Water Connects All: Climate Change and Mountain Hydrology in a Watershed Context

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HJ Andrews Long Term Ecological Research Site

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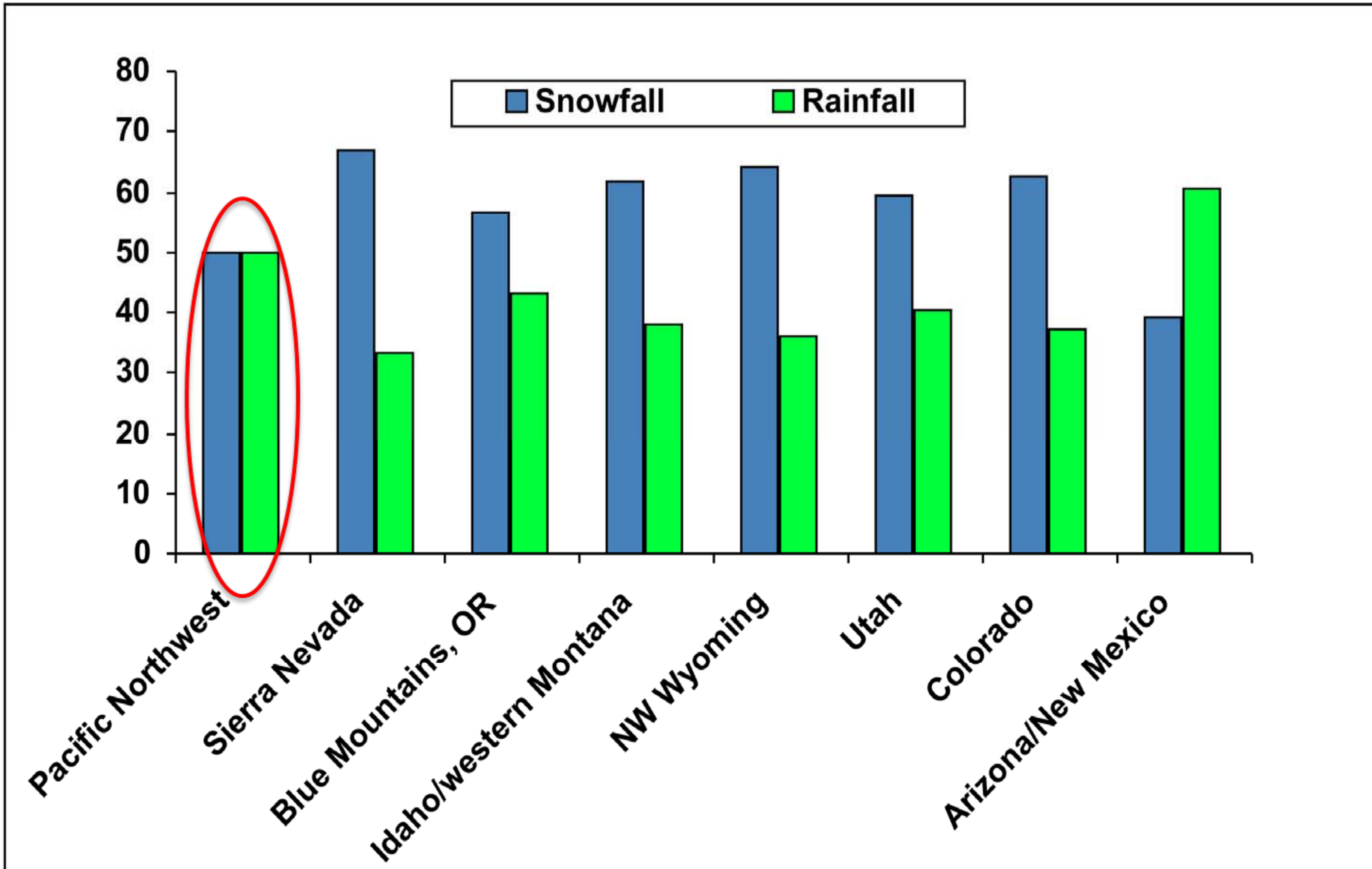
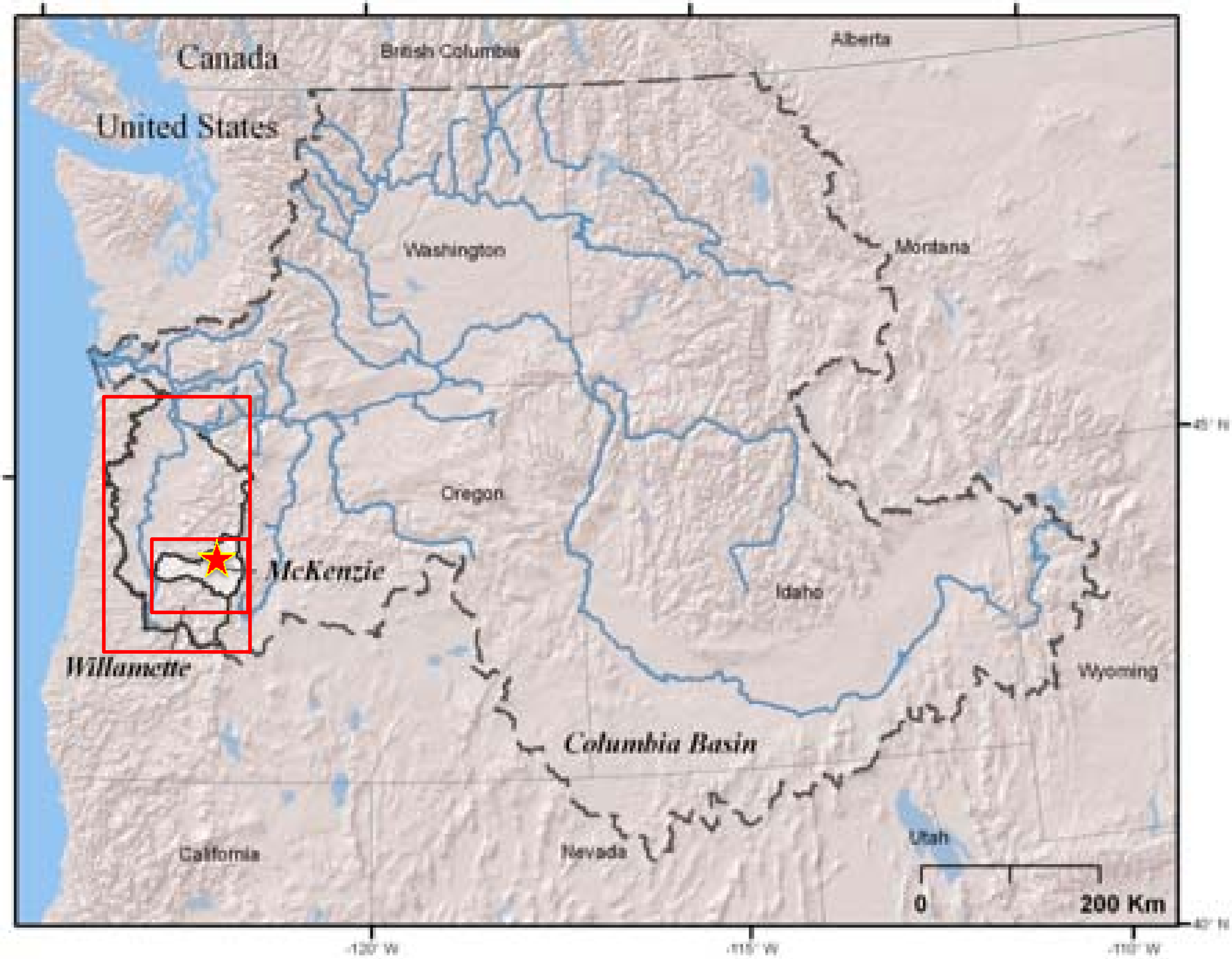
Outline

- Mountain watersheds: Highlands and lowlands
- Climate change and snow at various scales
- Temperature variability and change
- New paradigm for examining water scarcity

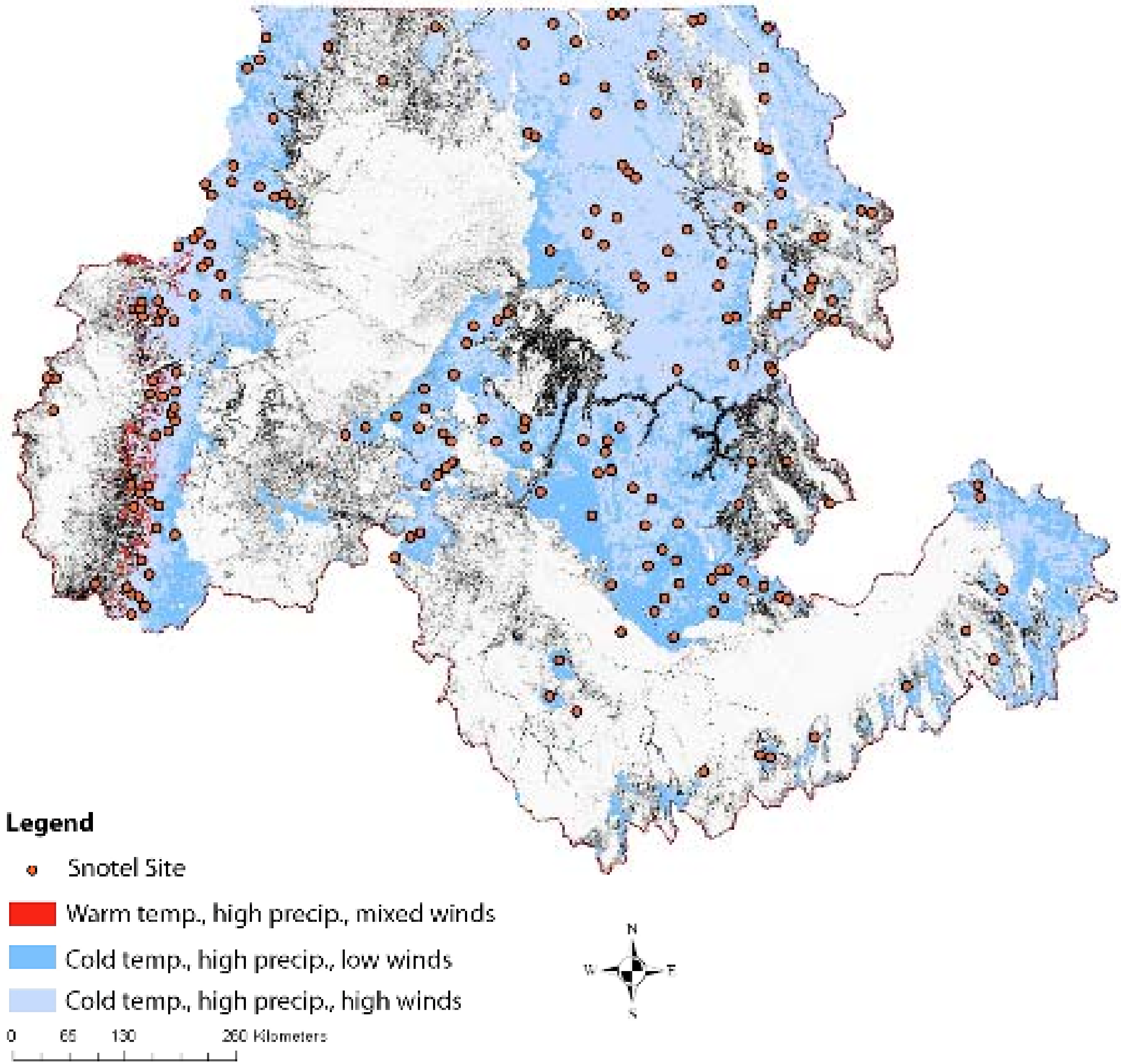
Percent Rainfall & Snowfall in Mountain Regions of the Western US



