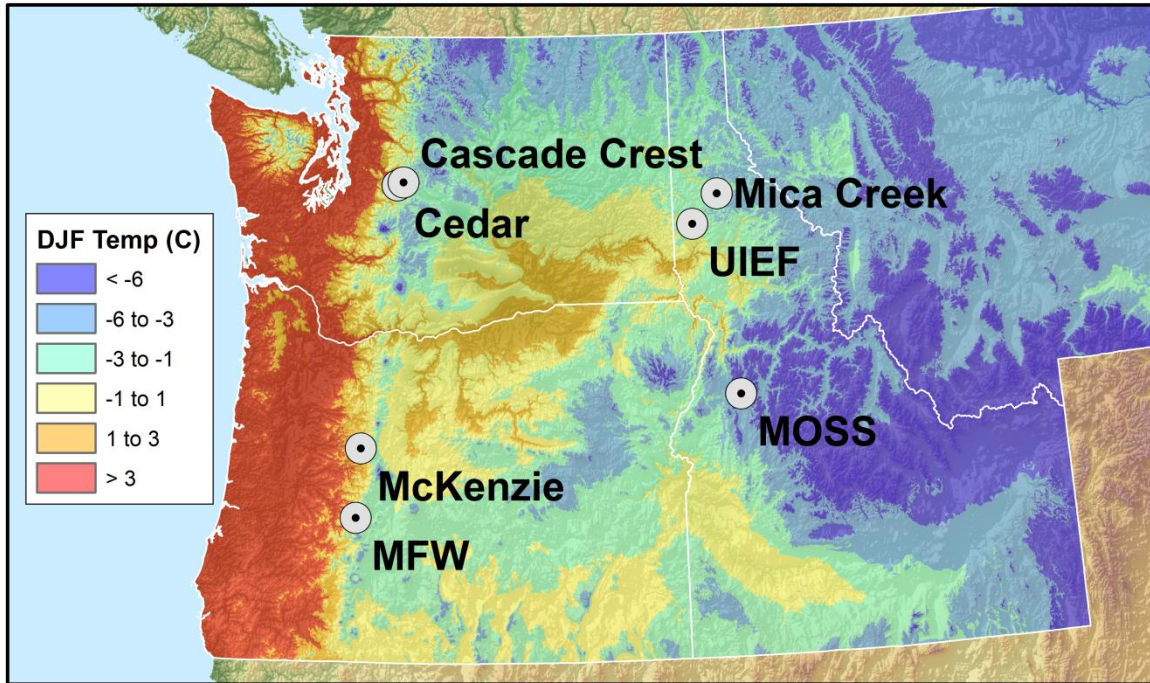
Background: Forest-Snow Processes

Research: Snow Storage across the PNW

Application: Decision Tree and Examples



Research: Questions

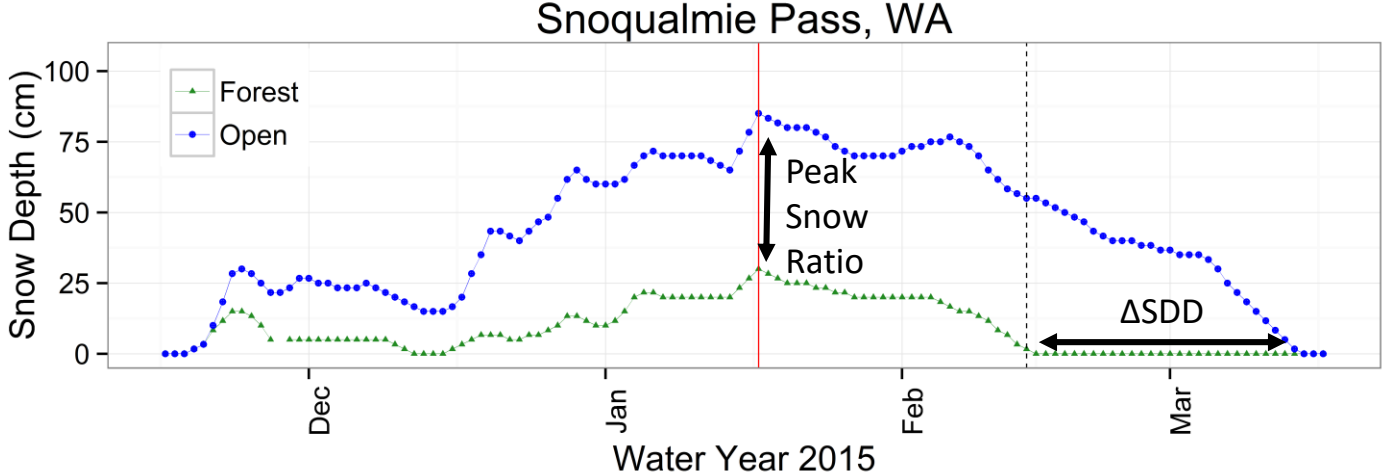


How do forests and forest change affect the magnitude and duration of snow storage across the PNW?

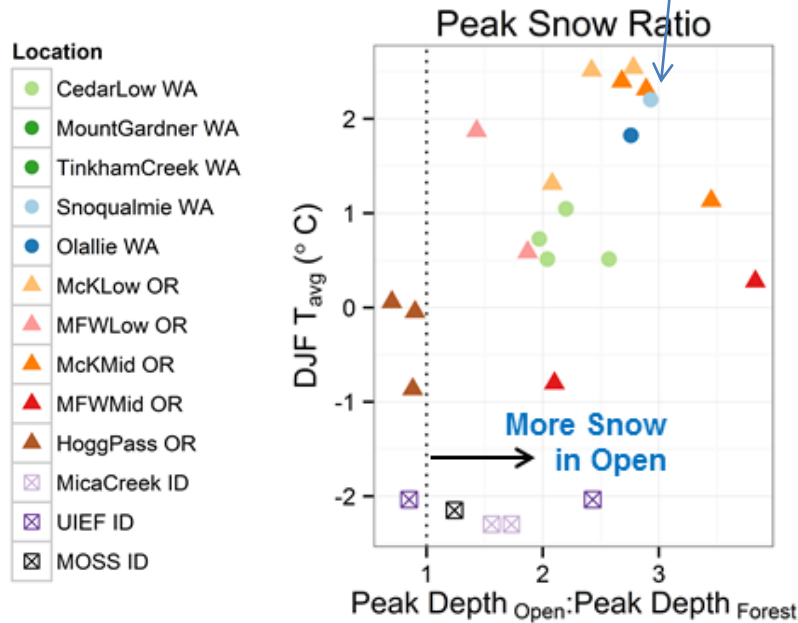
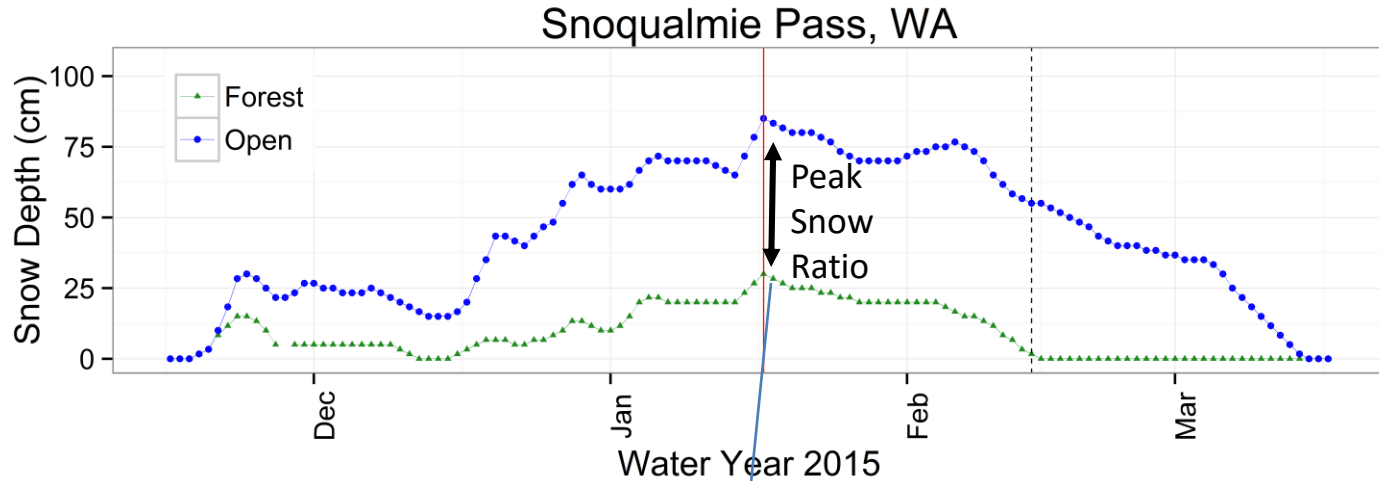
Today and in a warming climate?

