Anne Nolin
Department of Geosciences
Oregon State University

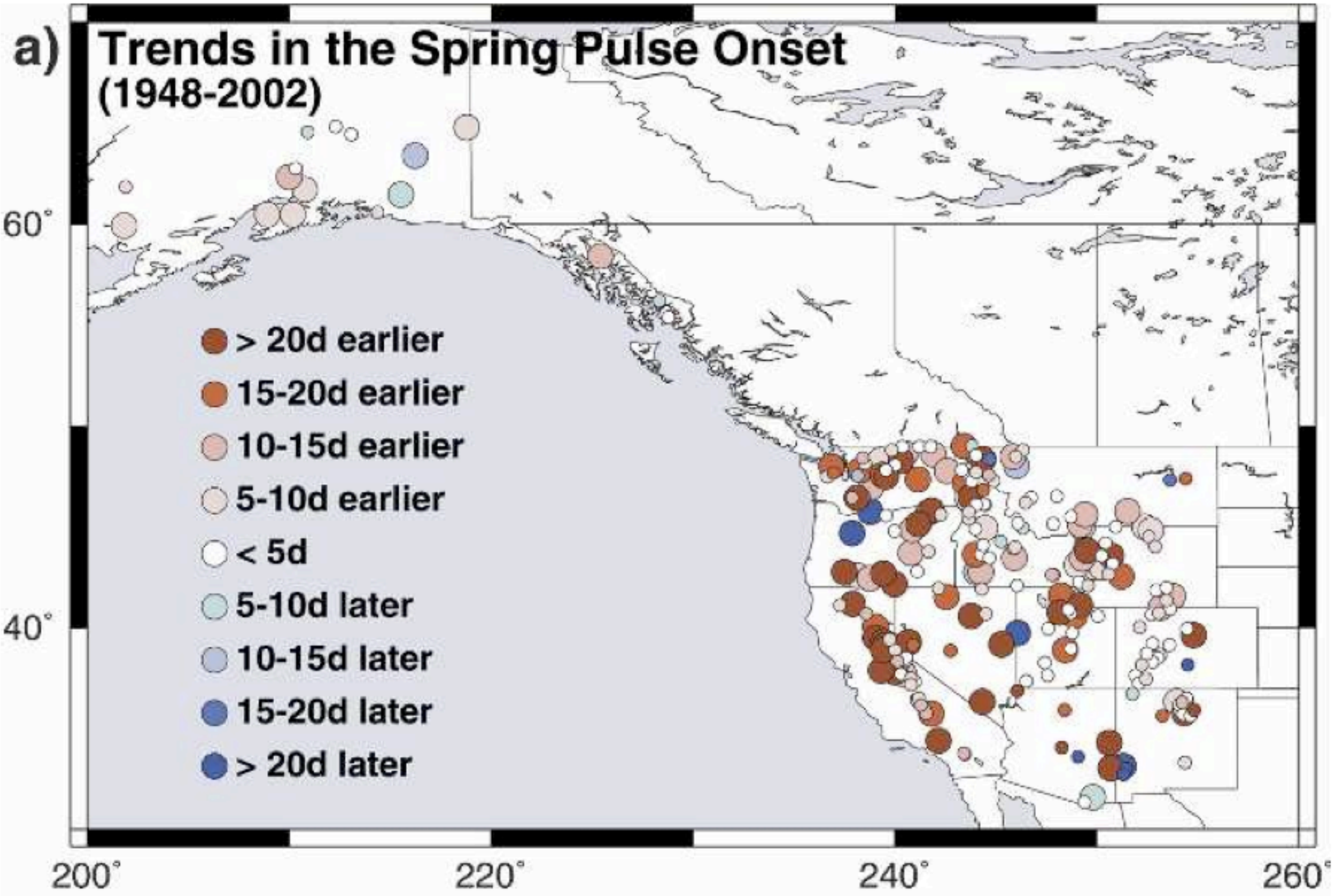
The Importance of Watershed Characteristics in Understanding Climate Change Impacts on Streamflow

PNW-AWWA **May 6, 2009**

Watershed-scale issues and climate change: points to consider

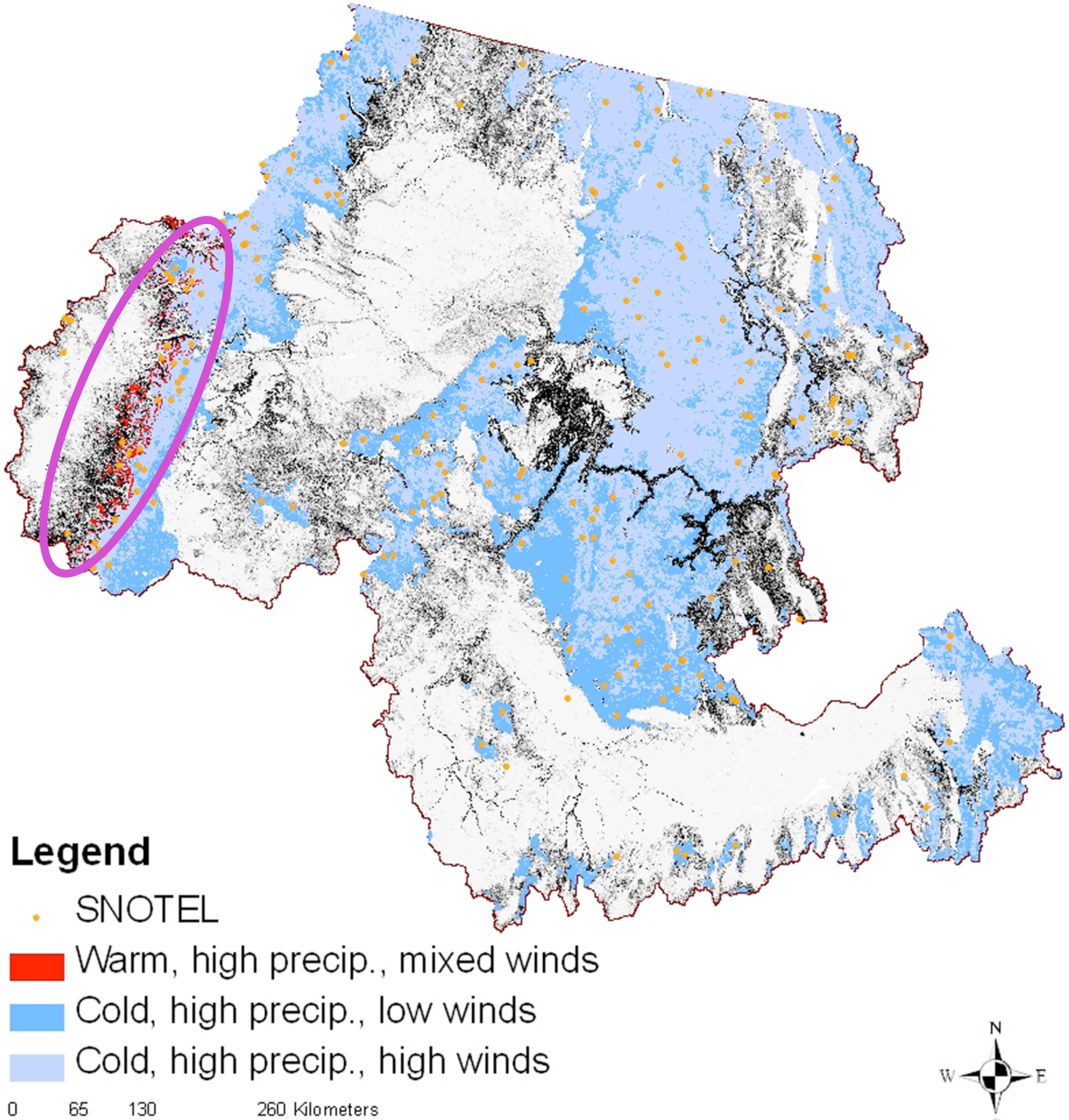
- Rain-snow partitioning
- Watershed geology
- Watershed hypsometry
- Ecosystem response
- Observation networks

Western US snowmelt and springtime stream flow are occurring earlier



From: Stewart et al., 2005 (Fig 2.) Spring melt onset at USGS Hydro-Climatic Data Network (HCDN) stream gages