(Based on Serreze et al. 1999)


Canada
British Columbia
Alberta
United States
Washington
Montana
Oregon
McKenzie
Idaho
Willamette
Wyoming
Columbia Basin
California
Nevada
Utah
0
200 Km
45° N
40° N
-120° W
-115° W
-110° W

“At Risk” Snow in the US Columbia River Basin



“At-Risk” Snow:

A 2°C winter warming is projected to shift mid-winter precipitation from snowfall to rainfall

Greatest impacts are for midwinter snow at lower elevations in the Western Cascades

(Nolin and Daly, 2006; Nolin et al., accepted)

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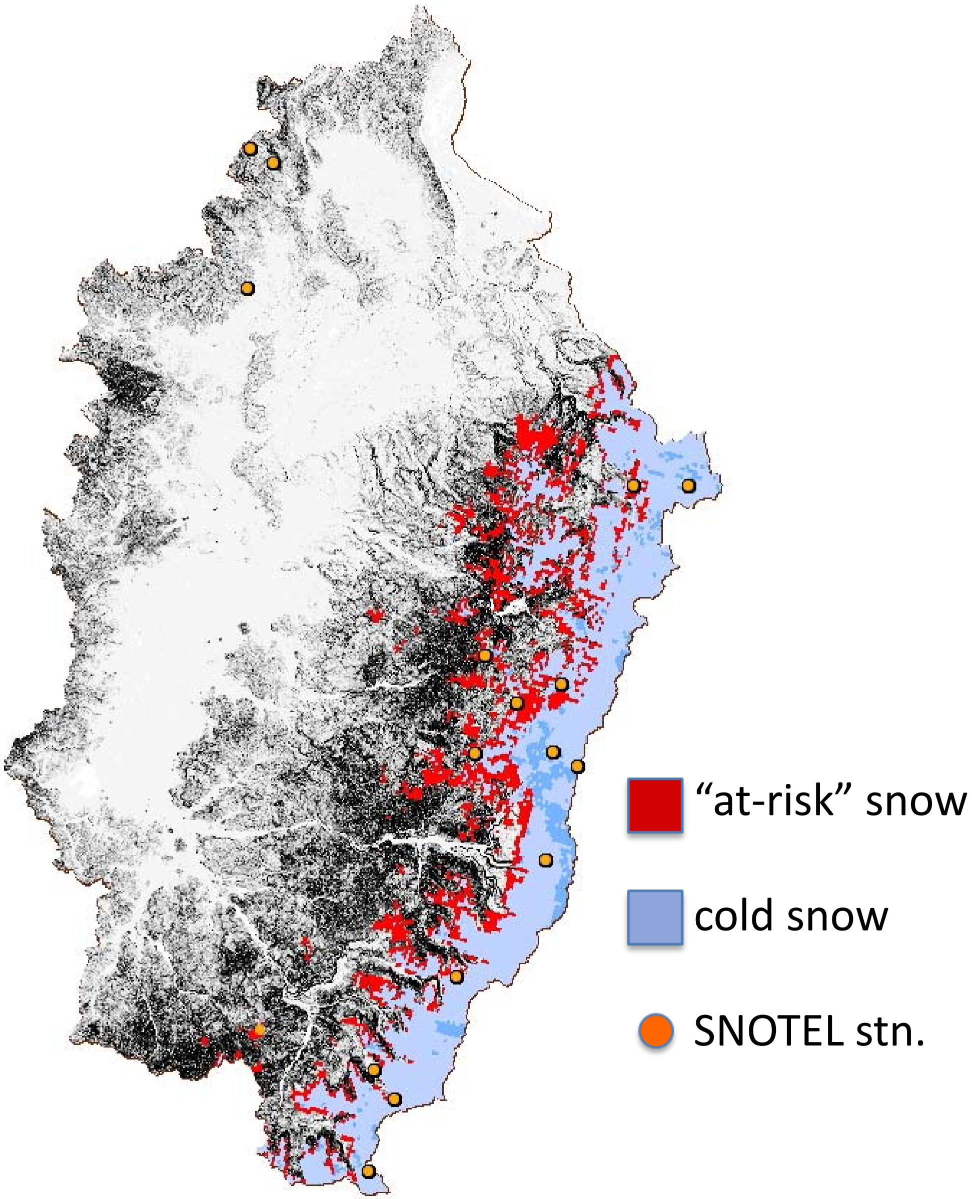
Willamette River Basin, Oregon



Willamette River Basin:

- 29,000 km^2
- 70% of Oregon’s population
- Water use: hydropower, fish, irrigation, municipal

At-Risk Snow:

- For a 2^{o}C temperature increase we project a **25% decrease in snow covered area**
- Low elevation snowfall converts to rainfall
- ~4 km^3 of water volume per year

(Nolin and Daly, 2006; Nolin et al., accepted)

Geology also Controls Streamflow Patterns

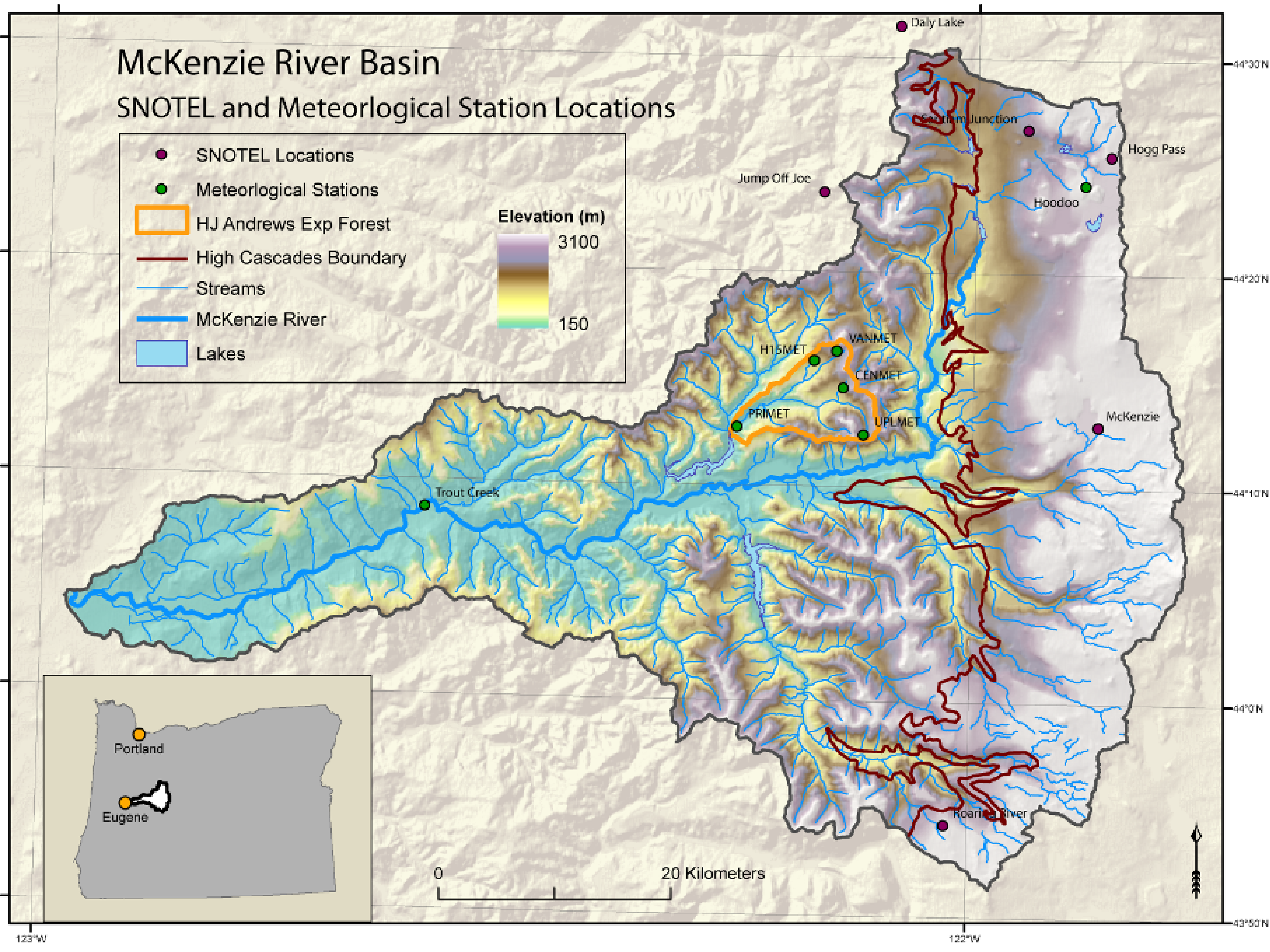
(Courtesy Gordon Grant)