(2 journal articles in review/preparation)

Research: Paired Observations of Snow Depth



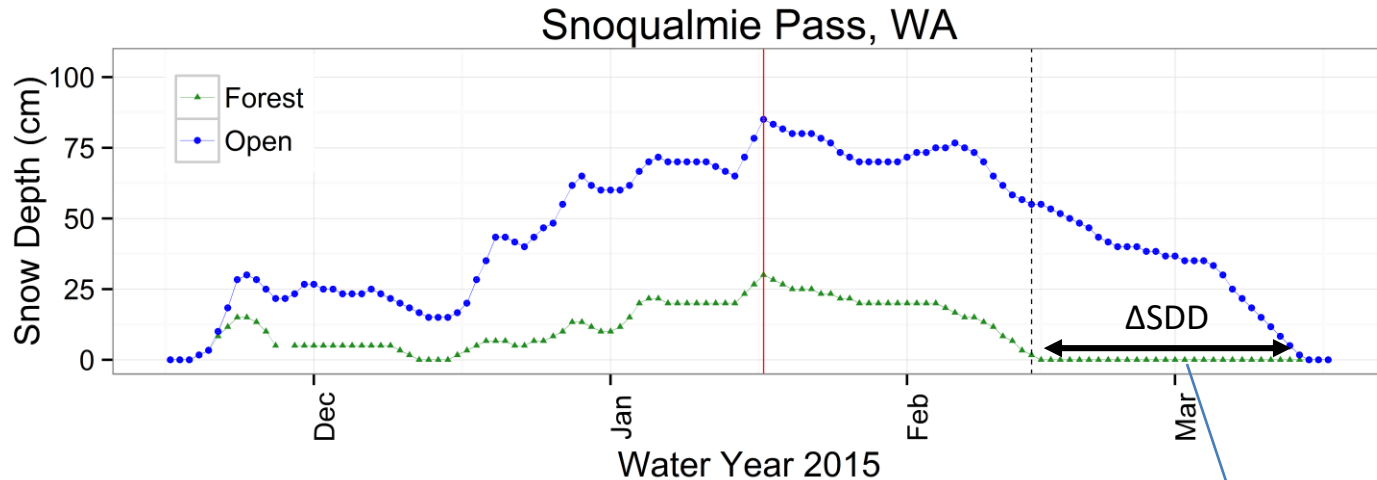
Research: Comparing Snow Depth



Comparing Peak Snow

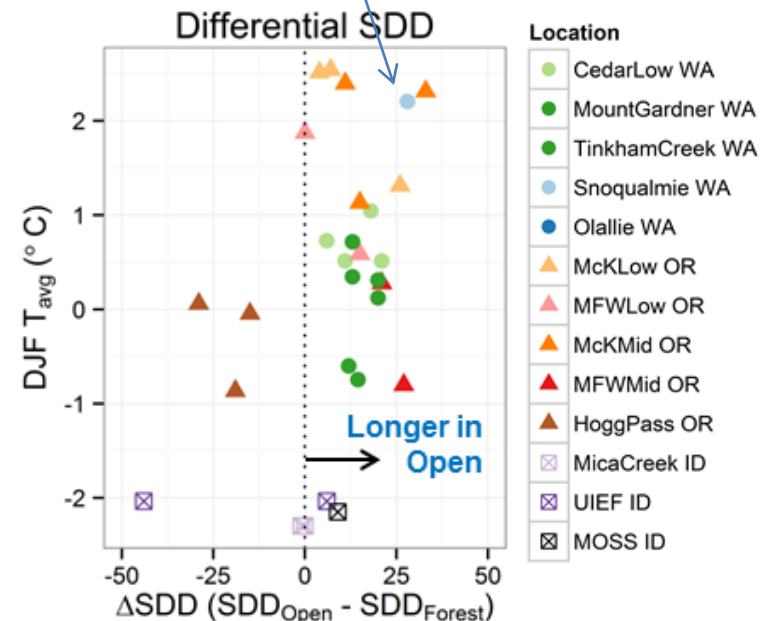
- Ranges from ~ 1 to > 3
- Canopy snow interception
- Subsequent loss

Research: Comparing Snow Duration



Comparing Difference in SDD

- Ranges from snow lasting 5 weeks longer in forest...
- To snow lasting > 4 weeks longer in open



Research: Conclusions

Findings

- Process analysis: **hierarchy**
- Limitations: Inter-annual **variability**, spatial **data gaps**
- **Patterns** observed

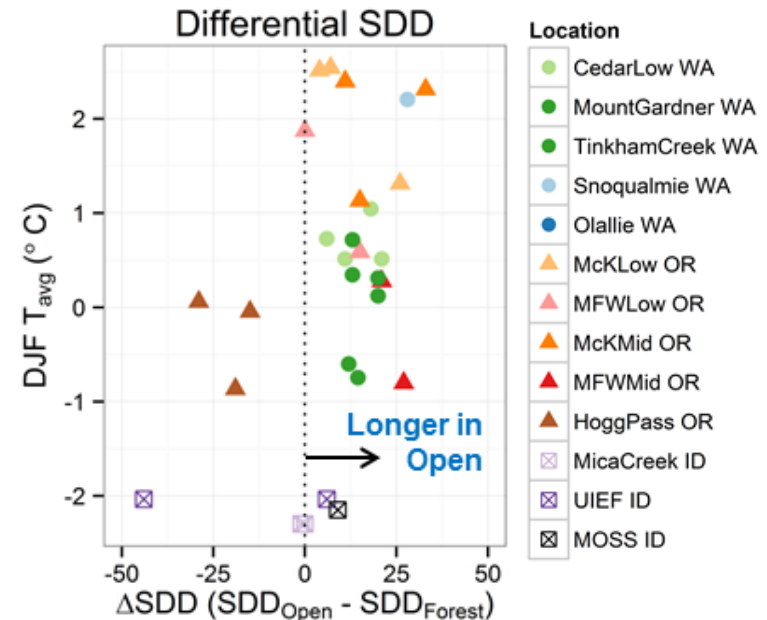
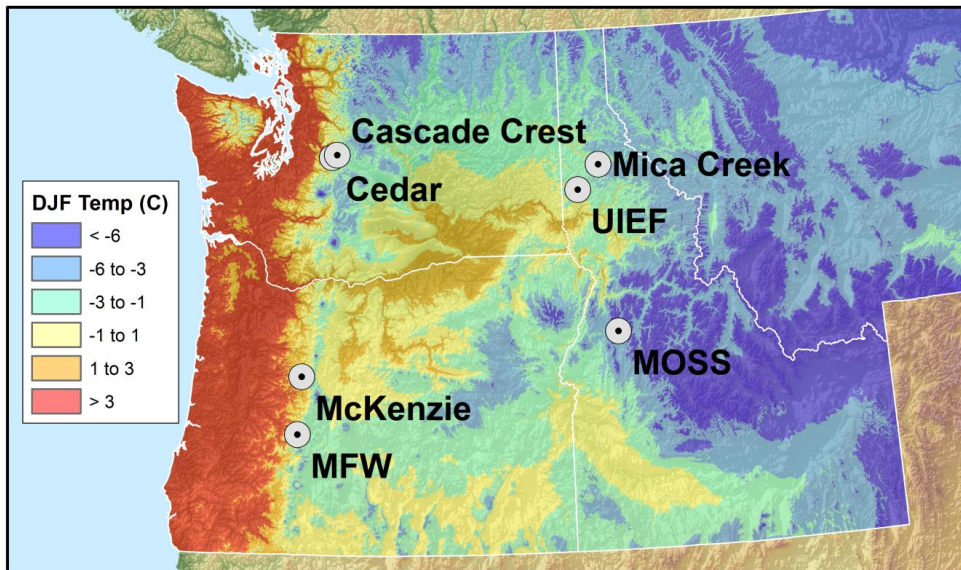


Figure 3, Dickerson-Lange, et al. 2016 (*in review*)

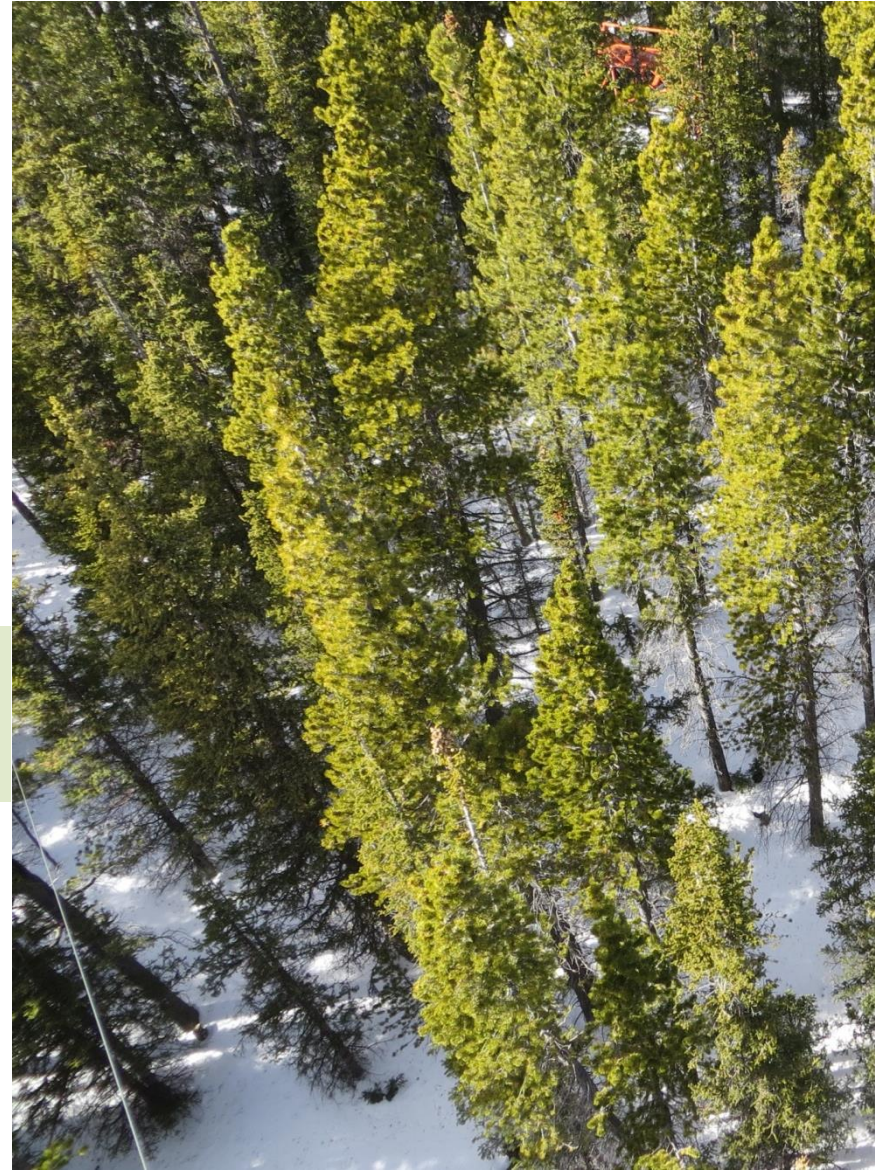
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Application: Decision Tree and Examples



Start Here To Consider Forest Effects on Snow Storage

Application: Decision Tree

High Wind Speeds?

yes

Forest acts as snow fence

no

Canopy Interception & Loss is Key Effect

Temp > -1

Interception Loss is High

Temp < -1

Interception Loss is Moderate

Average snow disappearance date (SDD) in the open?