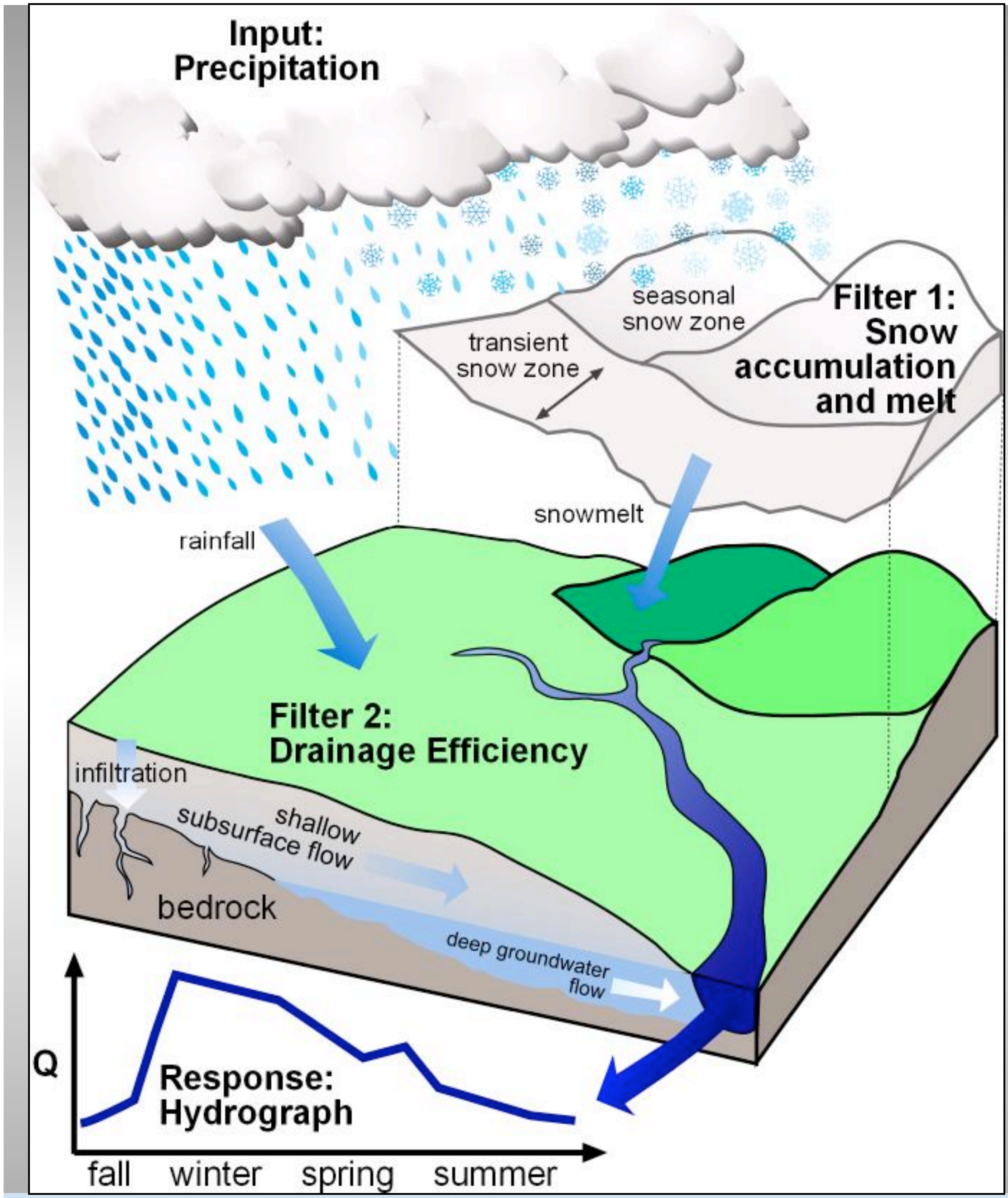
US Portion of the Columbia River Basin



Courtesy Aimee Brown

At-Risk Snow:

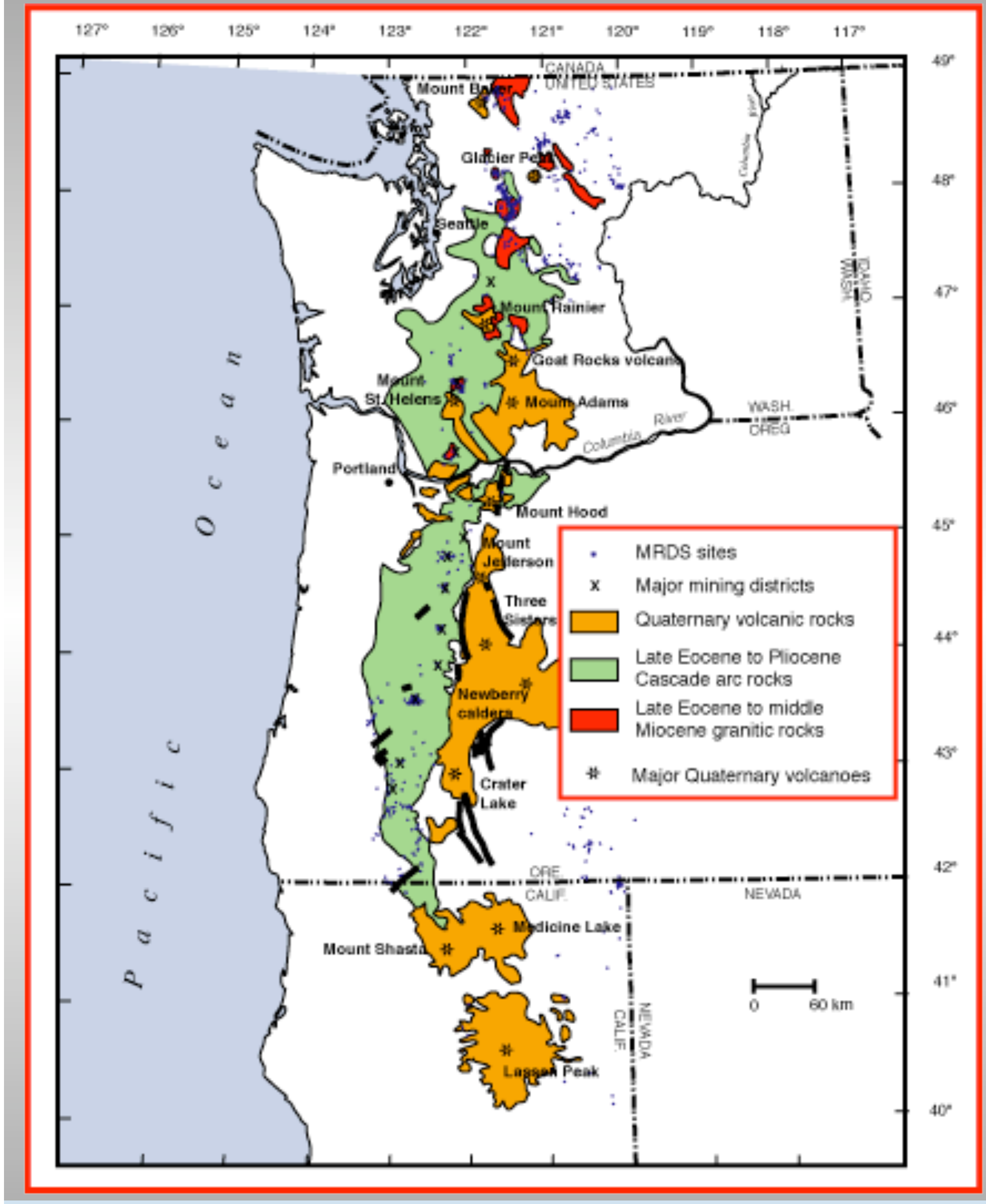
- A 2^{o}C winter warming is projected to cause some winter precipitation to fall as rain rather than snow
- Impacts vary across the Columbia River Basin but greatest impacts are for snow at lower elevations in the Western Cascades



Filter 1: Climate change impacts on snow accumulation and melt

Filter 2: Watershed geology controls drainage efficiency and the fate of rainfall and snowmelt runoff