High Cascades:
Young volcanic rocks
Groundwater-dominated

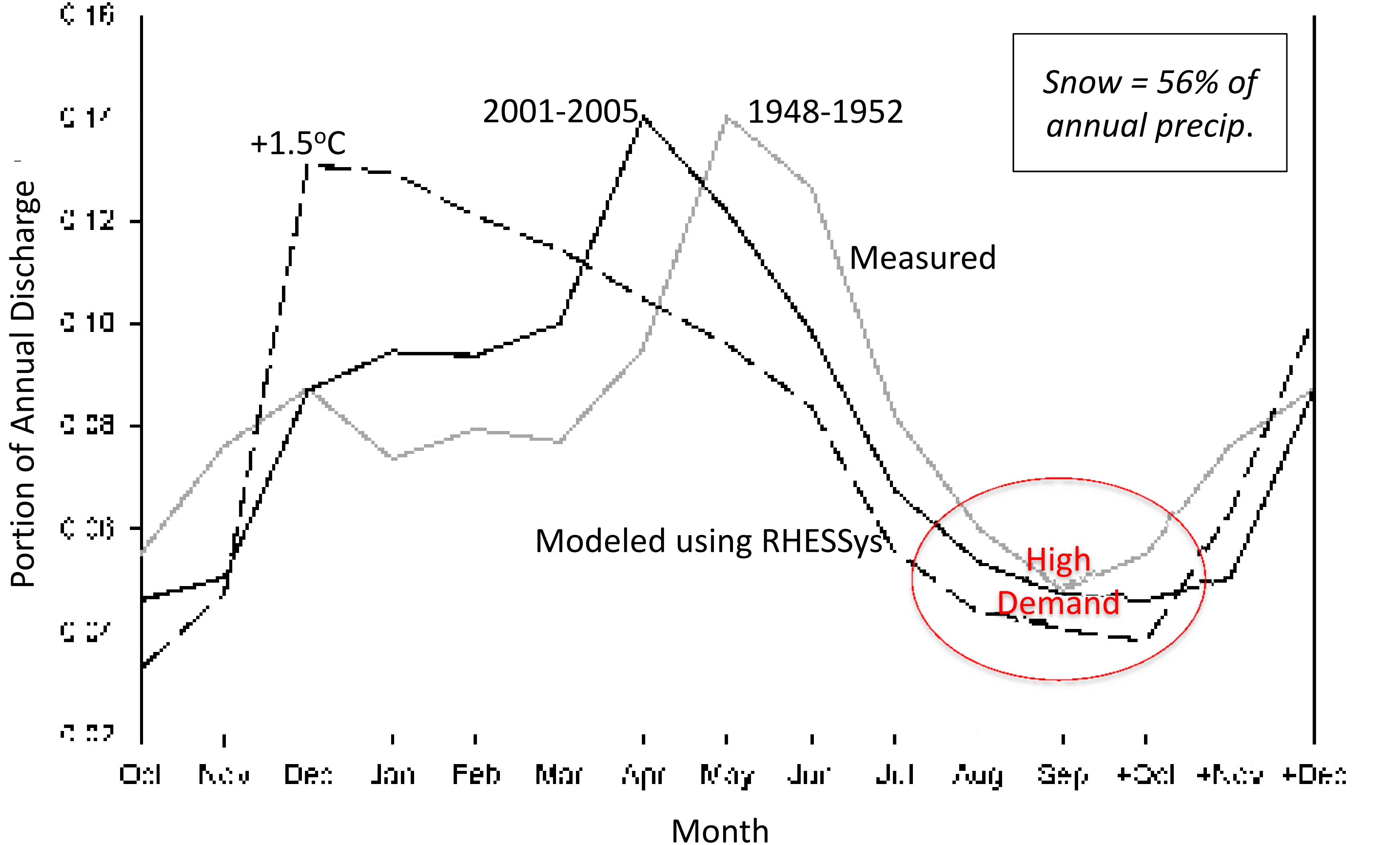
Western Cascades:
Older, weathered volcanic rocks
Surface runoff-dominated

Groundwater-dominated watersheds are more sensitive to changes in snowfall

When we make projections, we need to consider the geologic + climatic factors together

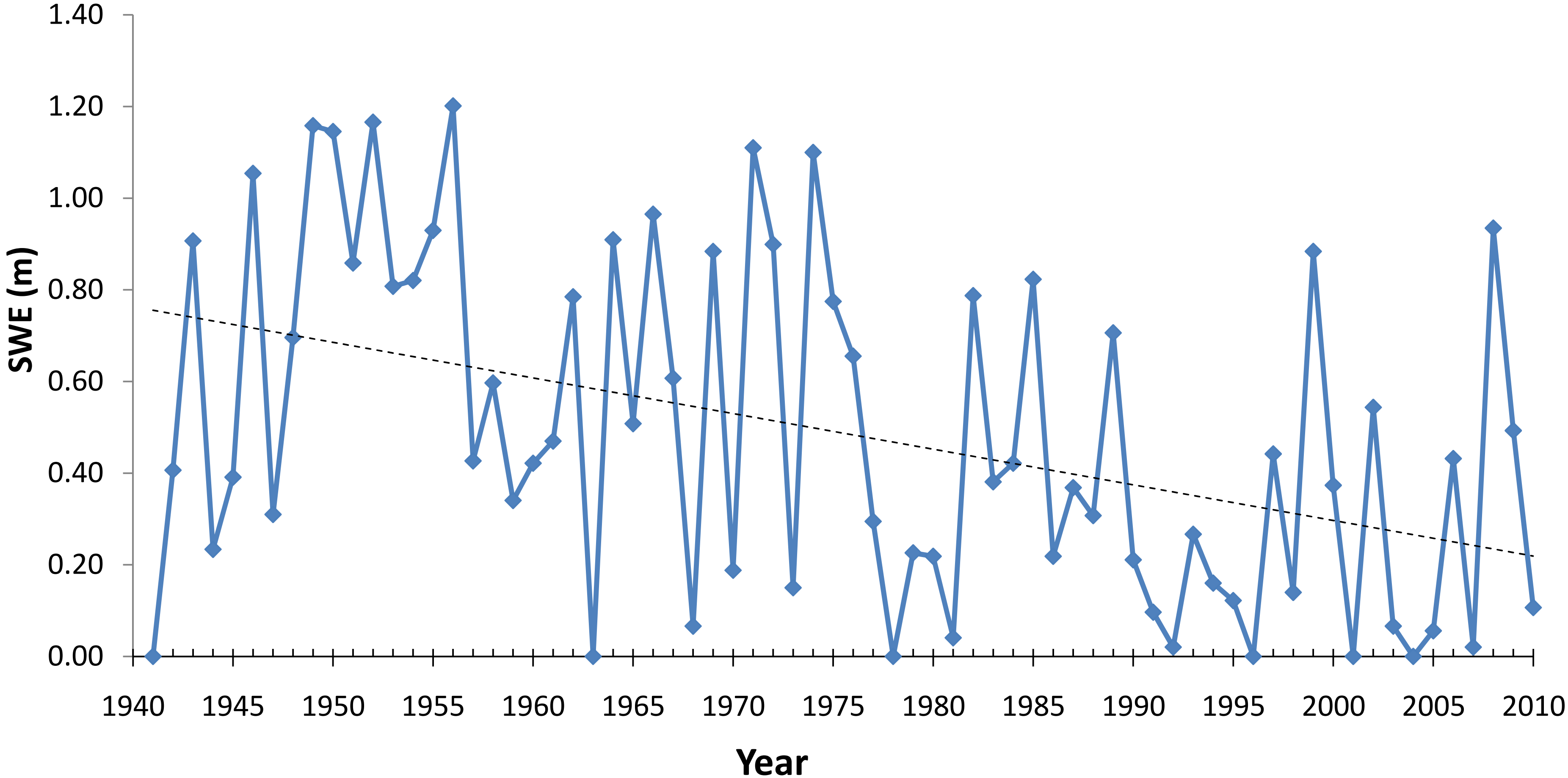

McKenzie River Basin
SNOTEL and Meteorlogical Station Locations
SNOTEL Locations
Meteorlogical Stations
HJ Andrews Exp Forest
High Cascades Boundary
Streams
McKenzie River
Lakes
Elevation (m)
3100
150
Daly Lake
Santiam Junction
Hogg Pass
Jump Off Joe
Hoodoo
H15MET
VANMET
CENMET
PRIMET
UPLMET
McKenzie
Trout Creek
Roaring River
Portland
Eugene
0
20 Kilometers
44°30'N
44°20'N
44°10'N
44°0'N
43°50'N
123°W
122°W

Measured and modeled flows, McKenzie River at Clear Lake, OR (elev. 918-2051) m)



From Jefferson et al., 2008; Hydrological Processes

Measured SWE at Santiam Junction on April 1 (elev. 1143 m)