Average cloudiness

+

Solar elevation

Estimate the importance of forest effects on shading the snow from sunlight

Early SDD + Cloudy

Late SDD + Cloudy

Early SDD + Sunny

Late SDD + Sunny

Interception loss dominates

Consider topographic position

Consider albedo effects of fire

Application: Decision Tree

Start Here To Consider Forest Effects on Snow

Storage

High Wind Speeds?

yes

WIND effects on Accumulation

Forest acts as snow fence

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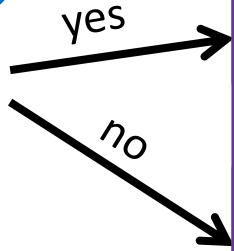
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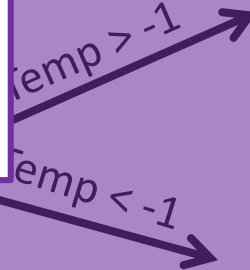
Application: Decision Tree

High Wind Speeds?



TEMPERATURE effects on Accumulation

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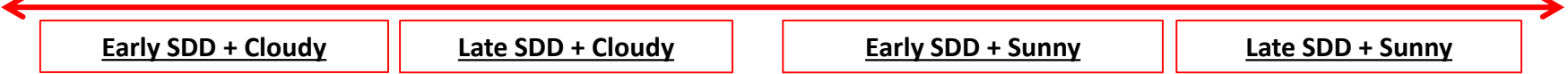
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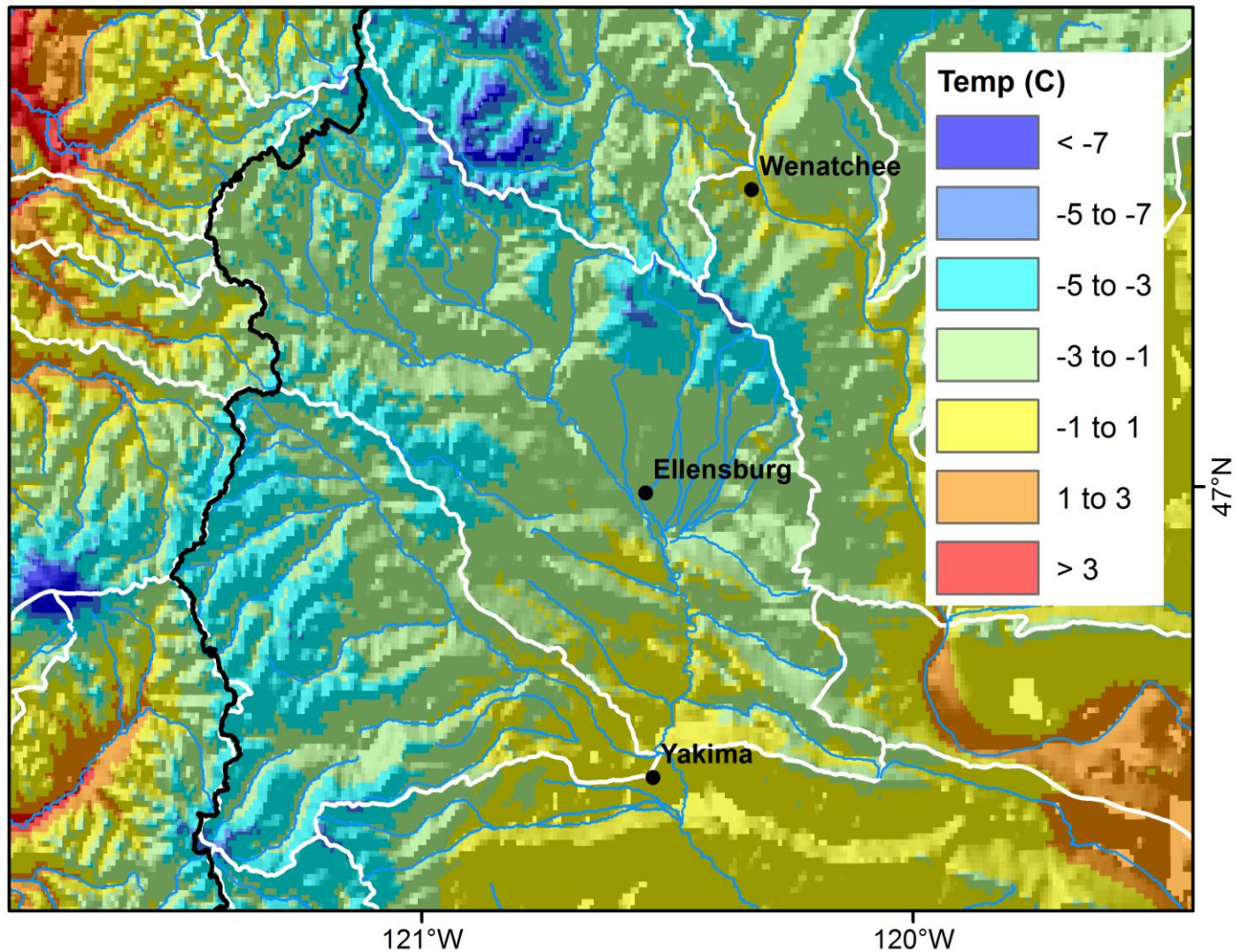
Interception loss dominates



Consider topographic position

Consider albedo effects of fire

Winter Temperature



Start Here To Consider Forest Effects on Snow Storage

Application: Decision Tree

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Forest acts as snow fence

no

Canopy Interception & Loss is Key Effect

$Temp > -1$

Interception Loss is High

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Interception Loss is Moderate



Average snow disappearance date (SDD) in the open?

Av

How Important is Forest SHADING?