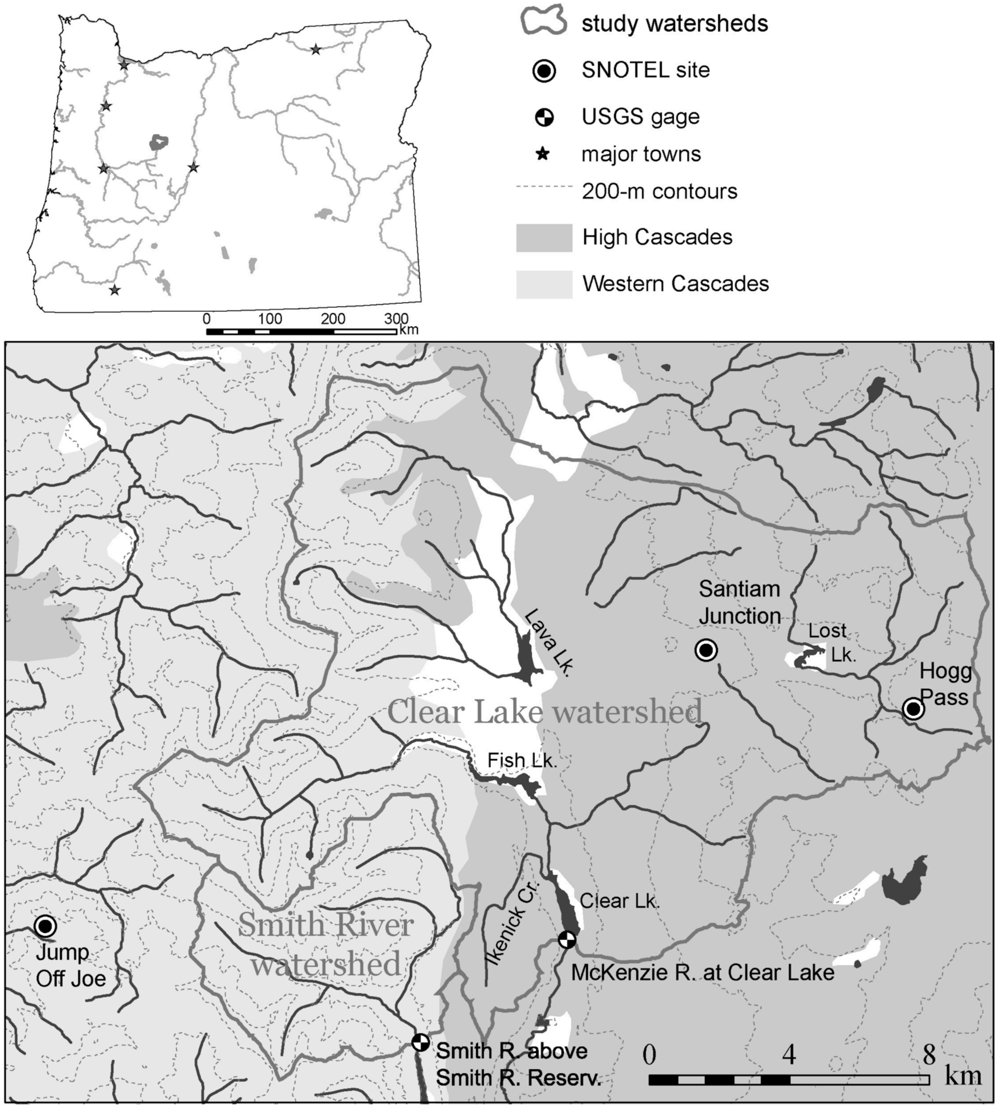
Streamflow depends on Geology



High Cascades (Orange):
Young volcanic rocks
Groundwater dominated
Sensitive to changes in amount of precipitation

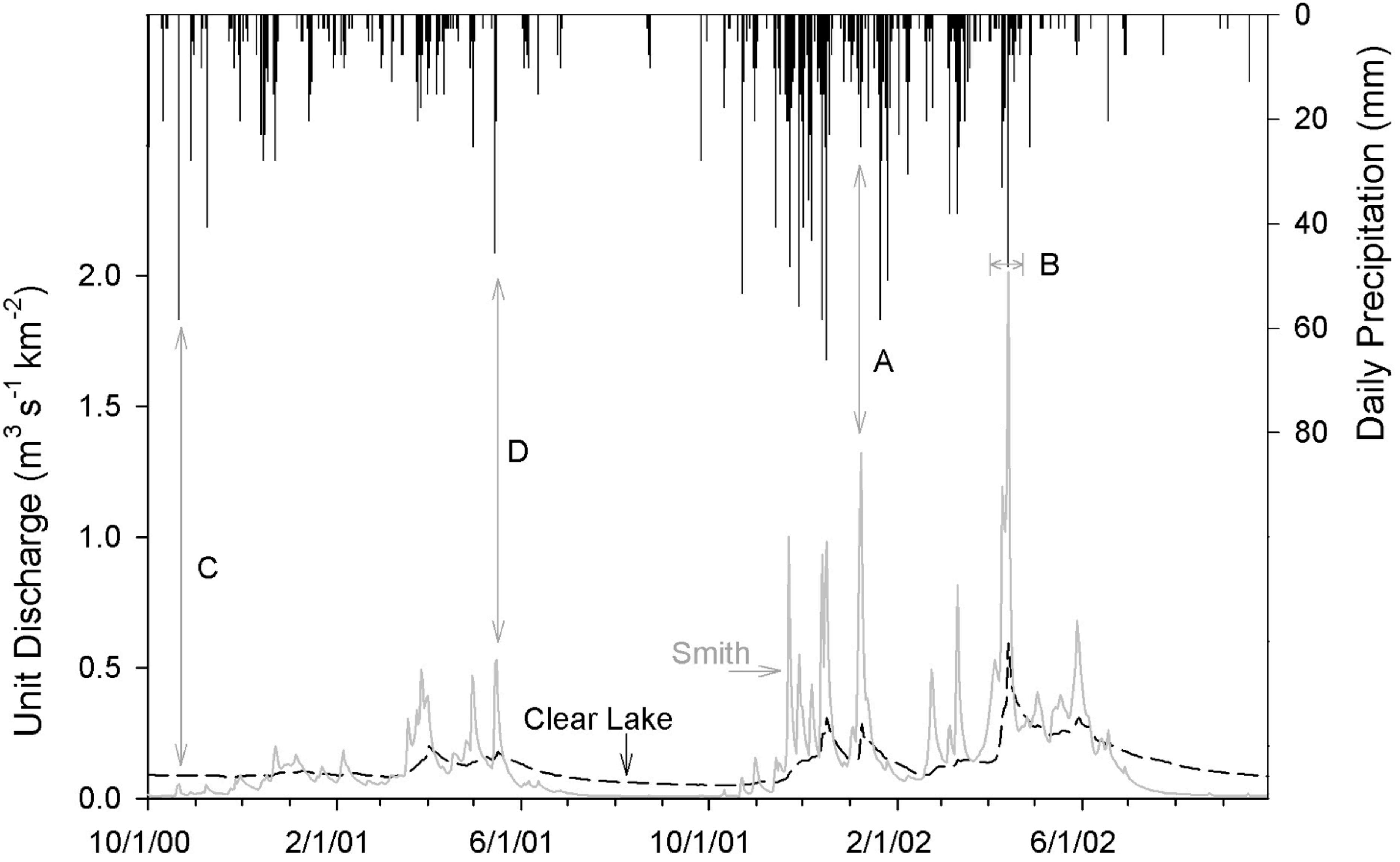
Western Cascades (Green):
Older, weathered volcanic rocks
Surface water dominated
Sensitive to changes in type and amount of precipitation

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



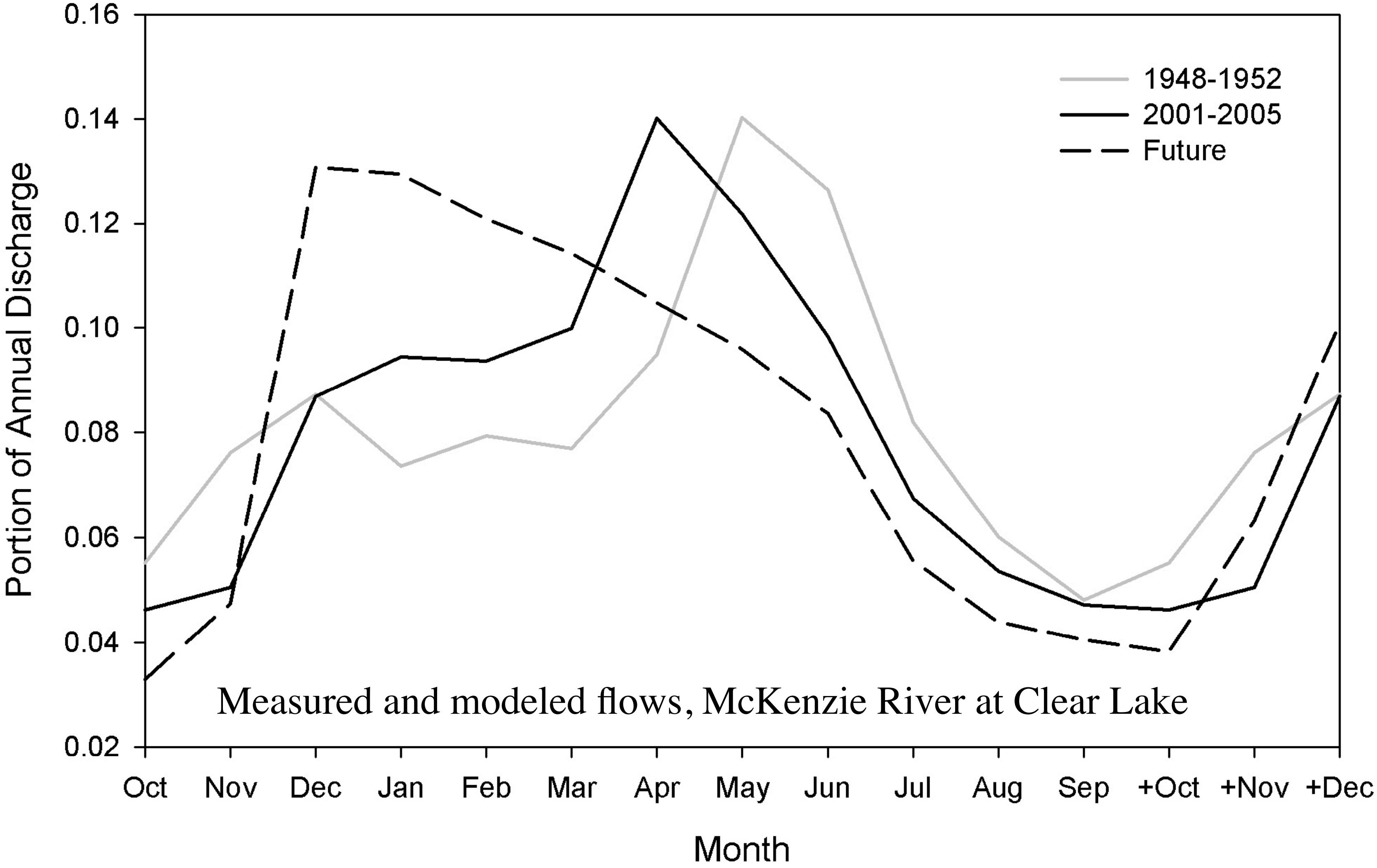
From Jefferson et al., 2008; Hydrological Processes