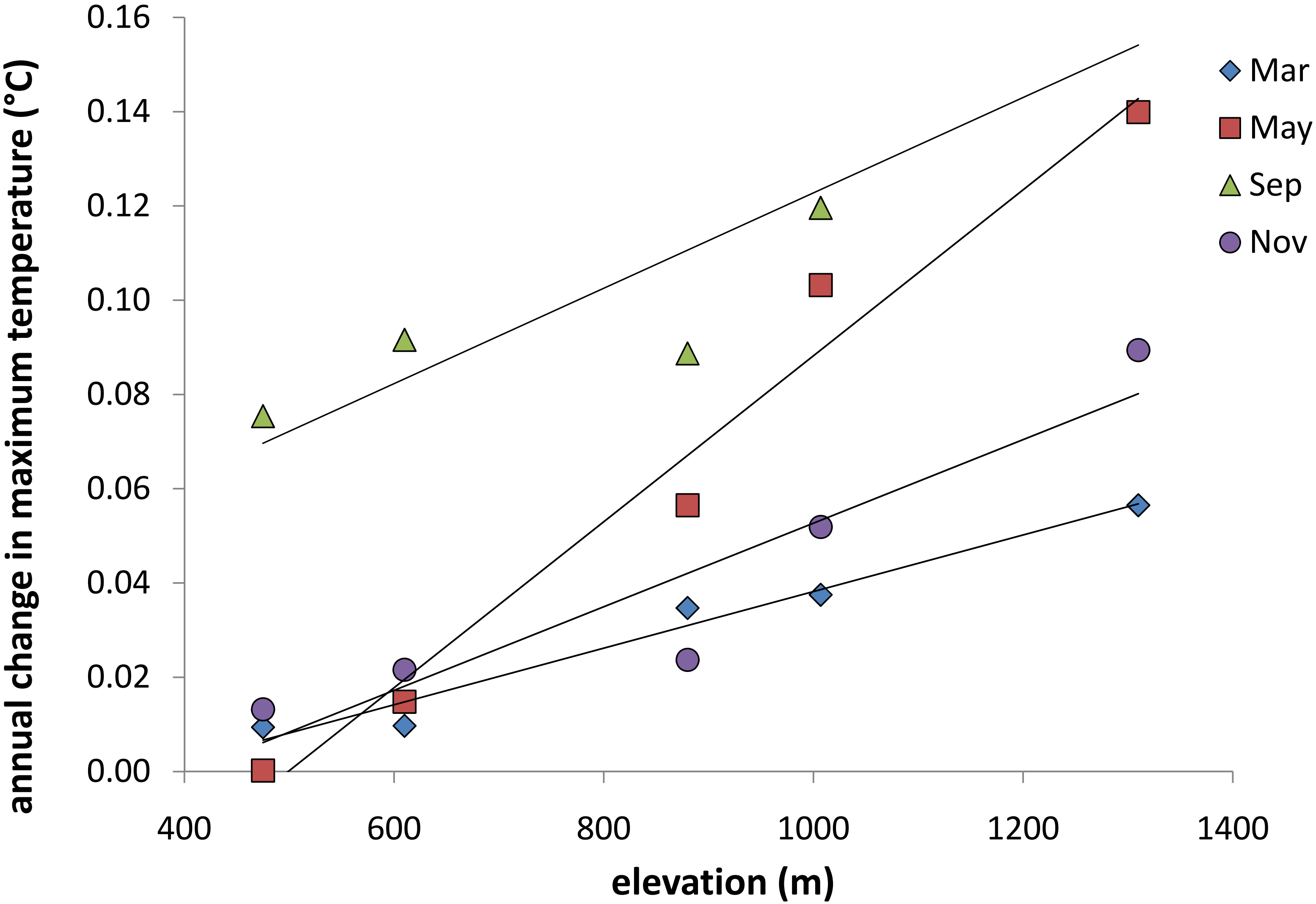


-8 mm/year

Significant at 0.99 level

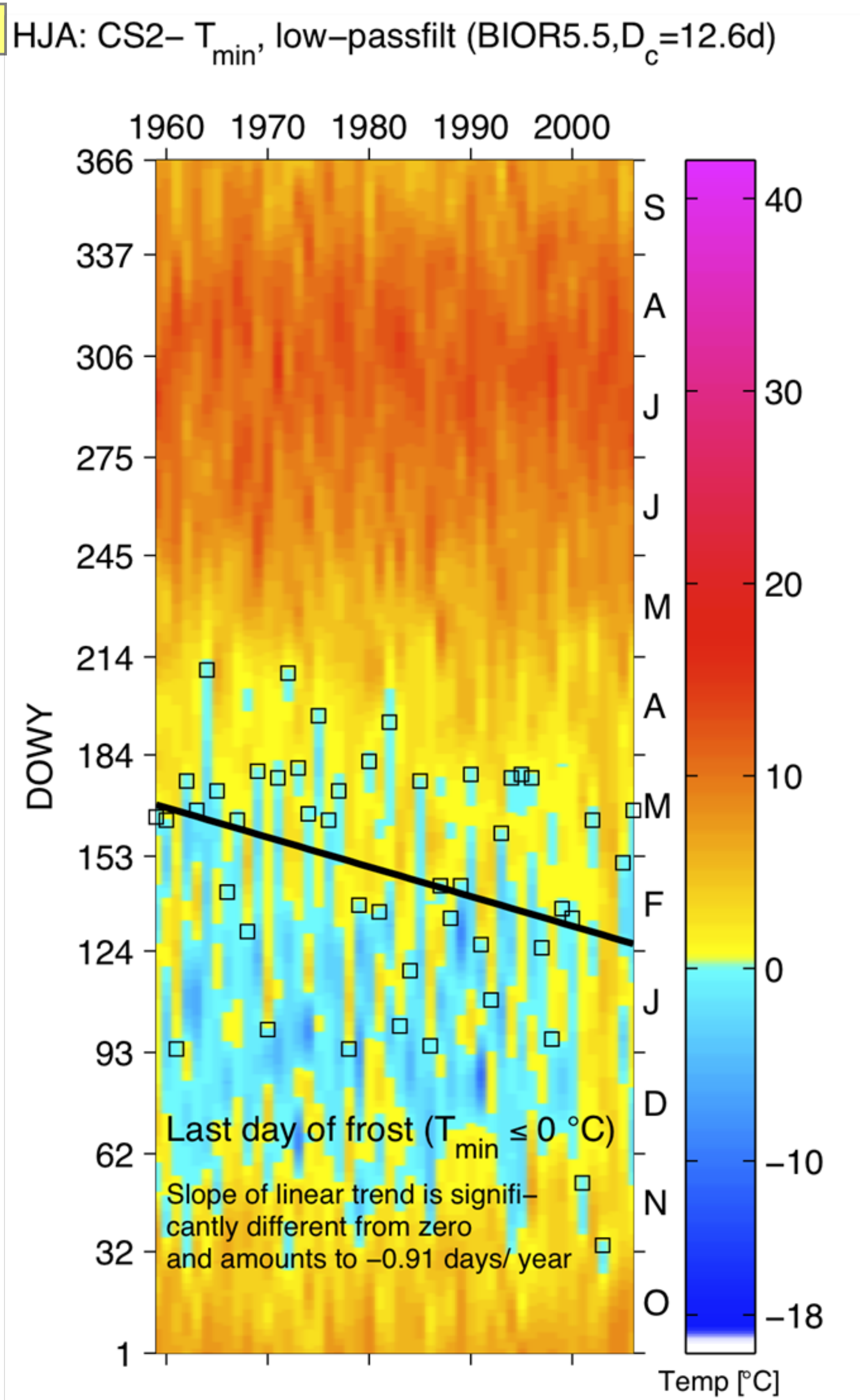
Water volume loss in a 500-m elevation band = 0.5 km^3

Average annual trends in maximum temperature at the HJA: 1973 - 2003



Courtesy Julia Jones

Earlier Spring at the HJA



Trend towards earlier spring at the HJA from 1958-2007

-0.9 days/year

The result?
Warming allow trees to use water from the soil earlier in the year

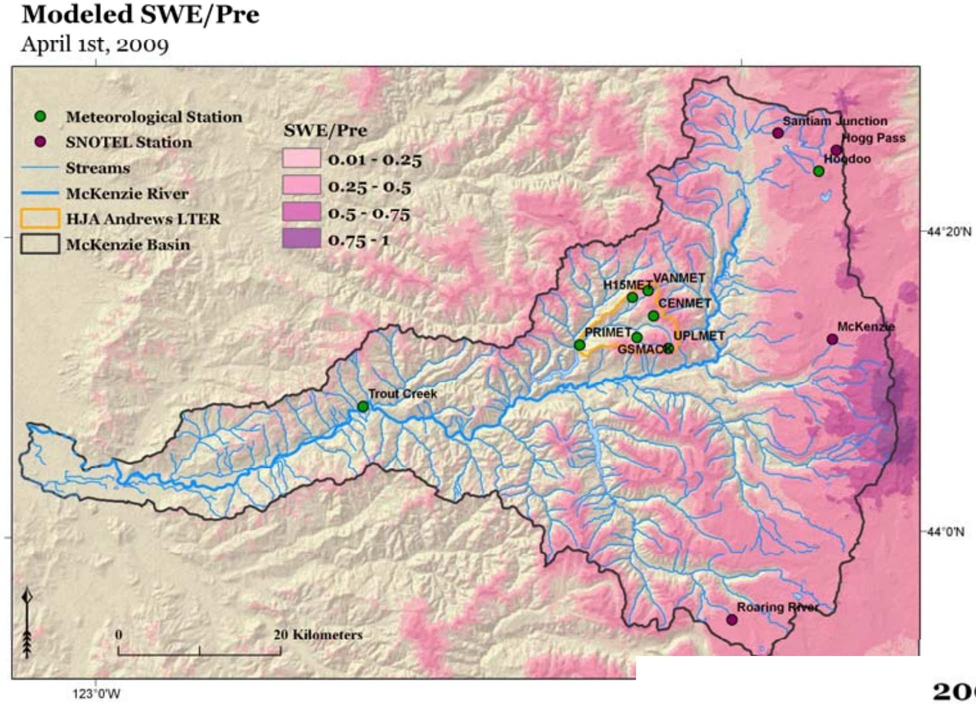
Courtesy C. Thomas, Oregon State University

Trends in Seasonal Streamflow at the HJ Andrews LTER

Runoff Ratio (Streamflow/Precipitation) at forested "control watersheds (all values shown are statistically significant)					
	Average runoff ratio	WS02 1958-05	WS08 1963-05	WS09 1968-05	Mack 1980-05
Yr	0.6-0.8		-0.13	-0.11	-0.19
MAM	0.7-1.2	-0.19	-0.40	-0.21	
SON	0.2-0.4			-0.04	
DJF	0.6-0.8		-0.09	-0.12	-0.25

Courtesy K. Miles, J. Jones, Oregon State University

Process-based Snow Modeling: Present-day and Future

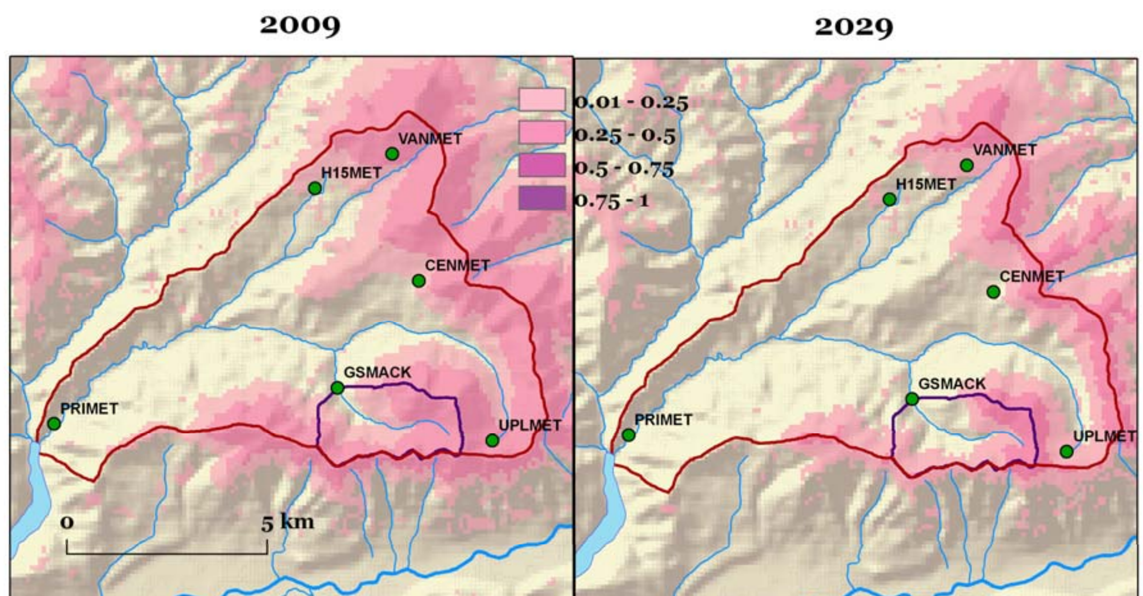


SnowModel (Glen & Liston, 2006)
Modified by Nolin & Sproles
100-m grid, daily time step
Winters, 1985-present
Future climate scenarios for 2020s, 2040s