Estimate the importance of forest effects on shading the snow from sunlight

Early SDD + Cloudy

Late SDD + Cloudy

Early SDD + Sunny

Late SDD + Sunny

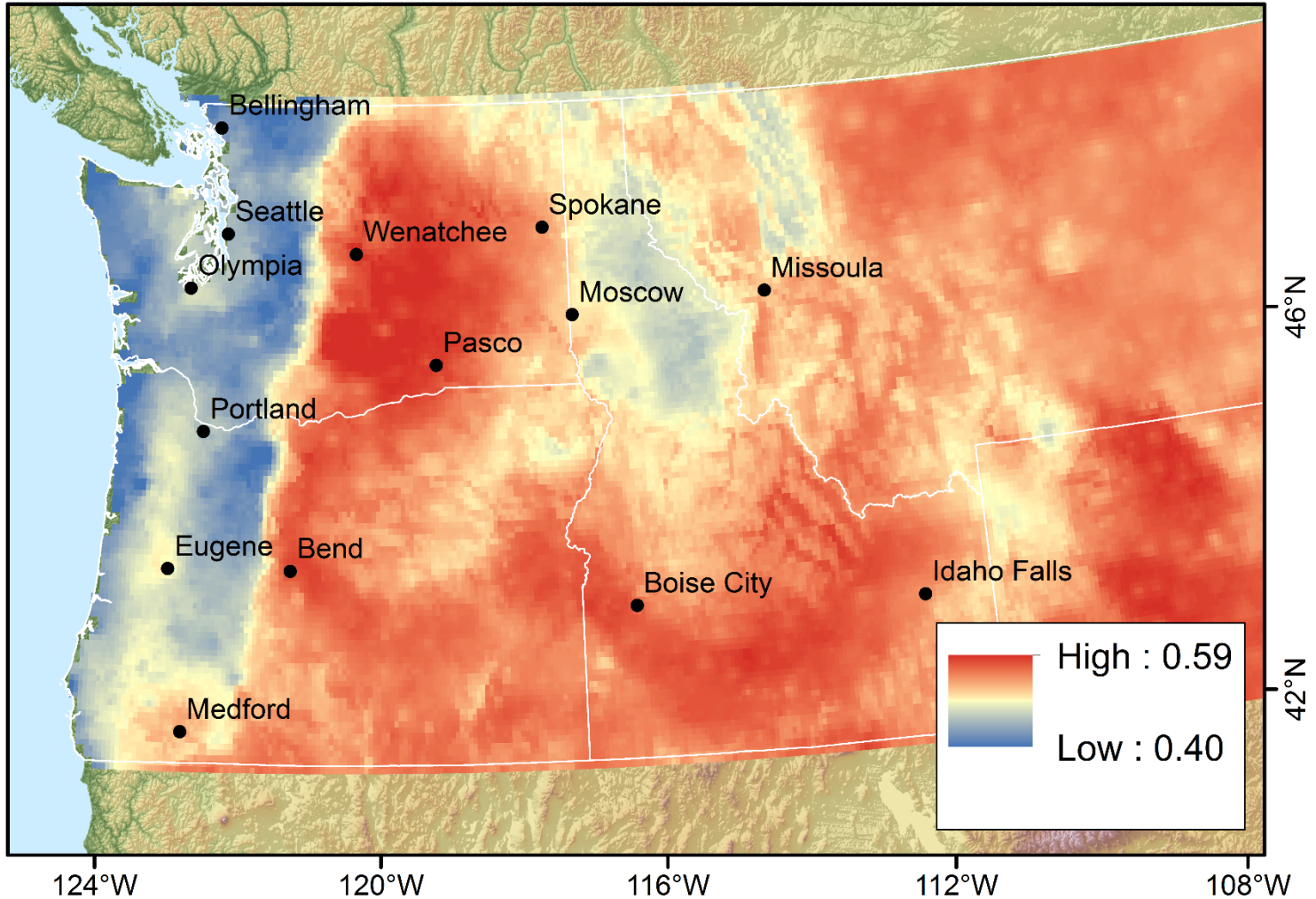
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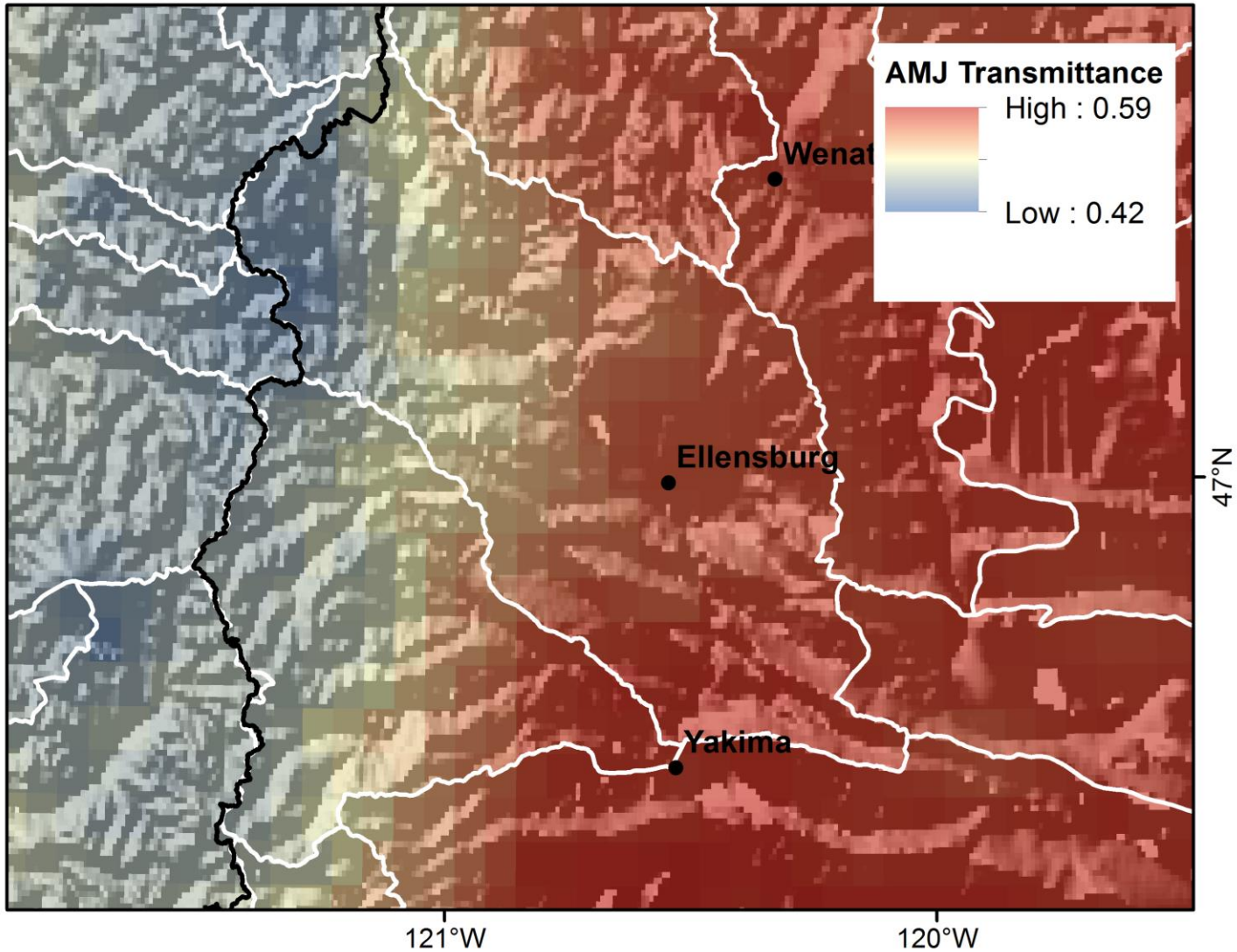
Consider albedo effects of fire

Cloudiness

Average March-April-May Atmospheric Transmittance



Cloudiness



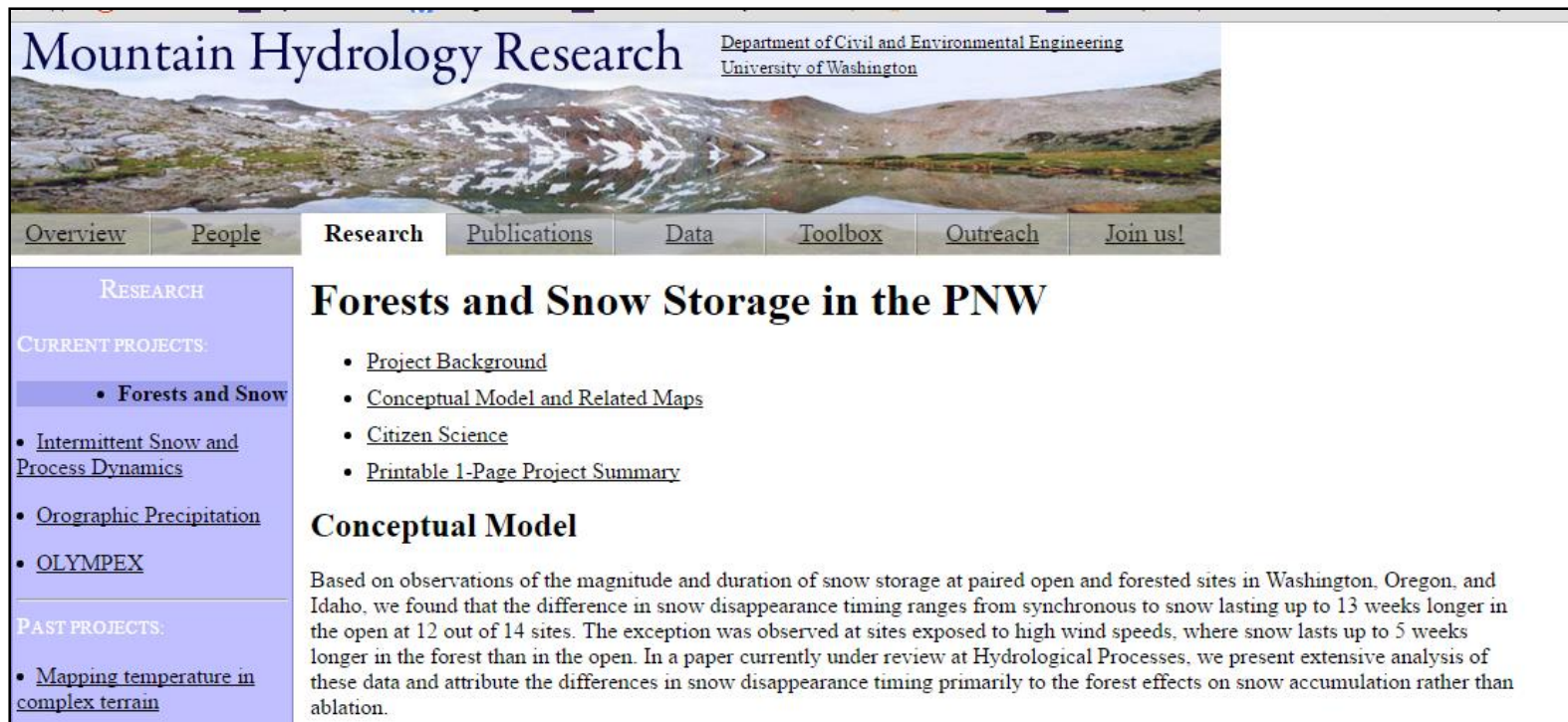
Cloudiness based on Bristow & Campbell (1984) equation applied to Livneh, et al. (2015) data.

Application: Decision Tree and Maps

Decision Tree and Maps are available (Beta Versions!):

<http://depts.washington.edu/mtnhydr/research/PNWsnowforestmap.shtml>

- Decision Tree
- Maps: Images, Google Earth, Rasters
- Webinar Overview



Mountain Hydrology Research Department of Civil and Environmental Engineering
University of Washington

Overview People **Research** Publications Data Toolbox Outreach Join us!

RESEARCH

CURRENT PROJECTS:

- **Forests and Snow**
- [Intermittent Snow and Process Dynamics](#)
- [Orographic Precipitation](#)
- [OLYMPEX](#)

PAST PROJECTS:

- [Mapping temperature in complex terrain](#)

Forests and Snow Storage in the PNW

- [Project Background](#)
- [Conceptual Model and Related Maps](#)
- [Citizen Science](#)
- [Printable 1-Page Project Summary](#)

Conceptual Model

Based on observations of the magnitude and duration of snow storage at paired open and forested sites in Washington, Oregon, and Idaho, we found that the difference in snow disappearance timing ranges from synchronous to snow lasting up to 13 weeks longer in the open at 12 out of 14 sites. The exception was observed at sites exposed to high wind speeds, where snow lasts up to 5 weeks longer in the forest than in the open. In a paper currently under review at Hydrological Processes, we present extensive analysis of these data and attribute the differences in snow disappearance timing primarily to the forest effects on snow accumulation rather than ablation.