Groundwater- vs. surface water-dominated streams



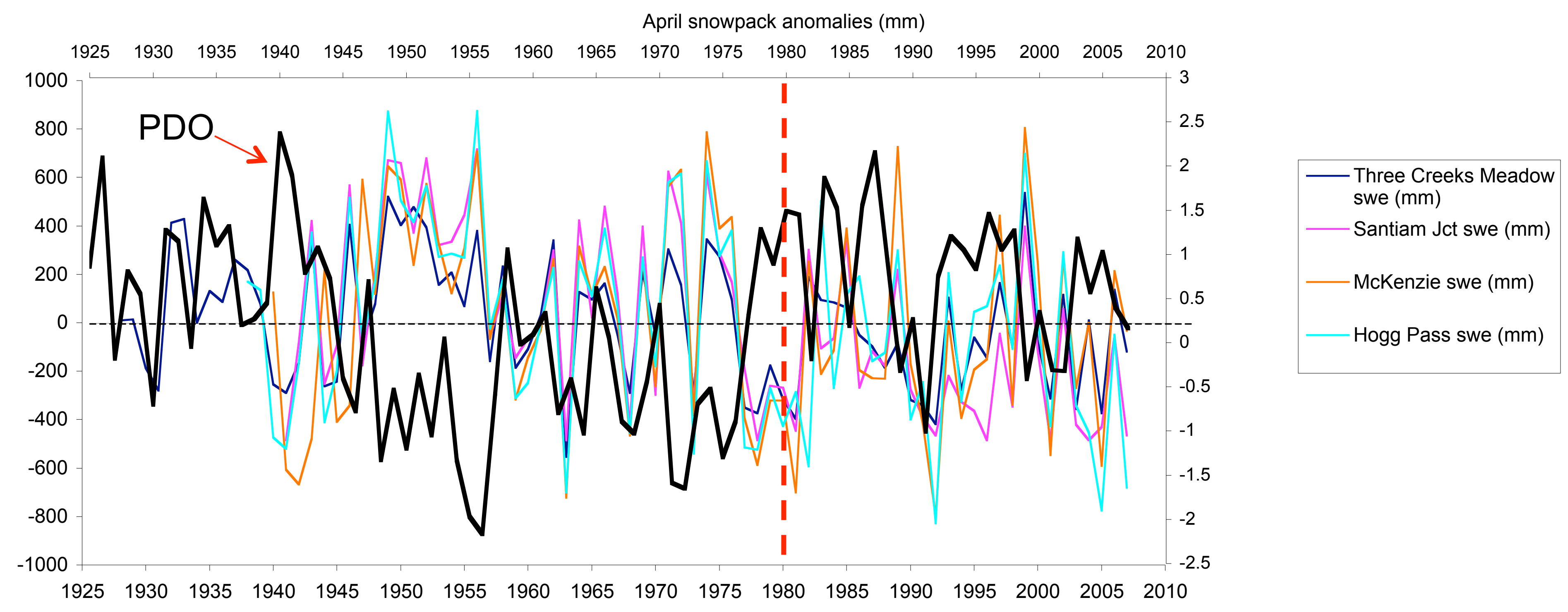
From Jefferson et al., 2008; Hydrological Processes

Peak flow is projected to come earlier, low flows to be 50% lower than 1948


Measured and modeled flows, McKenzie River at Clear Lake

From Jefferson et al., 2008; Hydrological Processes

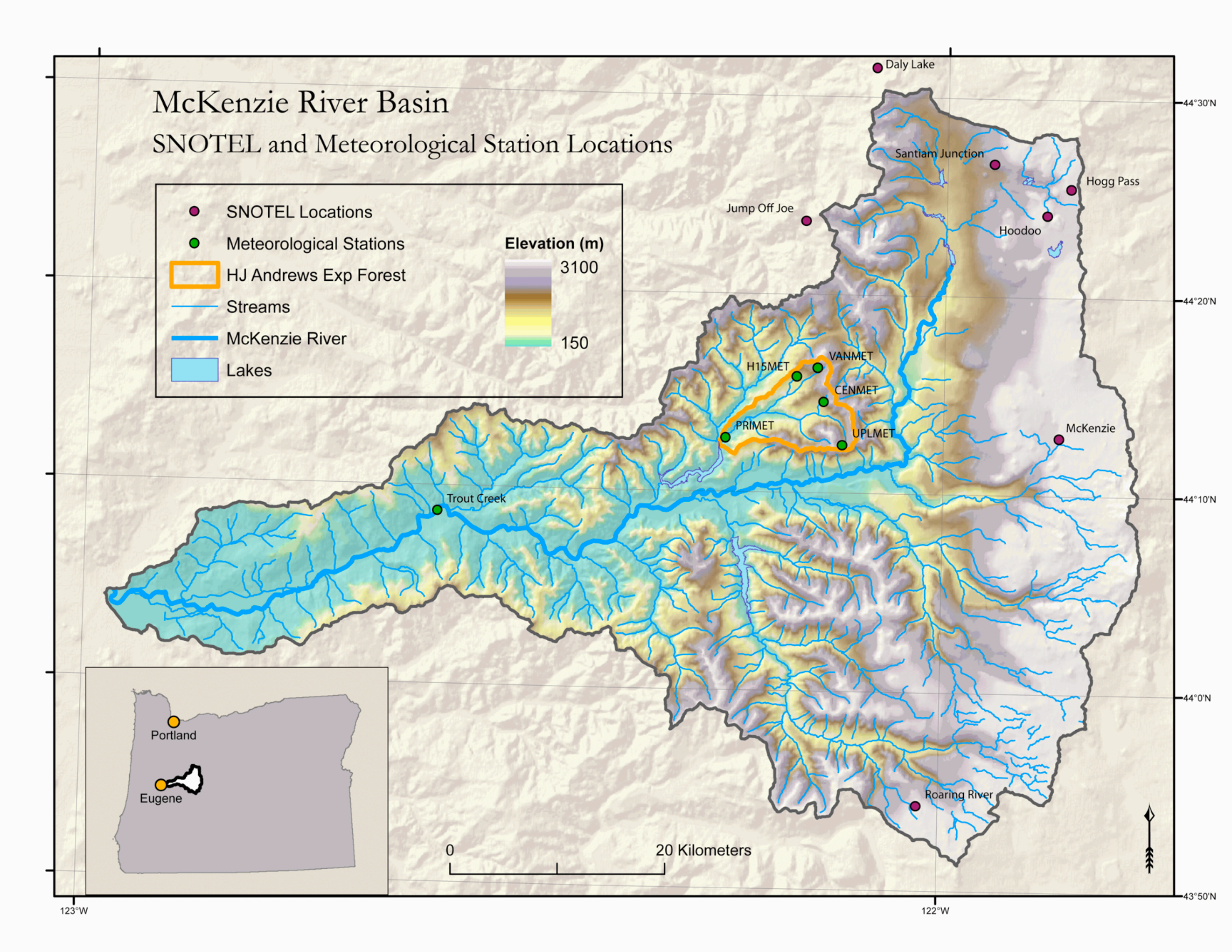
Pacific Decadal Oscillation (PDO) and Snow