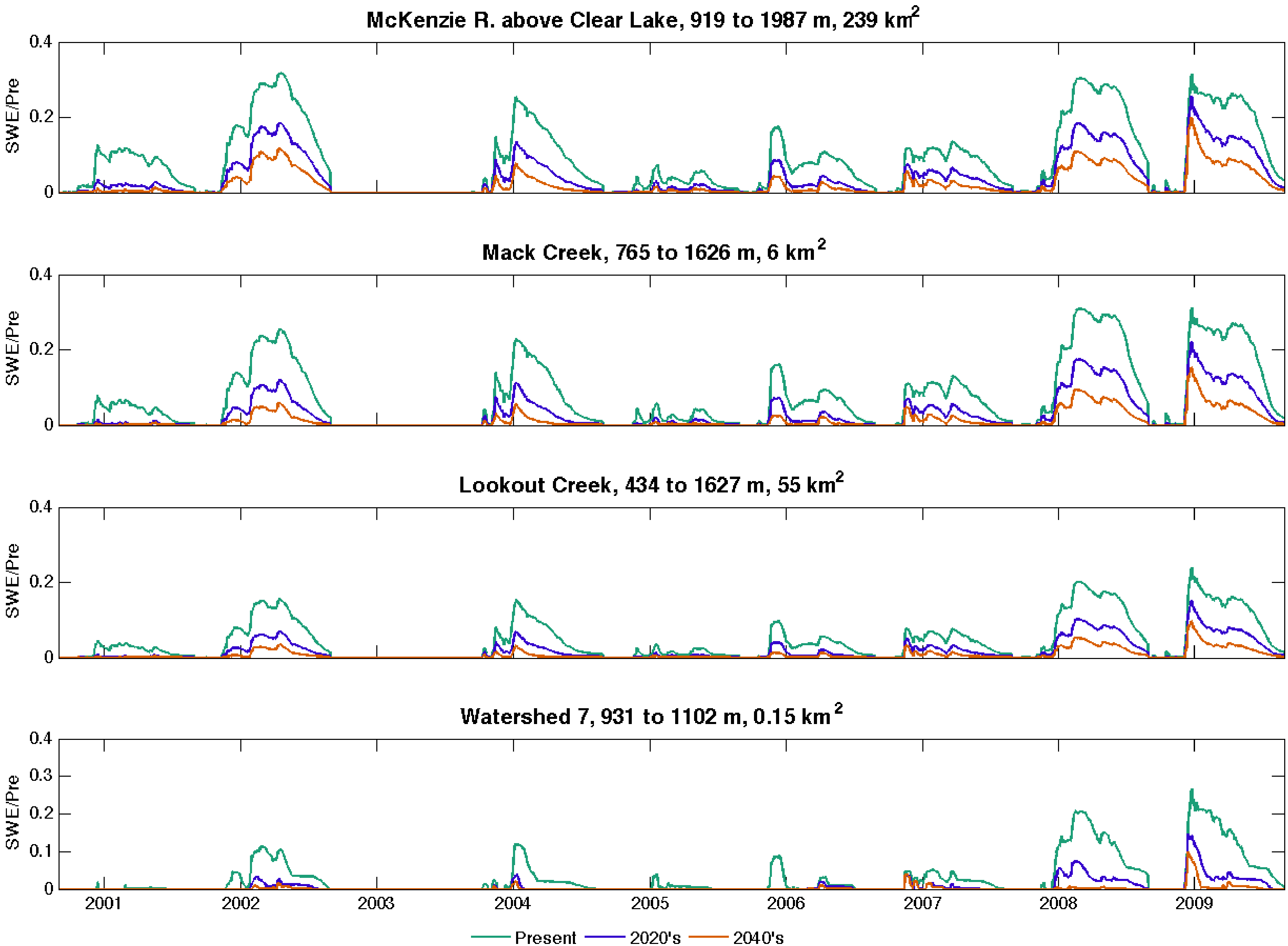
SWE sensitivity:

1. elevation
2. vegetation type
3. forest density

Input:
Met station daily T & Precip
Output:
Spatially-distributed T & Precip
SWE
Validation:
T & Precip
MODIS SCA
SNOTEL



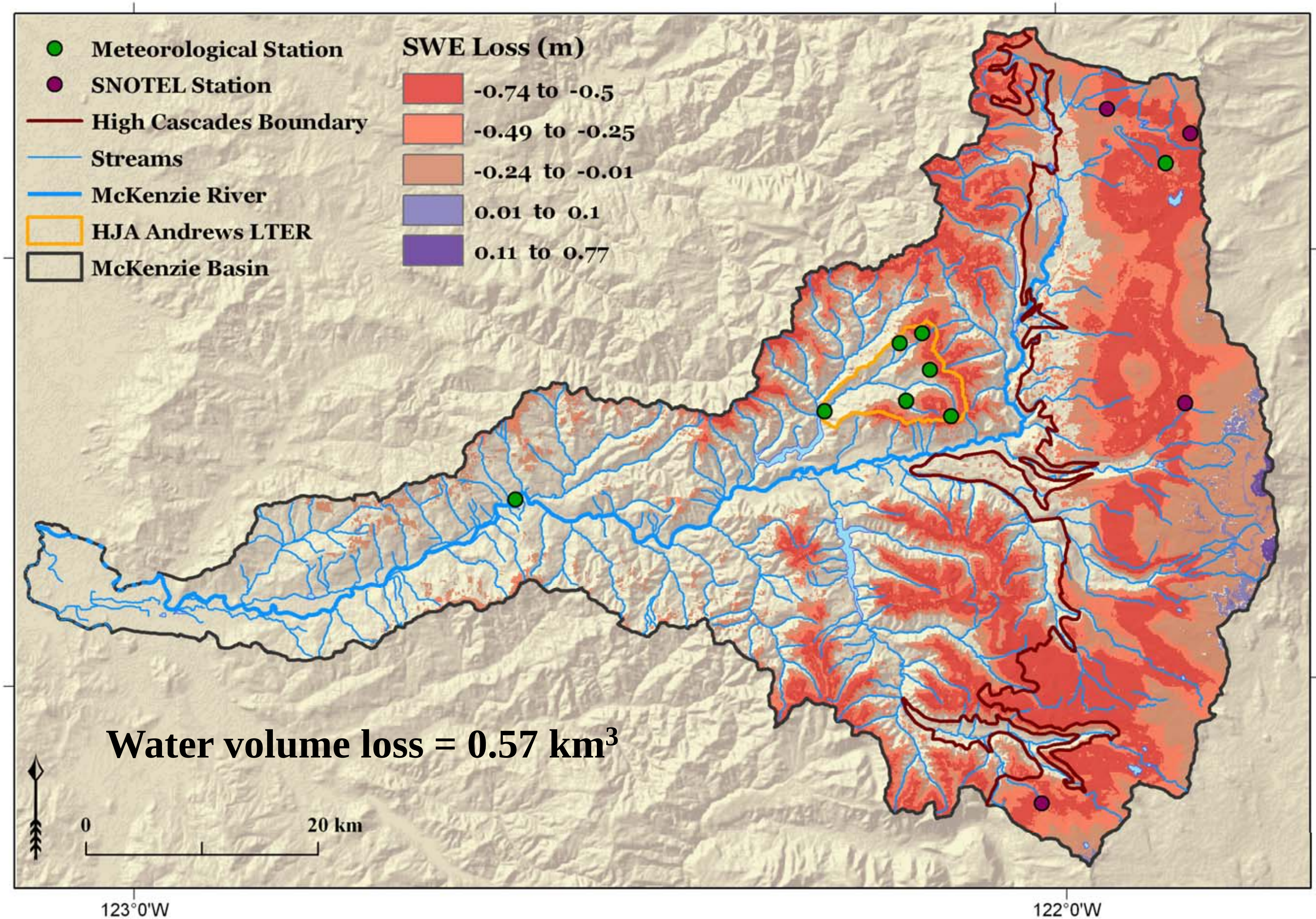
Courtesy Eric Sproles



Courtesy Eric Sproles

Modeled Loss of Snow Water Equivalent (April 1)

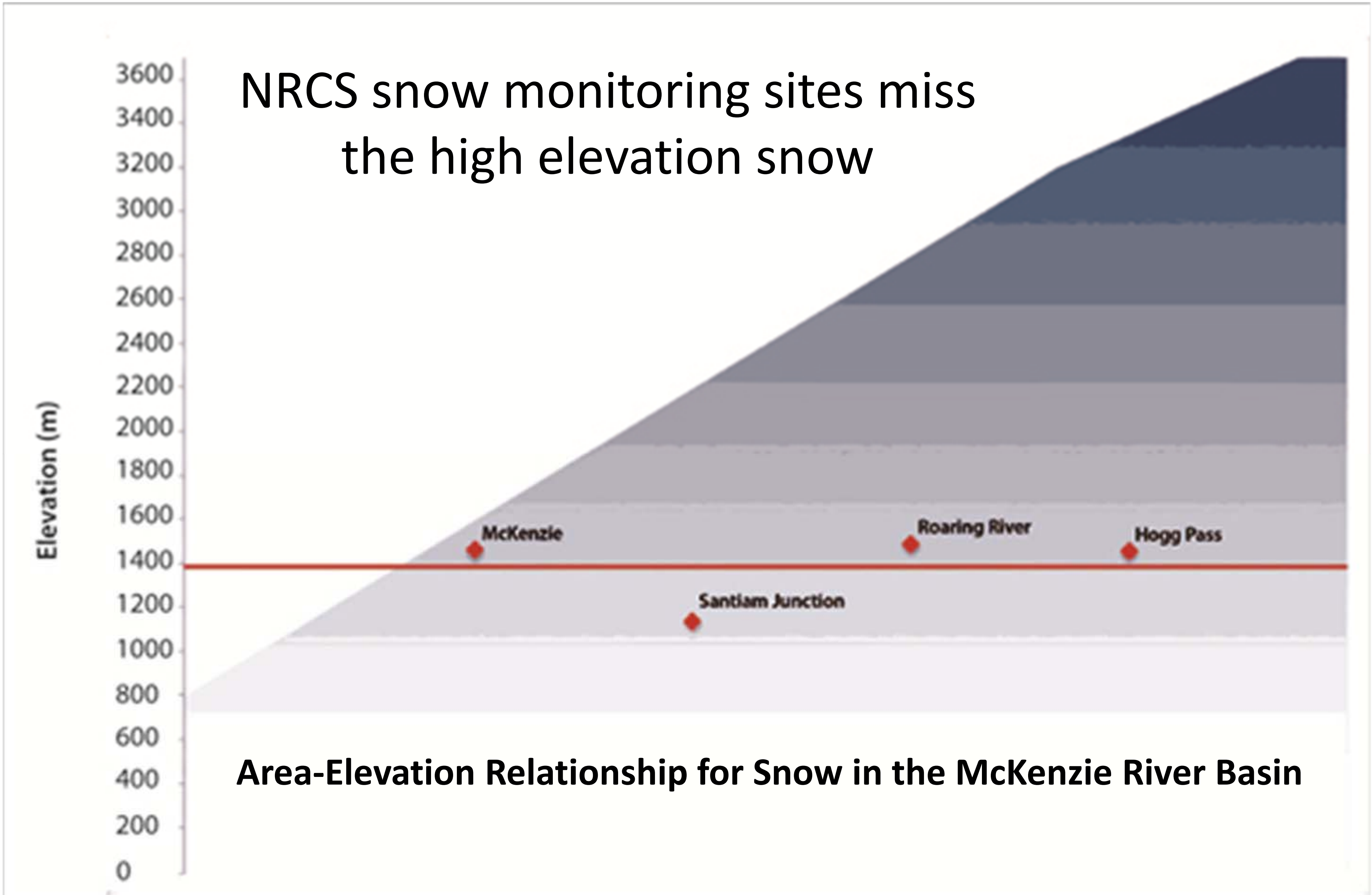
Winter with Average SWE - 2040s projected climate