Application: Maximize PNW Snow Storage

Characteristics

Today

Climate Change

Consider:

Western
Cascades

Warm Winter + Cloudy Spring:

- Interception & loss dominates
- Shading effect minimized
- Snow duration longer in open

Application: Maximize PNW Snow Storage

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Open
canopy
(gaps,
thinning)

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Consider:
Rising
rain/snow
Line

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Eastern
Cascades

Cold Winter + Sunny Melt Season:

- Less interception
- Shading effect important
- Snow duration equal

Application: Maximize PNW Snow Storage

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Forest
thinning

Open canopy
on north
slopes

Earlier
ablation in
future?

Application: Maximize PNW Snow Storage

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Earlier
ablation in
future?

Northern
Idaho

Cold Winter + Cloudy Melt Season:

Cascade
Crest

High Wind Exposure:

Conclusions

Motivation: Climate Change and Forest Change

Combined effects on snow important

Background: Forest-Snow Processes

Vary in time and space

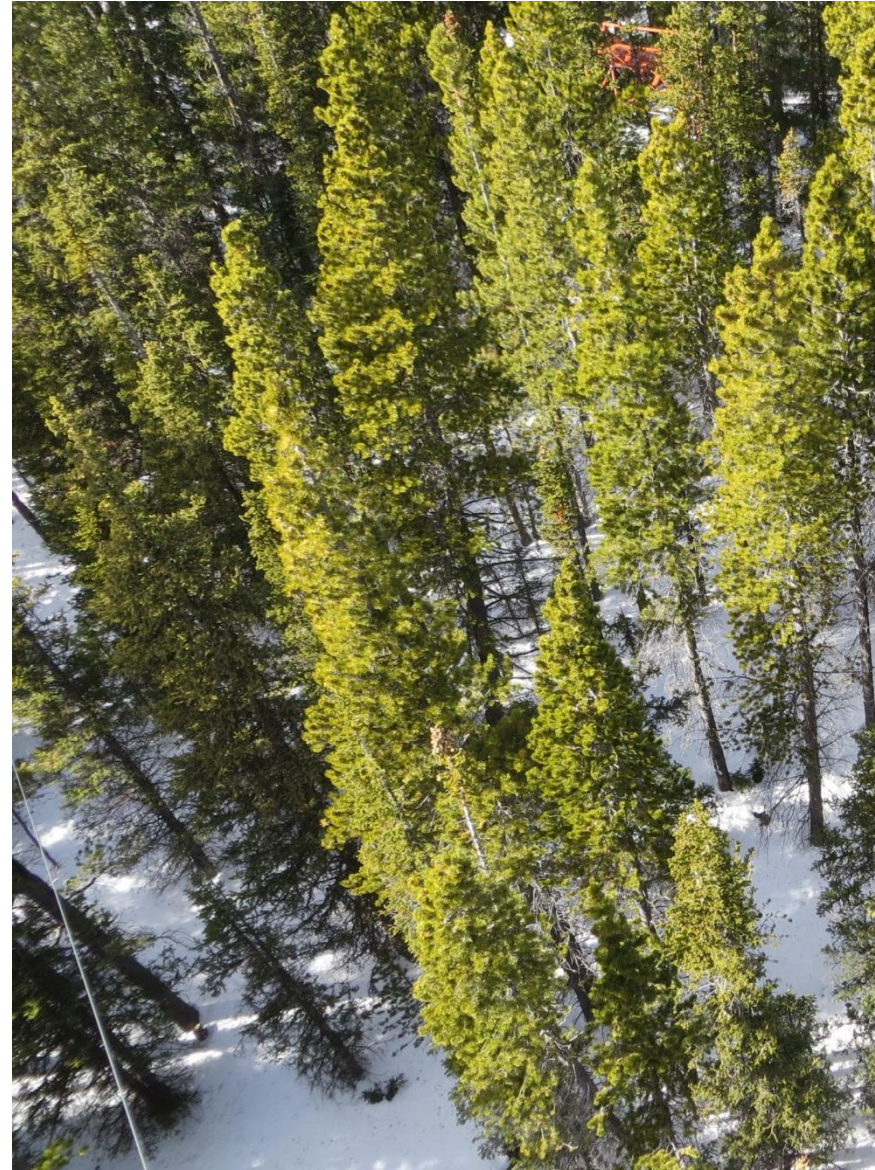
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Thanks!



Susan Dickerson-Lange

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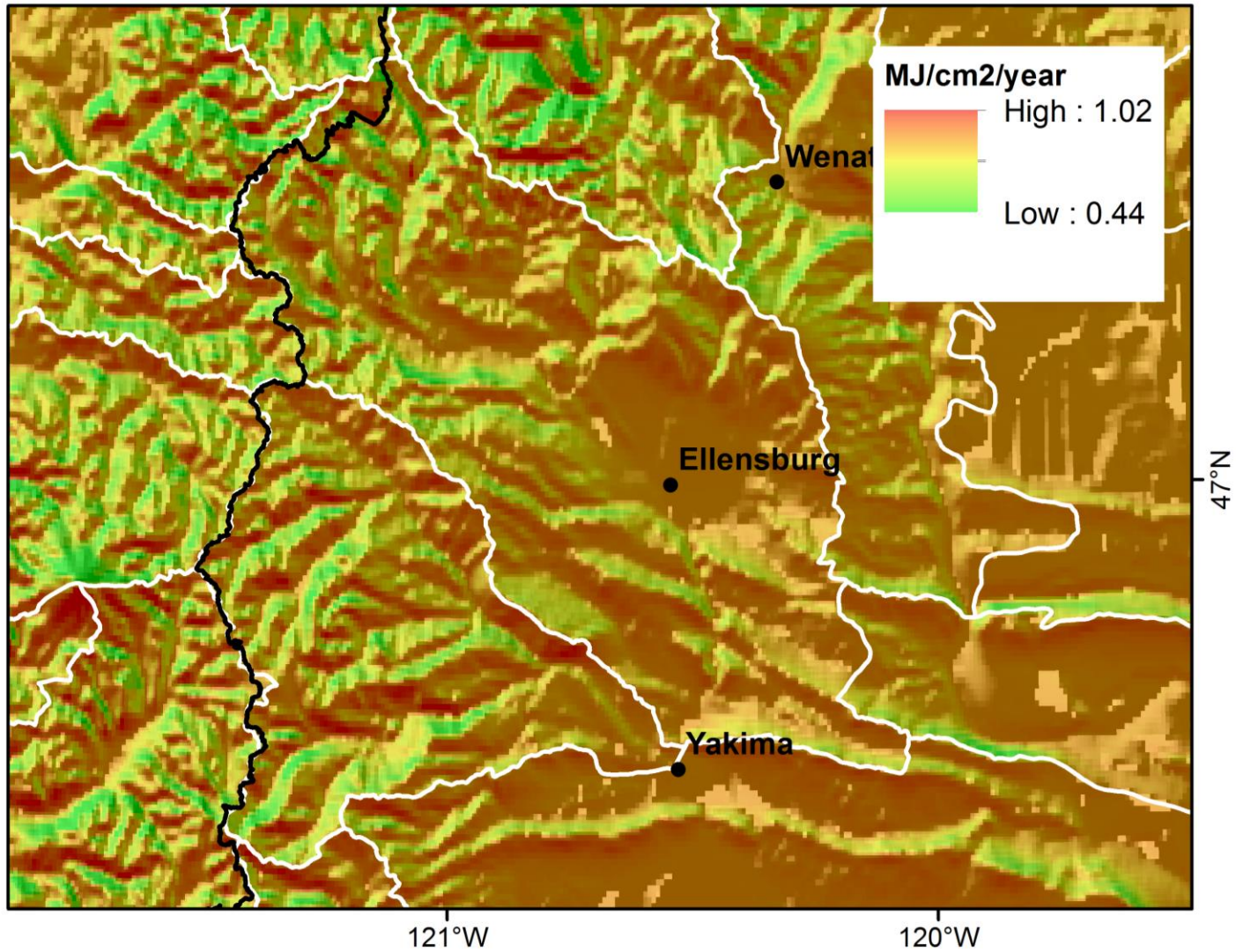


Funding:

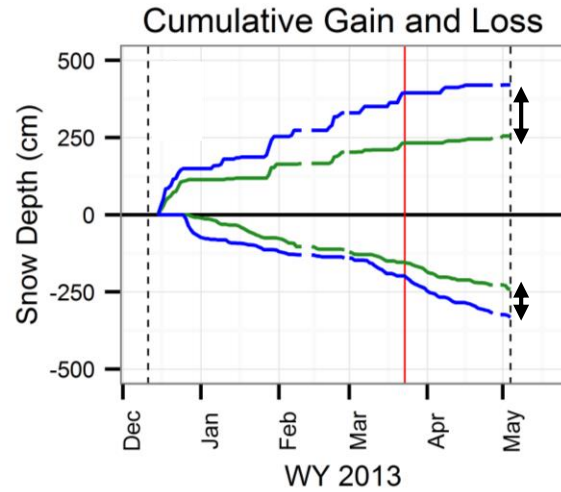
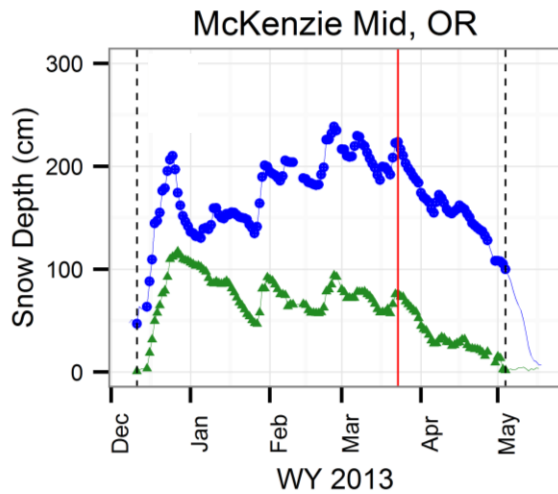
Northwest Climate Science Center (Dept of Interior)



Topographic Position



Analysis: How Do Forest-Snow Processes Vary?