NRCS SnoTel sites (Snowpack Telemetry)

- Short time series (early 1980s)
- Not representative of vegetation conditions or of topography within a forested mountain watershed

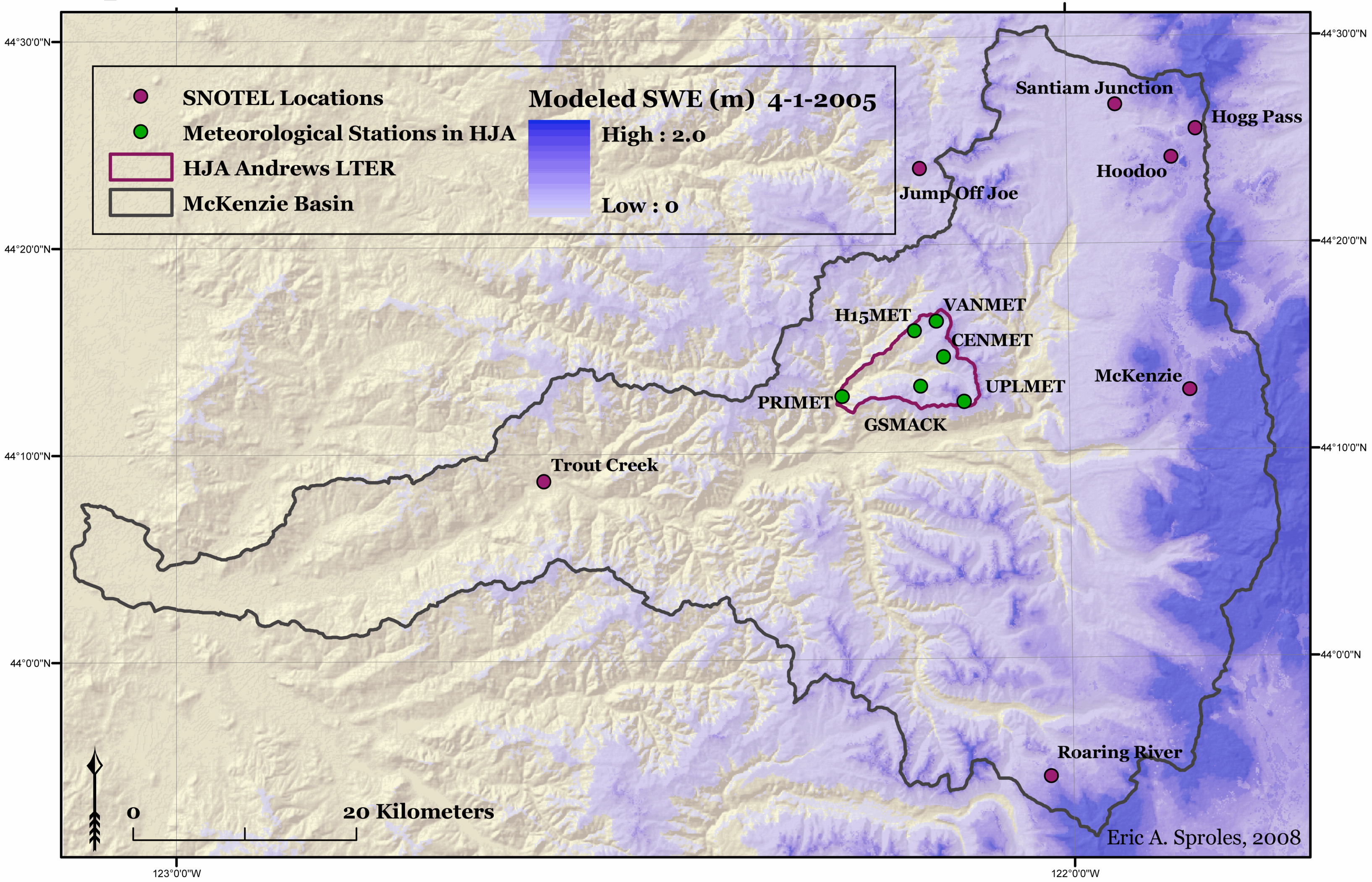
How can we use point-based measurements to represent watershed-scale processes?



McKenzie River Basin, Oregon

Modeled Snow Water Equivalent (m)