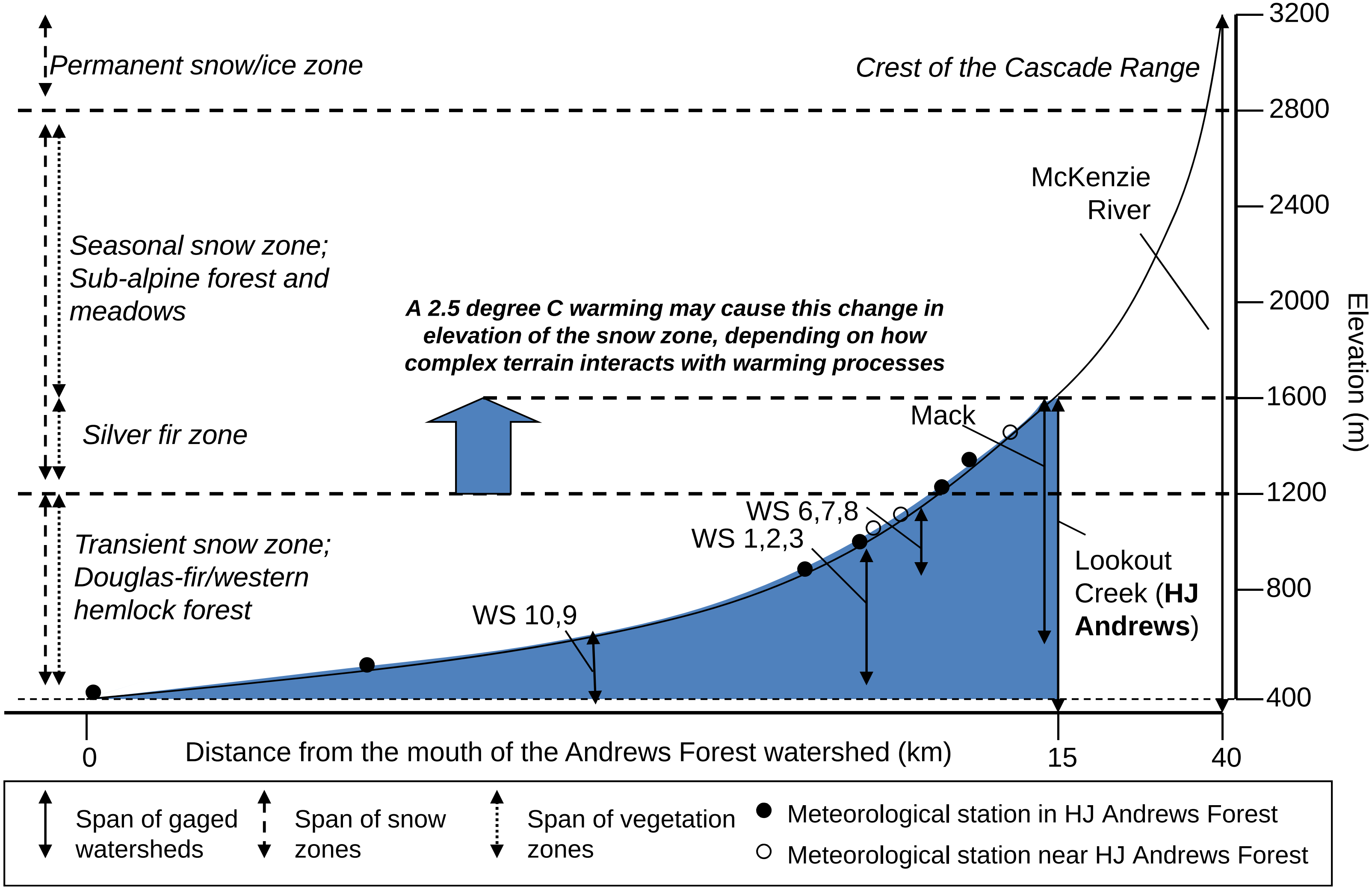
Observations and models help us conceptualize and quantify connections and feedbacks

Two major challenges:

- Monitoring systems are sparse, inadequate
- Integrated conceptual framework is needed

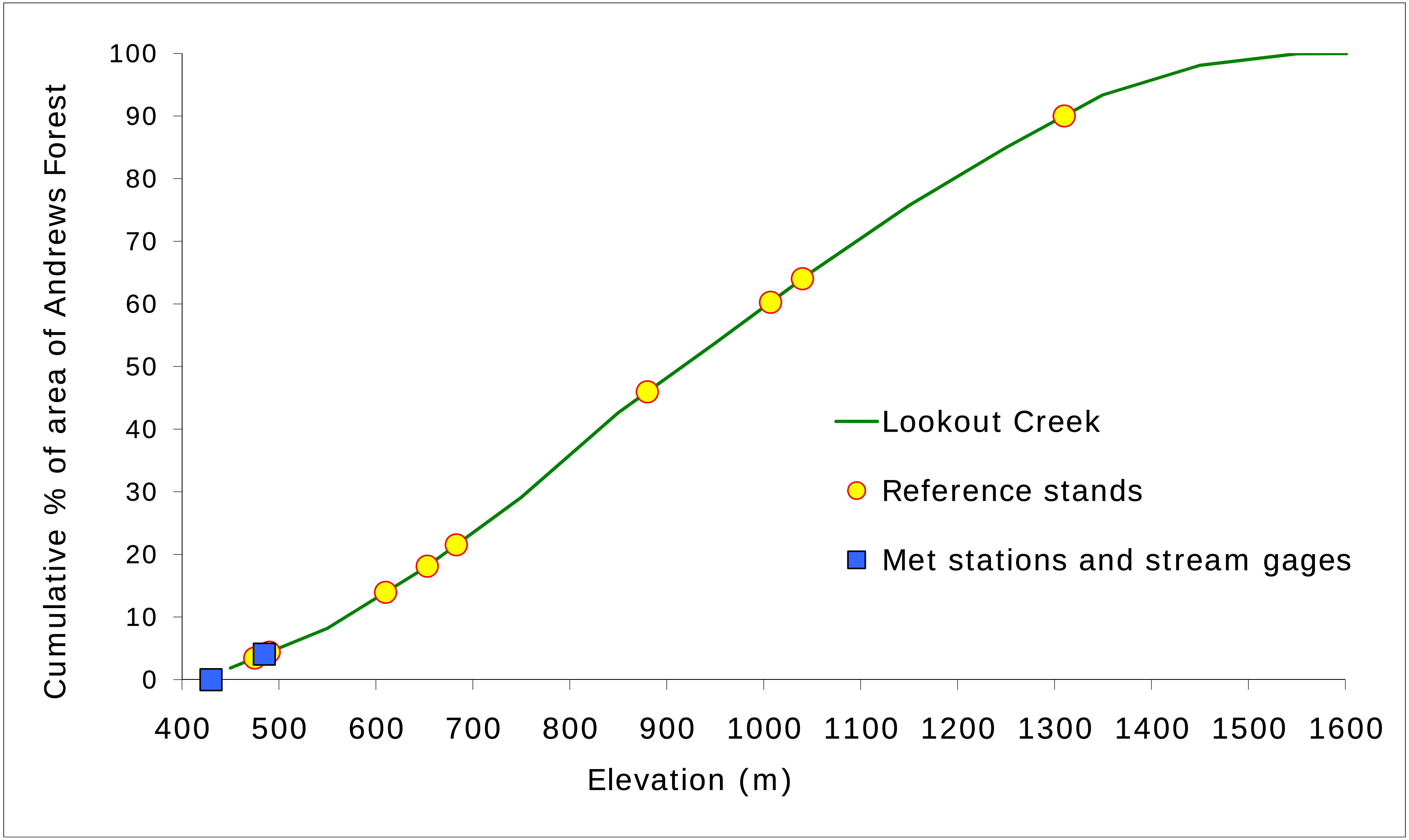

NRCS snow monitoring sites miss
the high elevation snow
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Elevation (m)
McKenzie
Roaring River
Hogg Pass
Santiam Junction
Area-Elevation Relationship for Snow in the McKenzie River Basin

Elevation Distribution and Location of Measurement Sites



Courtesy Julia Jones

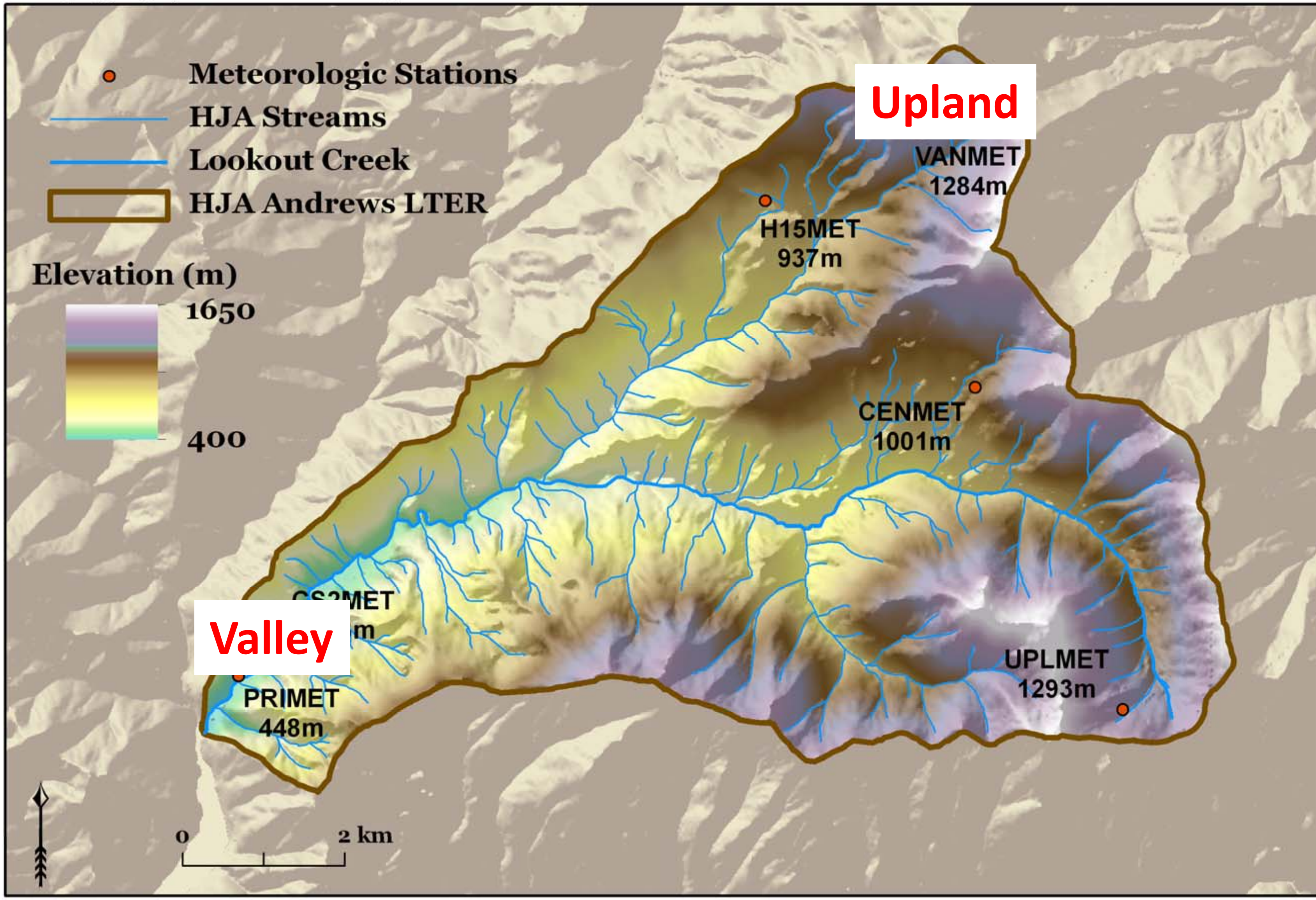
Elevation distribution of HJA sites with records >30 years