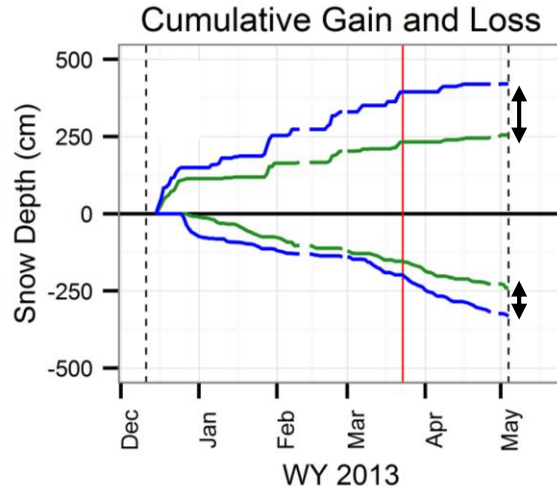
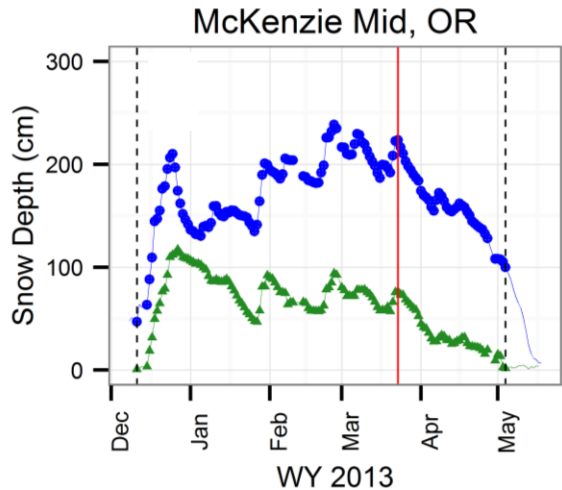


Difference in Accumulation Rate

Difference in Ablation Rate

Results:
Accumulation
and
ablation rates higher
in open

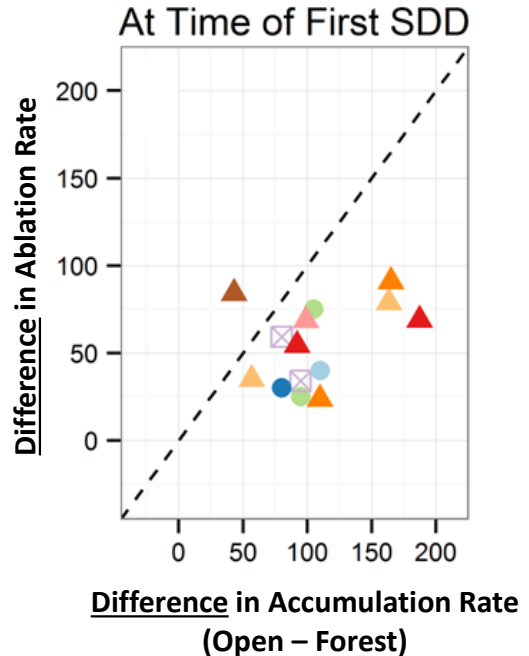
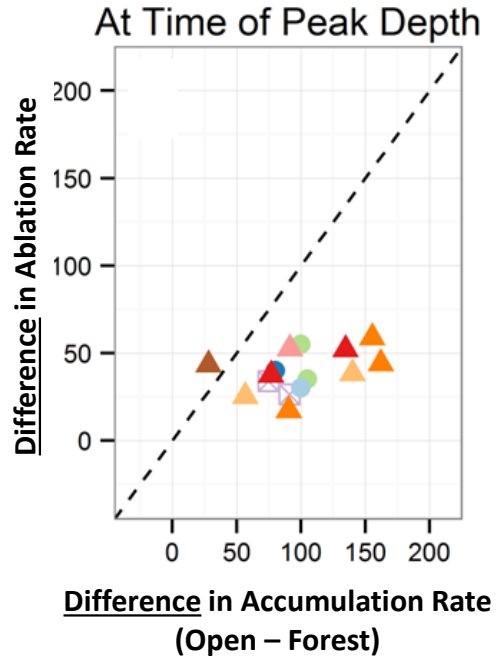
Results: More difference in accumulation rates



Difference in Accumulation Rate

Difference in Ablation Rate

- Location**
- CedarLow WA
 - Snoqualmie WA
 - Olallie WA
 - ▲ McKLow OR
 - ▲ MFWLow OR
 - ▲ McKMid OR
 - ▲ MFWMid OR
 - ▲ HoggPass OR
 - ⊠ MicaCreek ID



Results

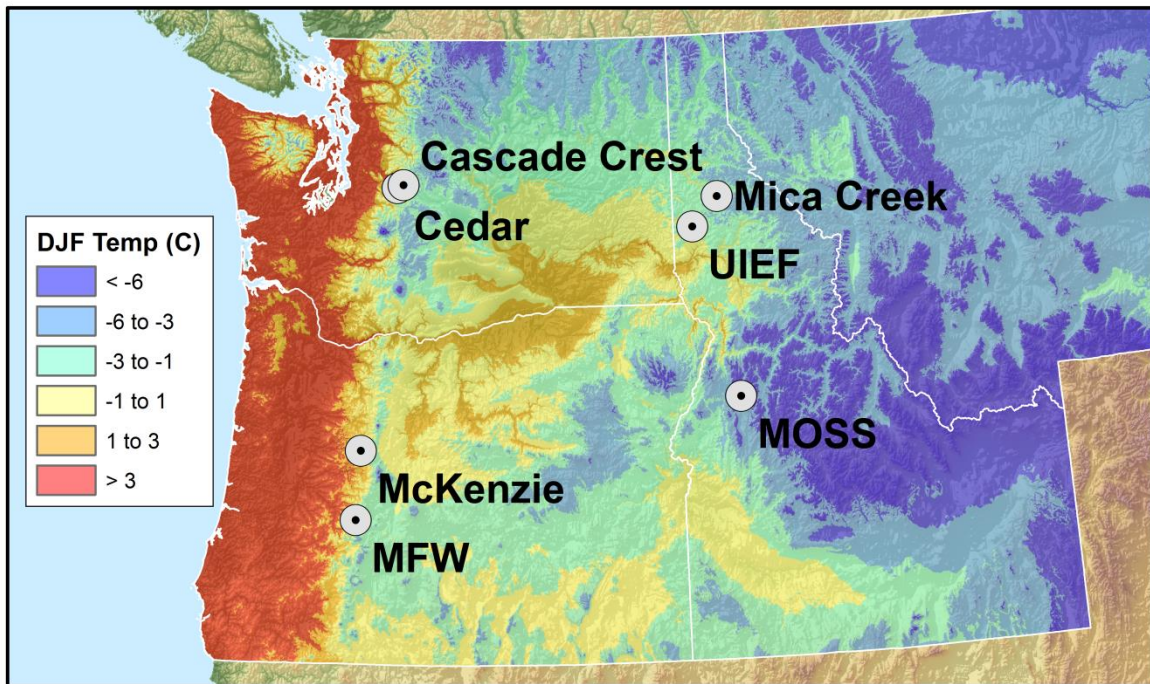
Δ accumulation rates
larger than
 Δ ablation rates
 at peak accumulation
 and
 at 1st snow disappearance

Figure 5, Dickerson-Lange, et al. 2016 (in review)

Conceptual Model: Possible Approaches

How do forests and forest change affect the magnitude and duration of snow storage across the PNW?

Today and in a warming climate?