April 1, 2005

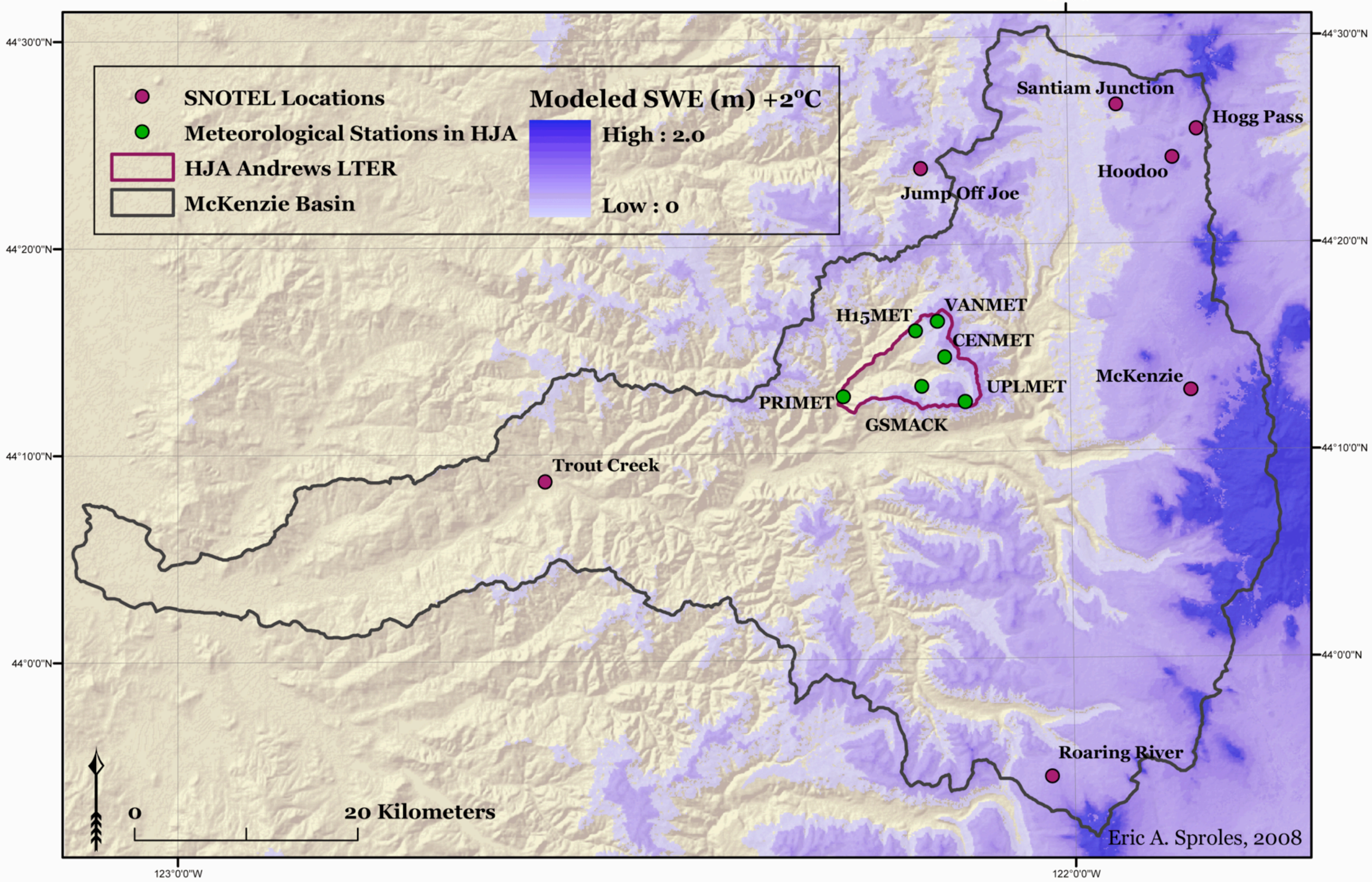


Courtesy Eric Sproles

McKenzie River Basin, Oregon

Modeled Snow Water Equivalent (m) - *Temperature Increased 2° C*

April 1, 2005

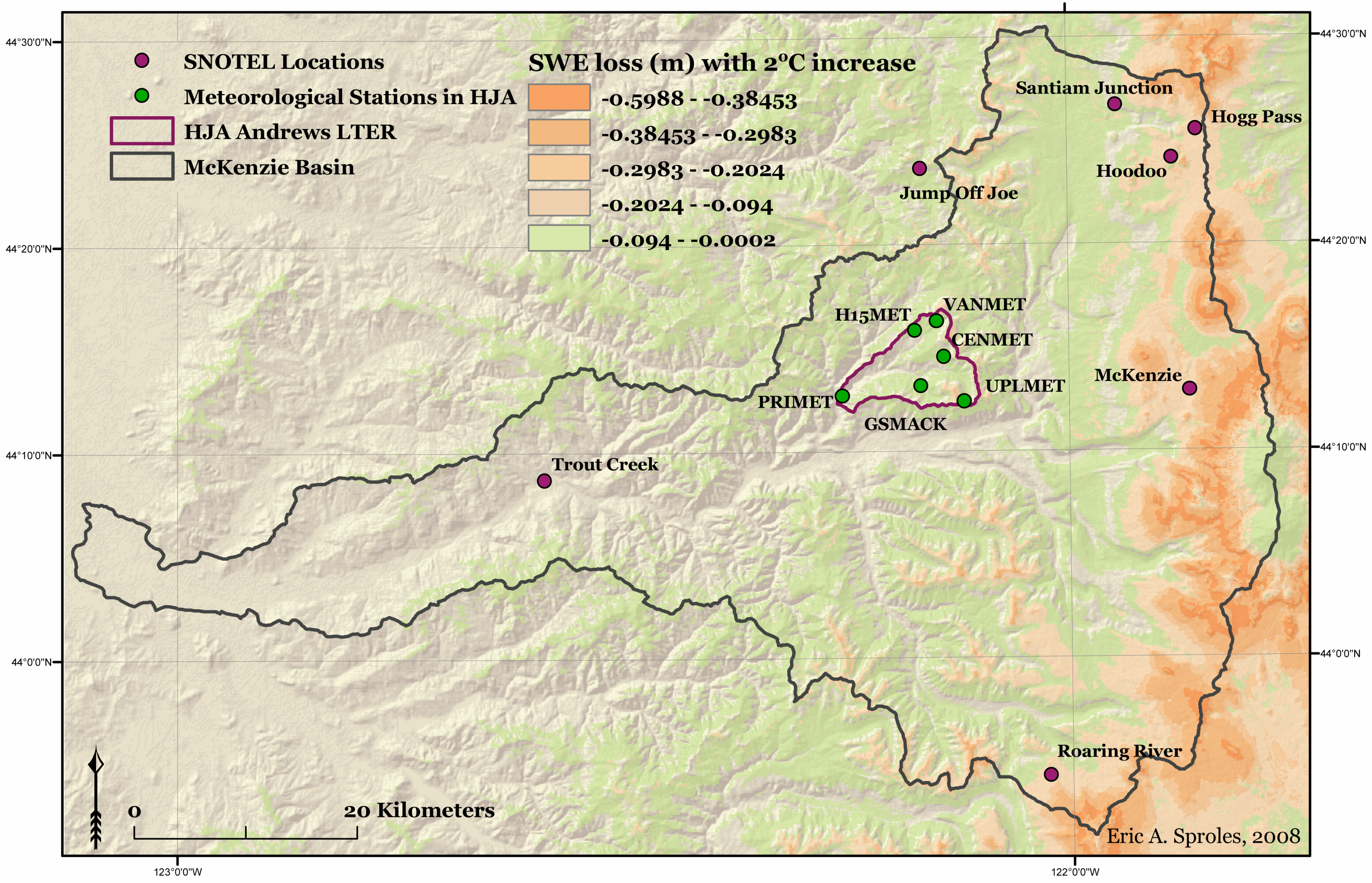


Eric A. Sproles, 2008

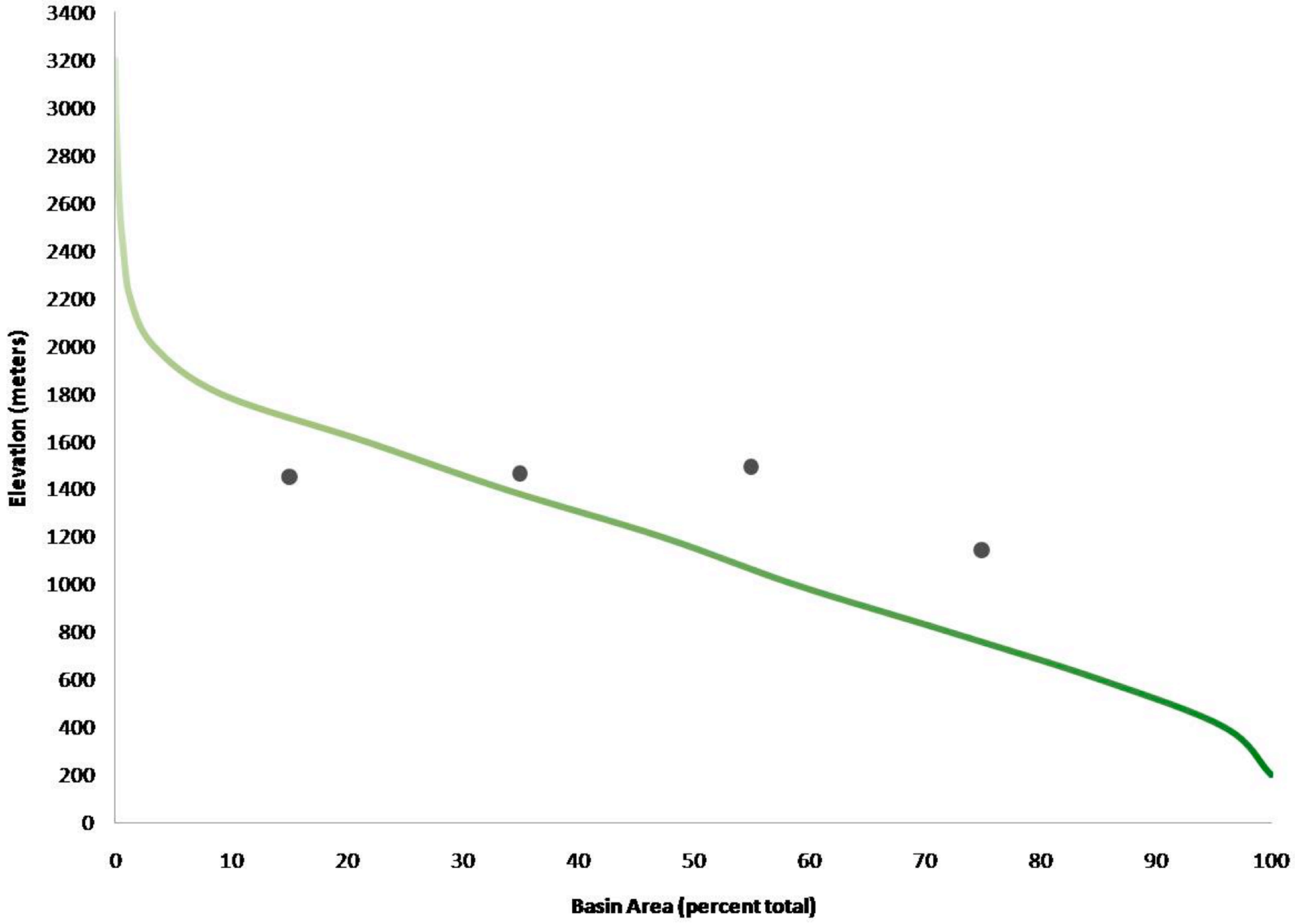
McKenzie River Basin, Oregon