Courtesy Julia Jones

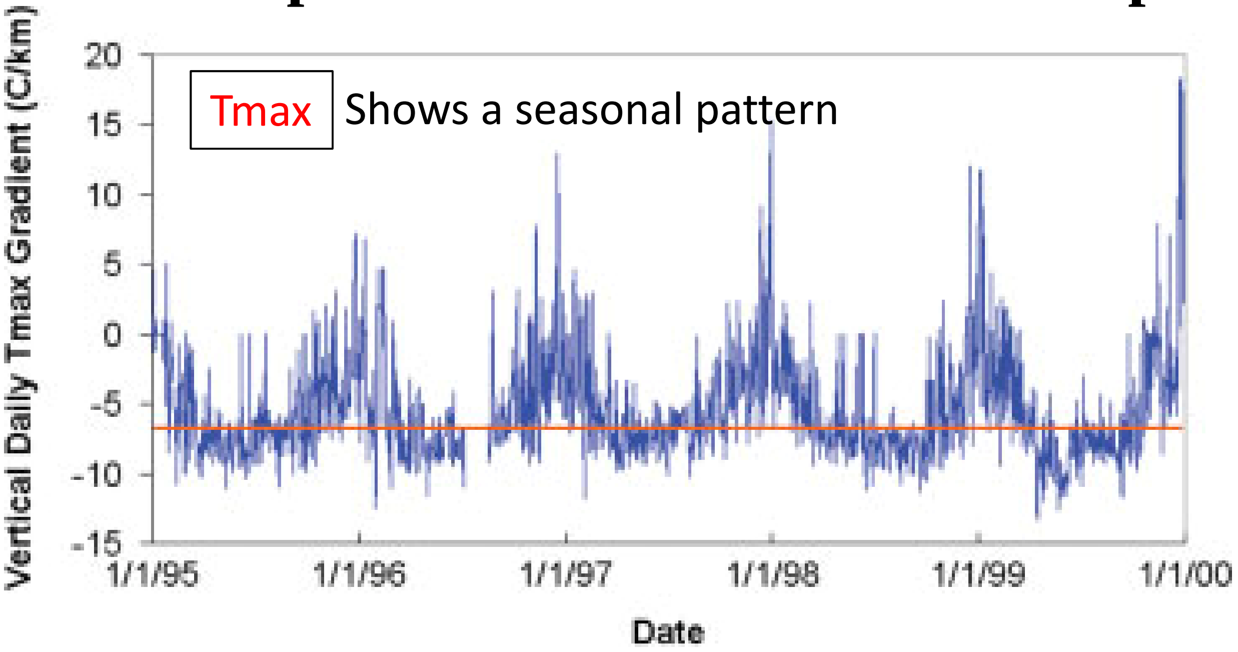
HJ Andrews Experimental Forest

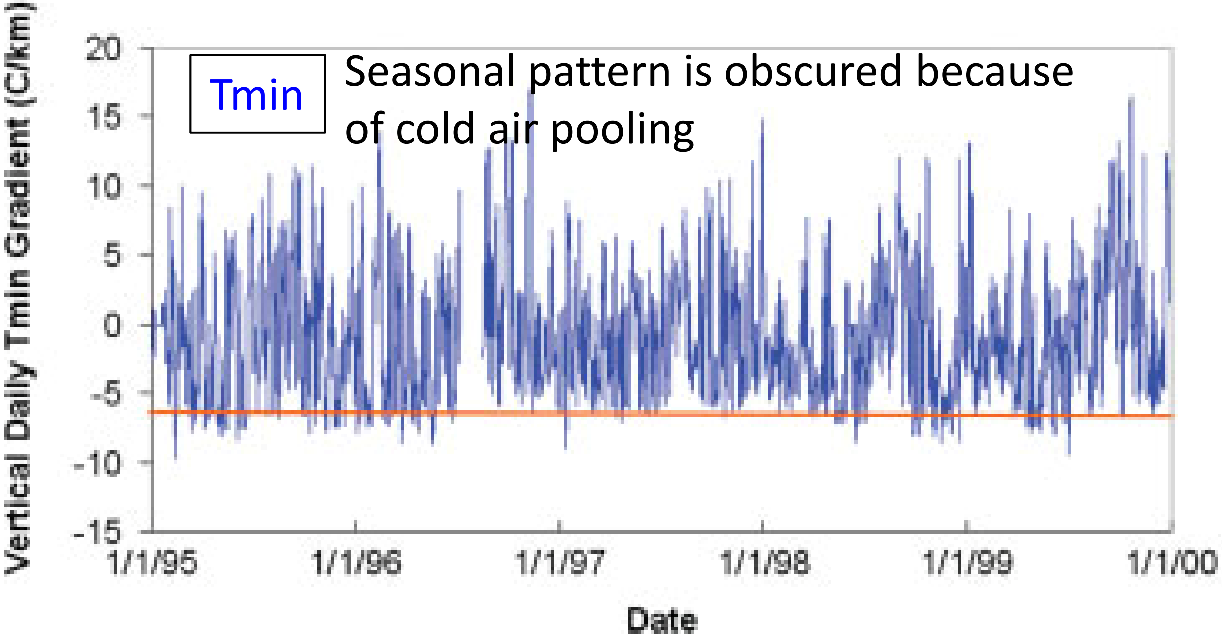
Topography and Meteorologic Stations



Courtesy E. Sproles

Temperature differences between uplands and valleys

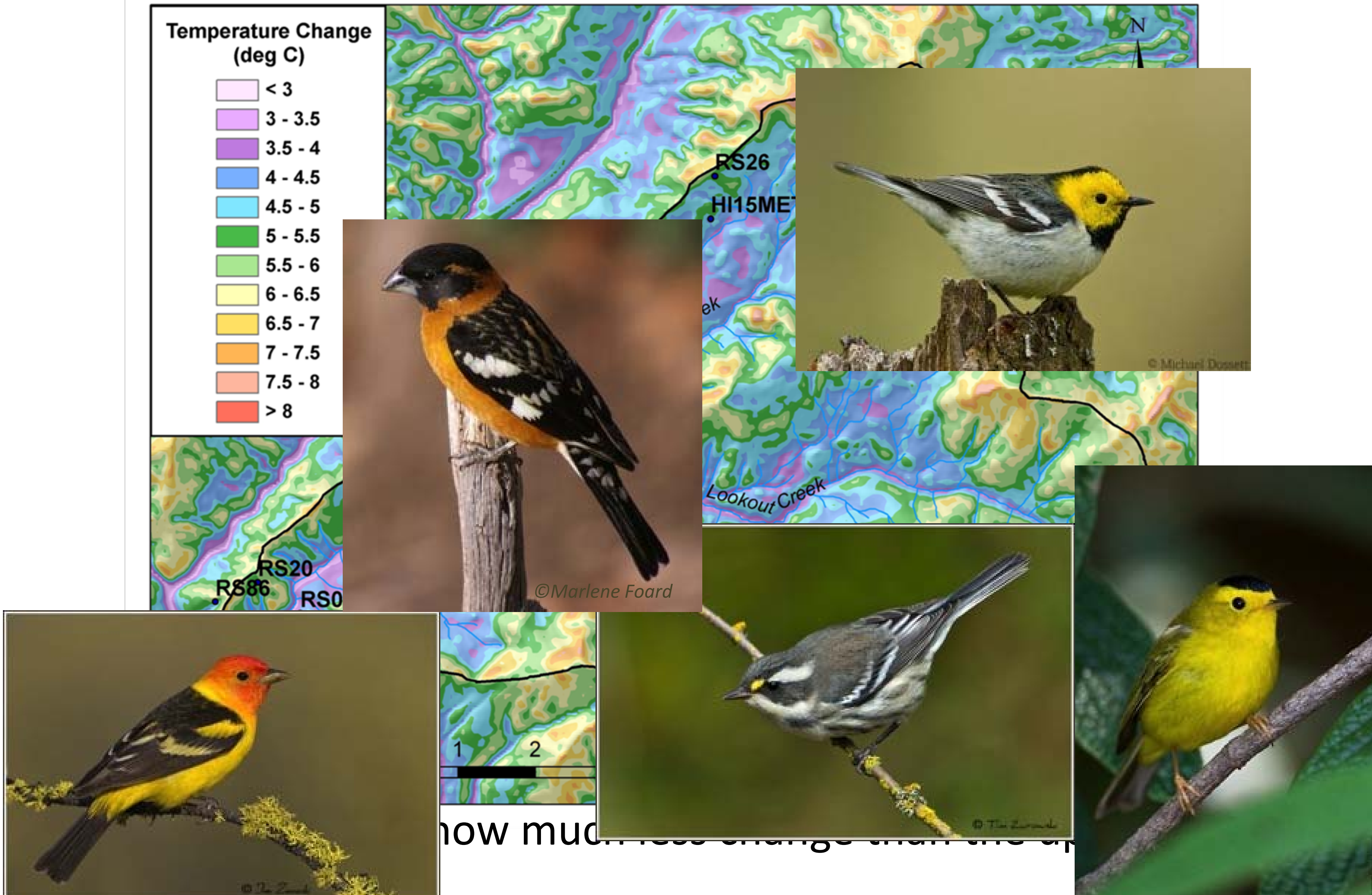




During "stable" atmospheric conditions, cold air flows downslope and pools in the valleys

The valleys become decoupled from the uplands

HJ Andrews Temperature Map for Projected Warming



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Changes in Land Cover and Land Use Modify Streamflow

But how much, when?