Empirical Model

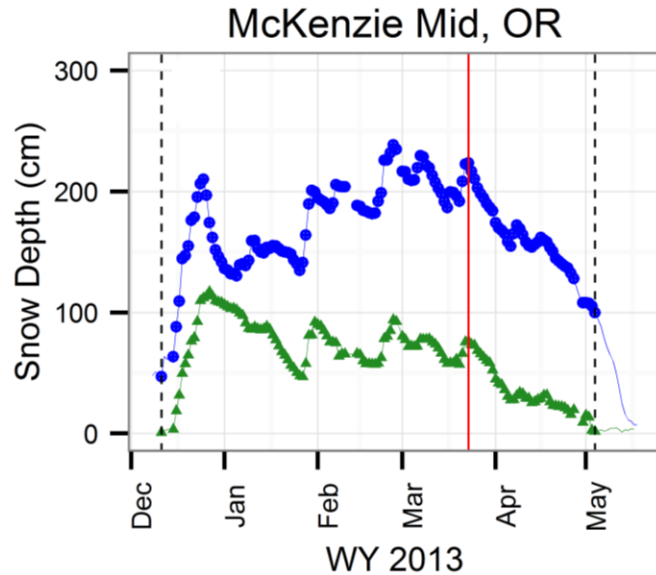
Lundquist et al. 2013
Robles et al. 2014

Distributed Model

Ellis et al. 2013
Du et al. 2016

Conceptual Model

1a. Canopy Snow Interception and Loss

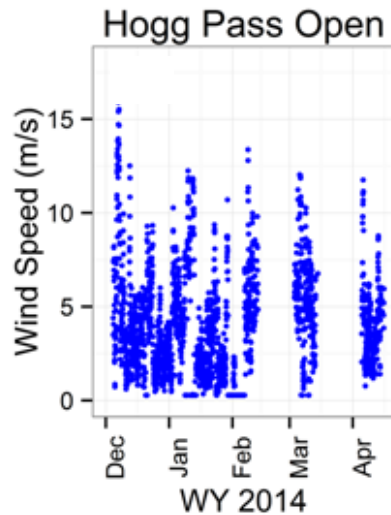
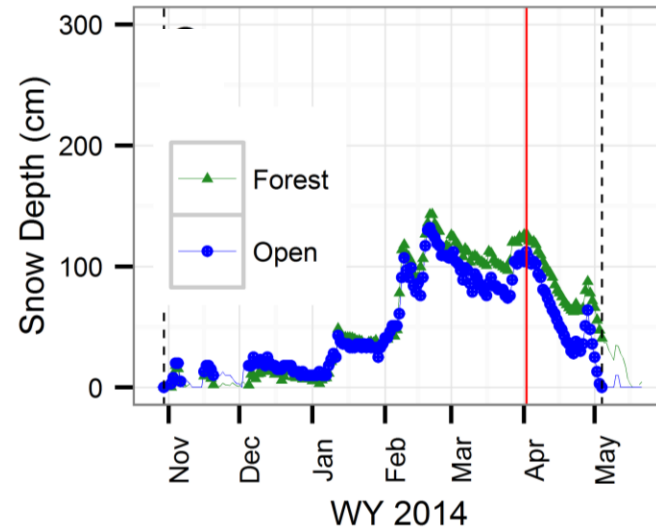
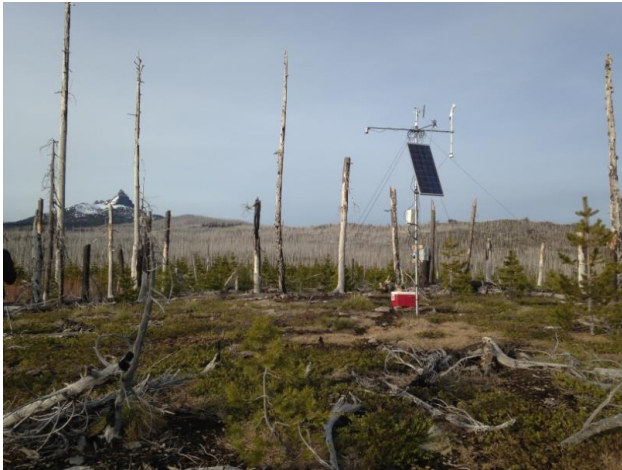


Canopy Snow Interception & Loss

- Forest canopy intercepts snow
- Snow melts, sublimates, or drops to snowpack

1b. Wind Effects

Example: Hogg Pass, OR – Cascade Crest



Wind-driven Snow Deposition

- High deposition of snow within forests
- Other mechanisms:
 - Redistribution?
 - Wind unloading?

1b. Wind Effects

Example 2: Palouse Region of north-central Idaho



1b. Wind Effects



Controls

- Topographic exposure
- Region
- Opening size & fetch

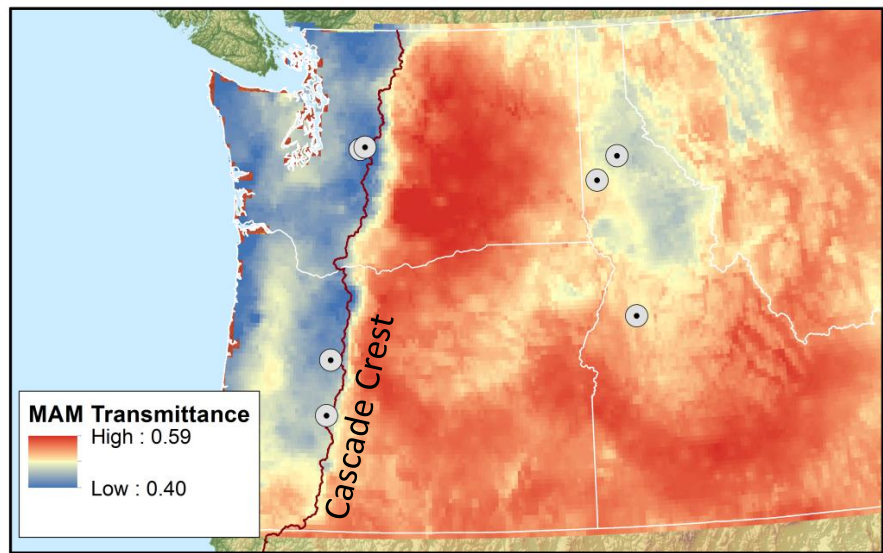
See: Hiemstra *et al.*, 2002
Geddes *et al.*, 2005
Qiu *et al.*, 2011

2. Forest Effects on Snow Ablation

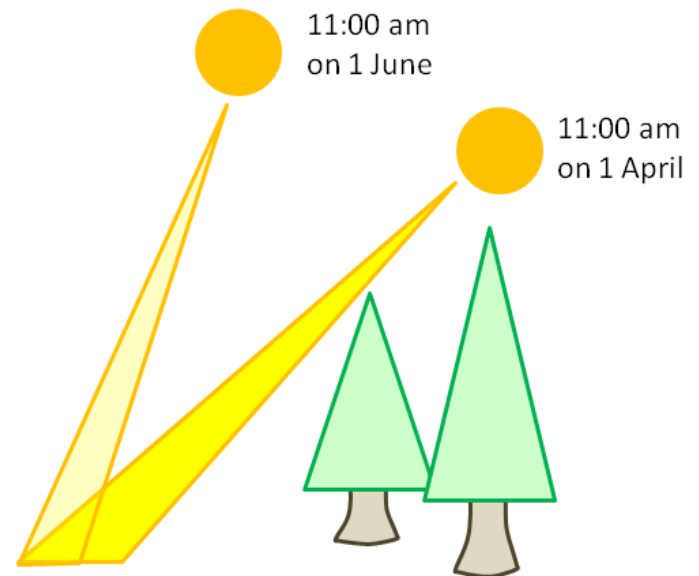
How much does forest shading modify ablation (melt) rates?