Loss of Snow Water Equivalent (m) with 2°C Increase in Temperature

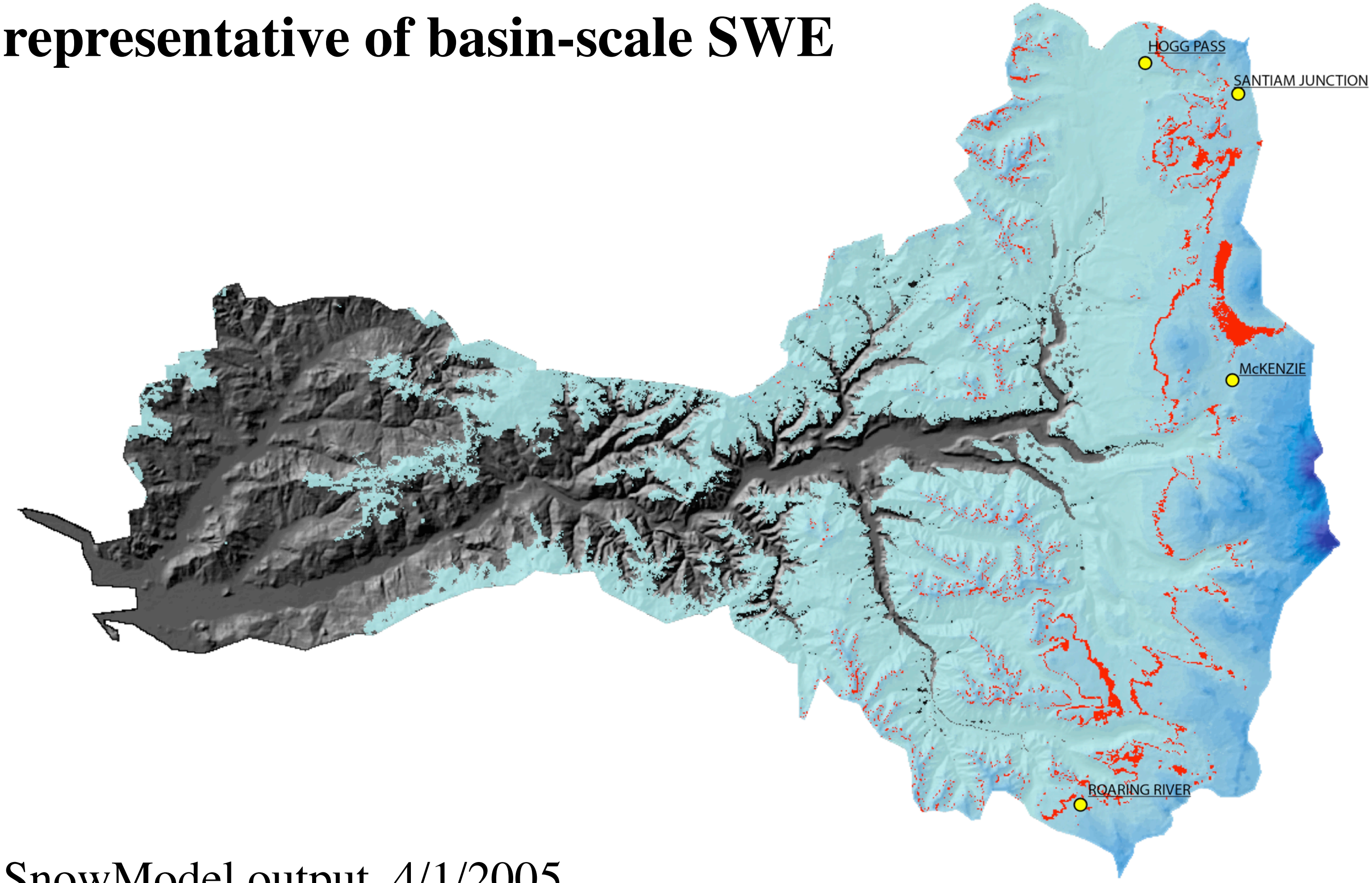
April 1, 2005



McKenzie River Basin, Percent Total Area by Elevation



Such models also demonstrate that point-based measurements of snow water equivalent (SWE) are not representative of basin-scale SWE