$$I^* = \overline{S}\left(0.27 + \frac{46}{\rho_s}\right)LAI$$

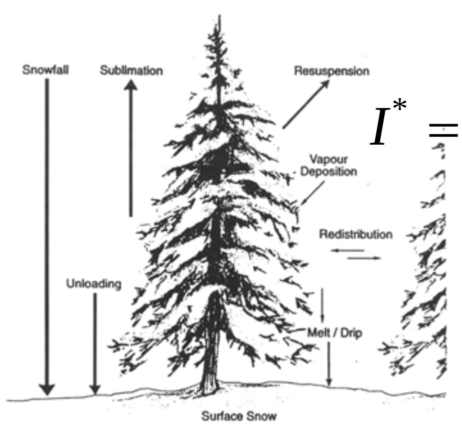
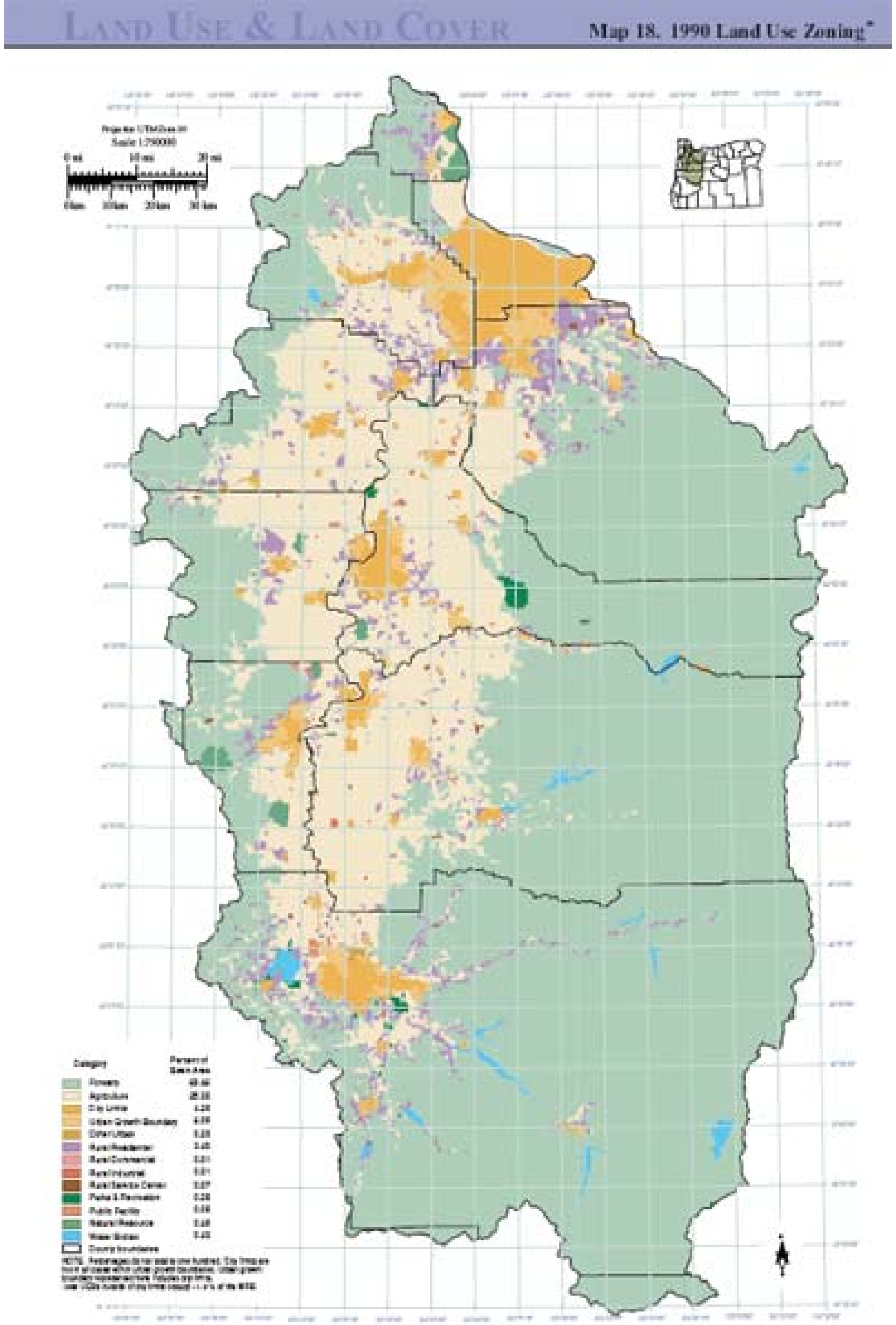


Figure 2.11. Mass fluxes associated with the disposition of winter snowfall in a boreal forest (after Pomeroy and Schmidt, 1993).

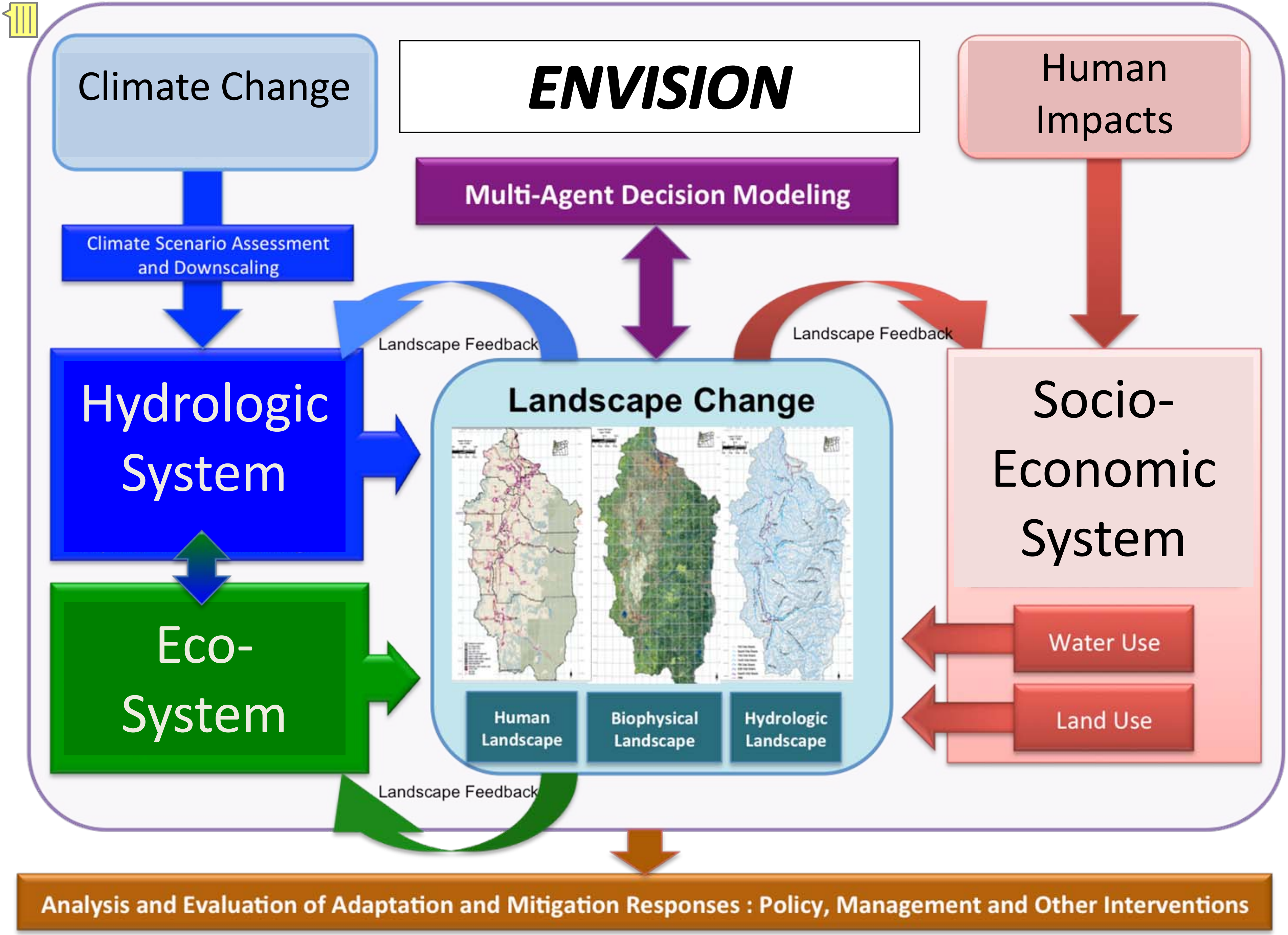
$$I^* = \overline{S}\left(0.27 + \frac{46}{\rho_s}\right)LAI$$



Water flows downhill but policy and population pressures flow uphill

Water scarcity is the relationship between supply and demand

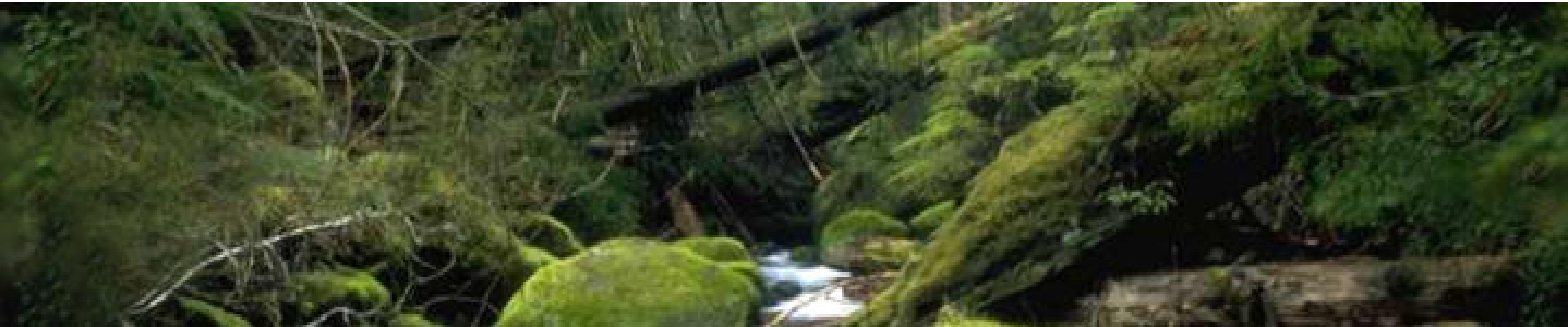
- **Annual vs. seasonal scarcity**
- **Local vs. regional**



Courtesy OSU **Willamette Water 2100** team (McDonnell, PI; NSF Hydrologic Sciences)

In summary:

- Snowpack is changing and long records are key
- Complex topography creates complex temperature patterns
- Measurement systems should be adapted so that they capture patterns of change
- Integrated modeling framework is needed to



Water connects all

Hearty thanks to my many collaborators and contributors:

- Eric Sproles
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- Julia Jones
- Kathleen Miles
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- Matt Betts
- Phil Mote
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