Depends on conditions during the snow ablation season

Spring Cloudiness



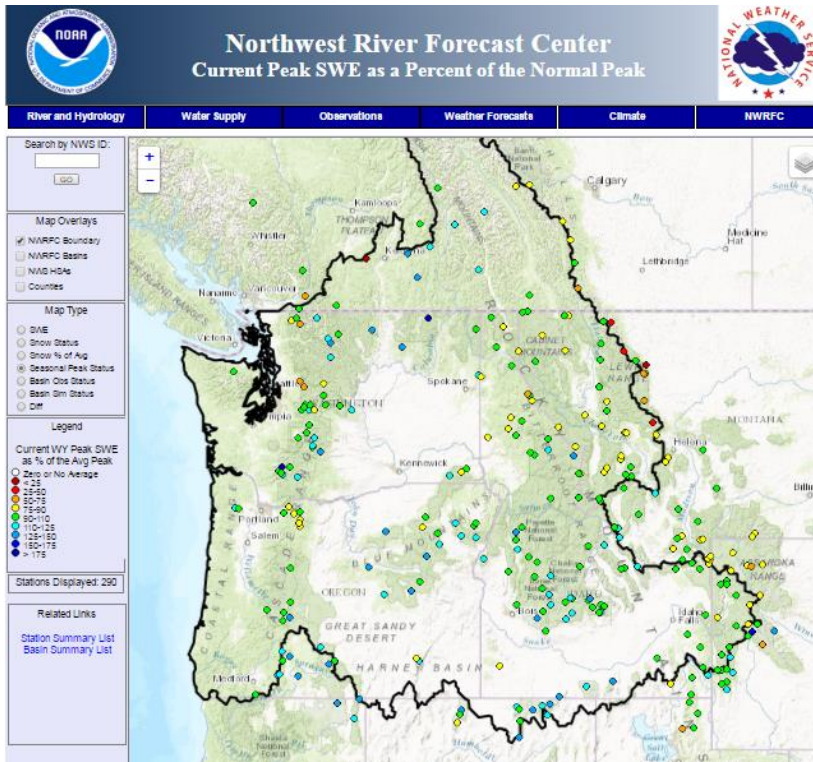
Solar Elevation



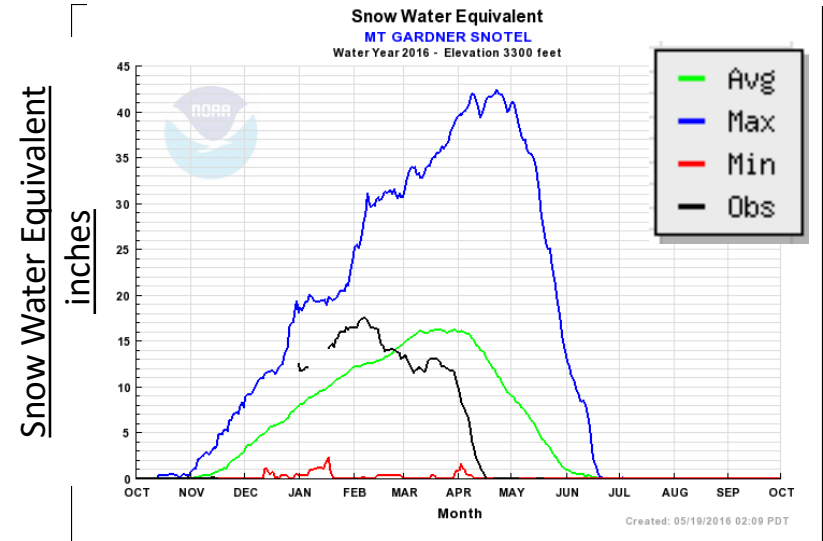
Average Snow Disappearance Timing

NRSC SNOTEL Data

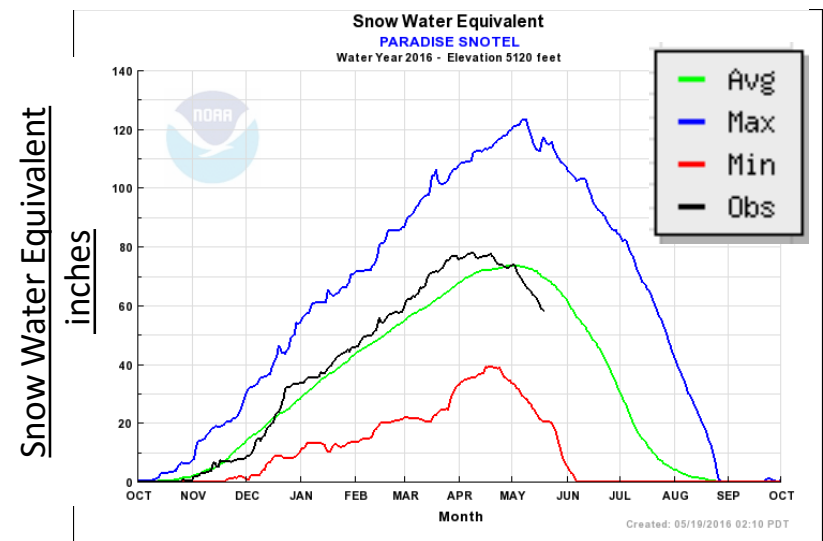
NW River Forecast Center Interface
<http://www.nwrfc.noaa.gov/snow/>



Mt Gardner SNOTEL (elev 3300 feet)



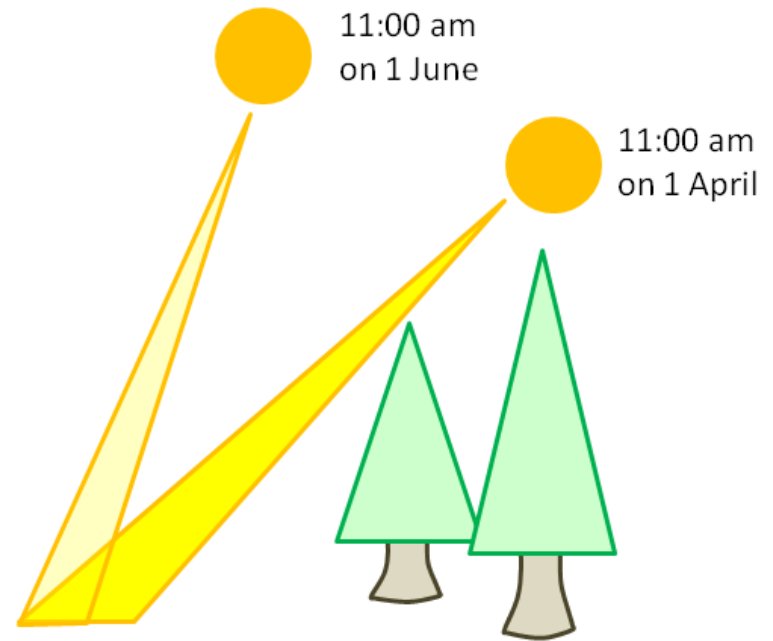
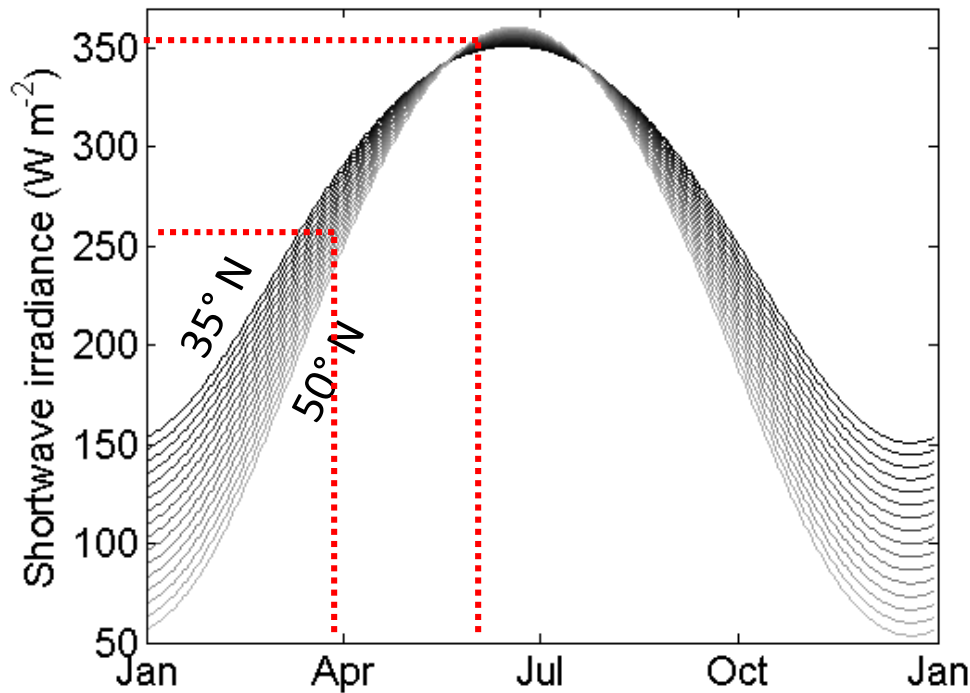
Paradise SNOTEL (elev 5120 feet)



Solar Elevation

Solar elevation varies with time of year and latitude,
and influences how important the forest is for shading

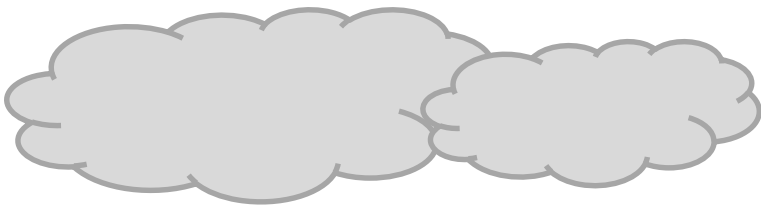
Earlier in the year:
less incoming solar radiation per unit area
AND
more likely to be shaded by topography and forest



Cloudiness + Solar Elevation

How important is the forest for shading from sunlight?

← Importance of forest effects on shading the snow from sunlight →

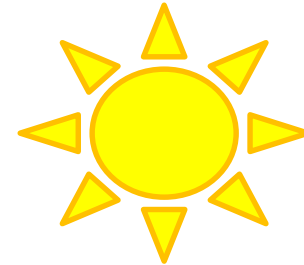


Early SDD + Cloudy

Low
forest shading
effect

Late SDD + Cloudy

Low
forest shading
effect



Early SDD + Sunny

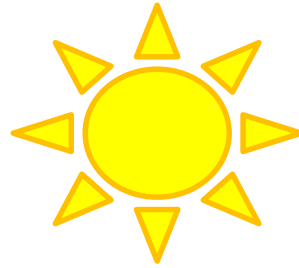
Medium
forest shading
effect

Late SDD + Sunny

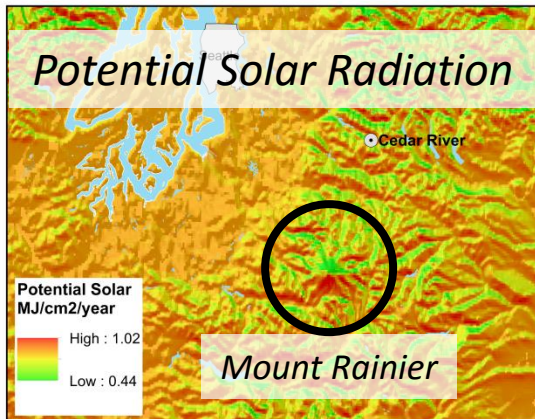
High
forest shading
effect

Cloudiness + Solar Elevation

How important is the forest for shading from sunlight?



Topographic Position



See:

Strasser *et al.*, 2011
Ellis *et al.*, 2013

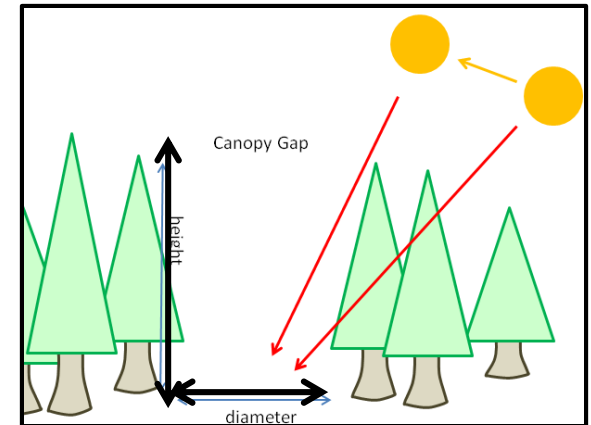
Black Carbon from Fire



See:

Burles and Boone, 2011
Gleason *et al.*, 2013
Gleason *et al.*, 2016

Forest Gap Geometry



See:

Seyednasrollah & Kumar, 2014
Musselman *et al.*, 2015