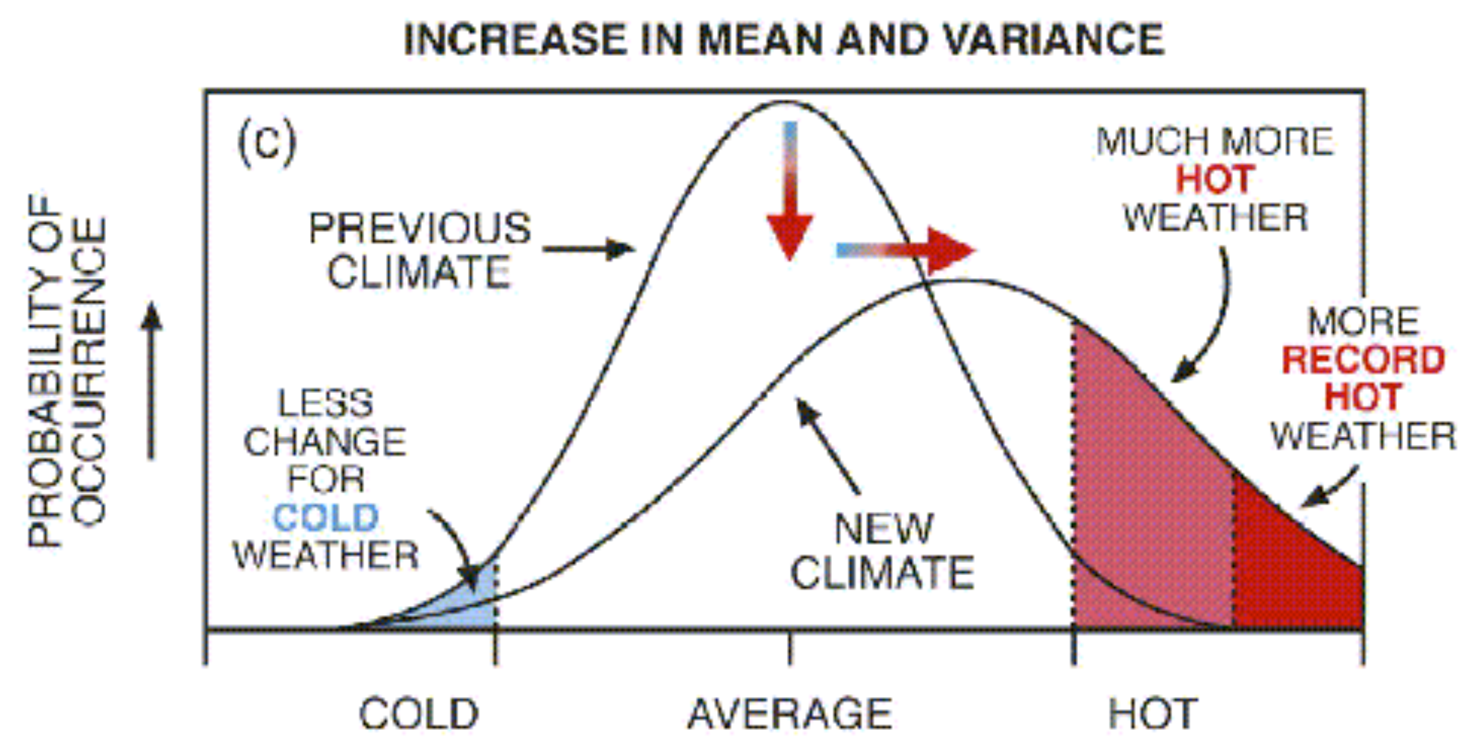


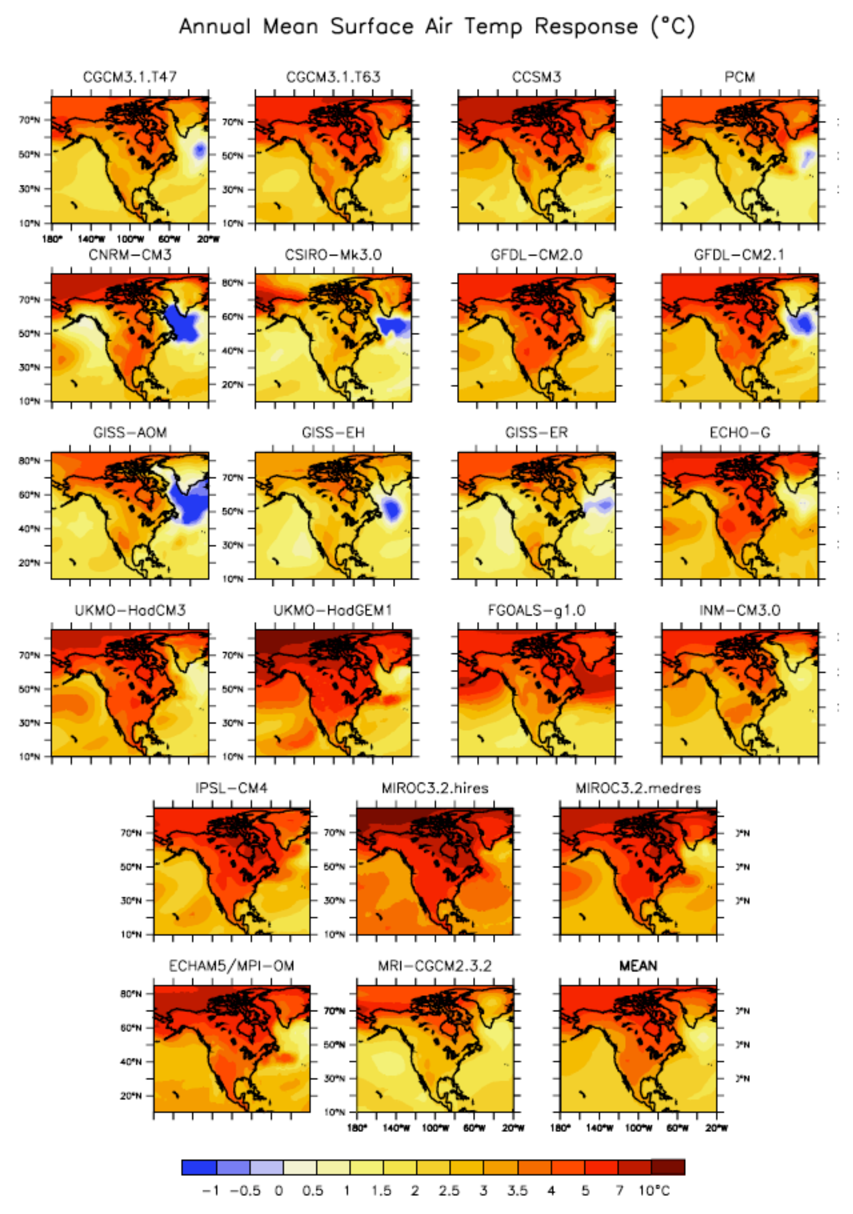
🟥 ± 10% basin avg. SWE

○ SNOTEL

SnowModel output, 4/1/2005

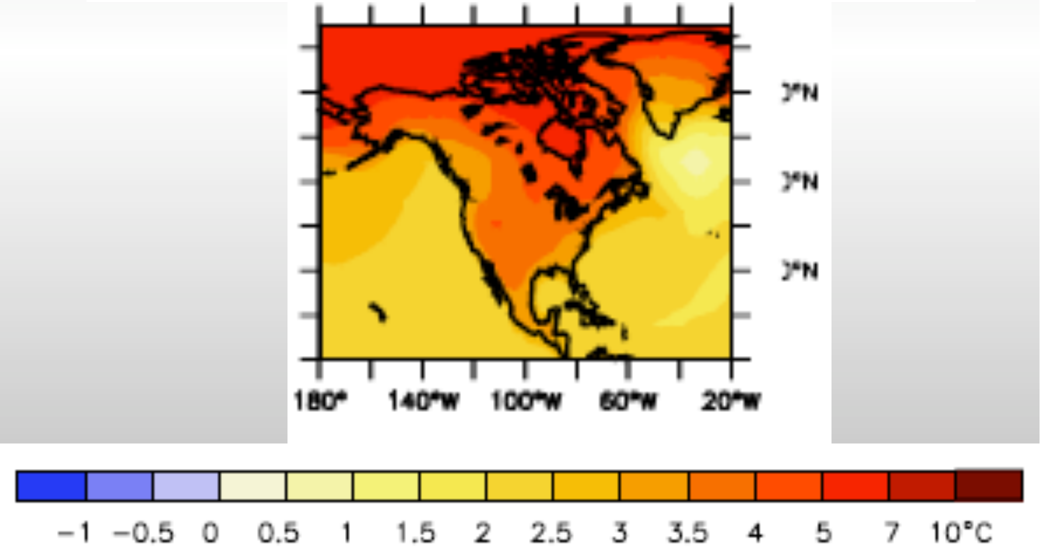
What is “normal” and what might be the new “normal”?



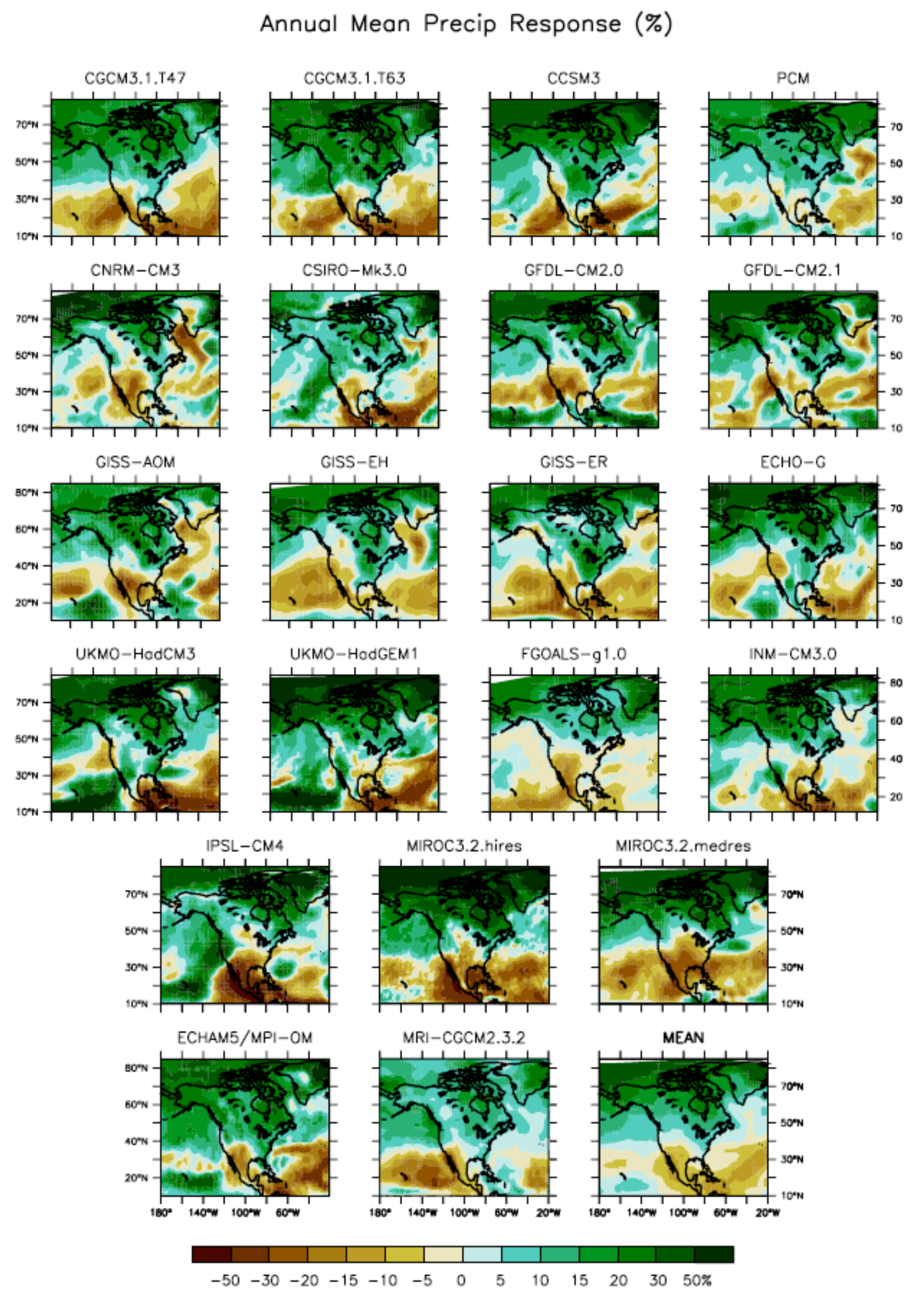


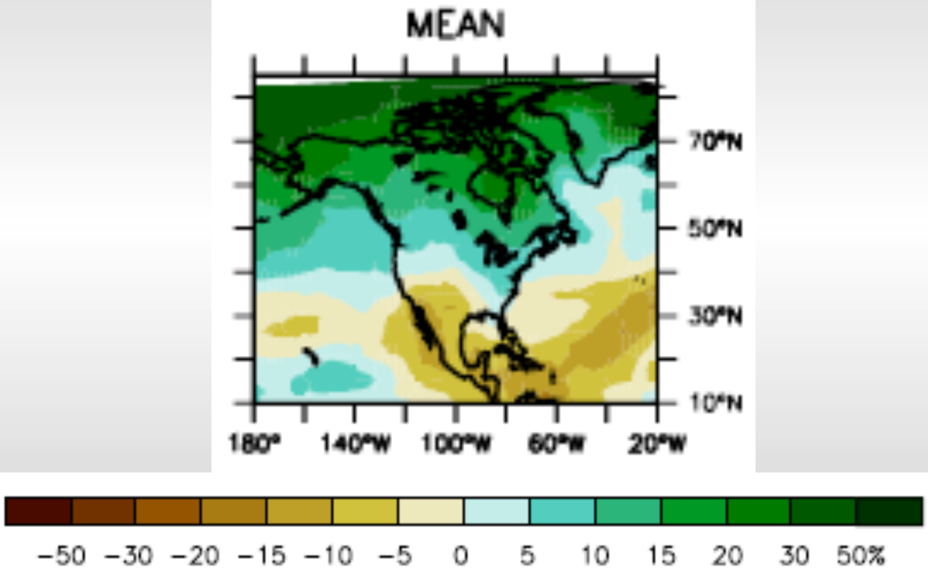
Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report

Projected Temperature Change by 2099

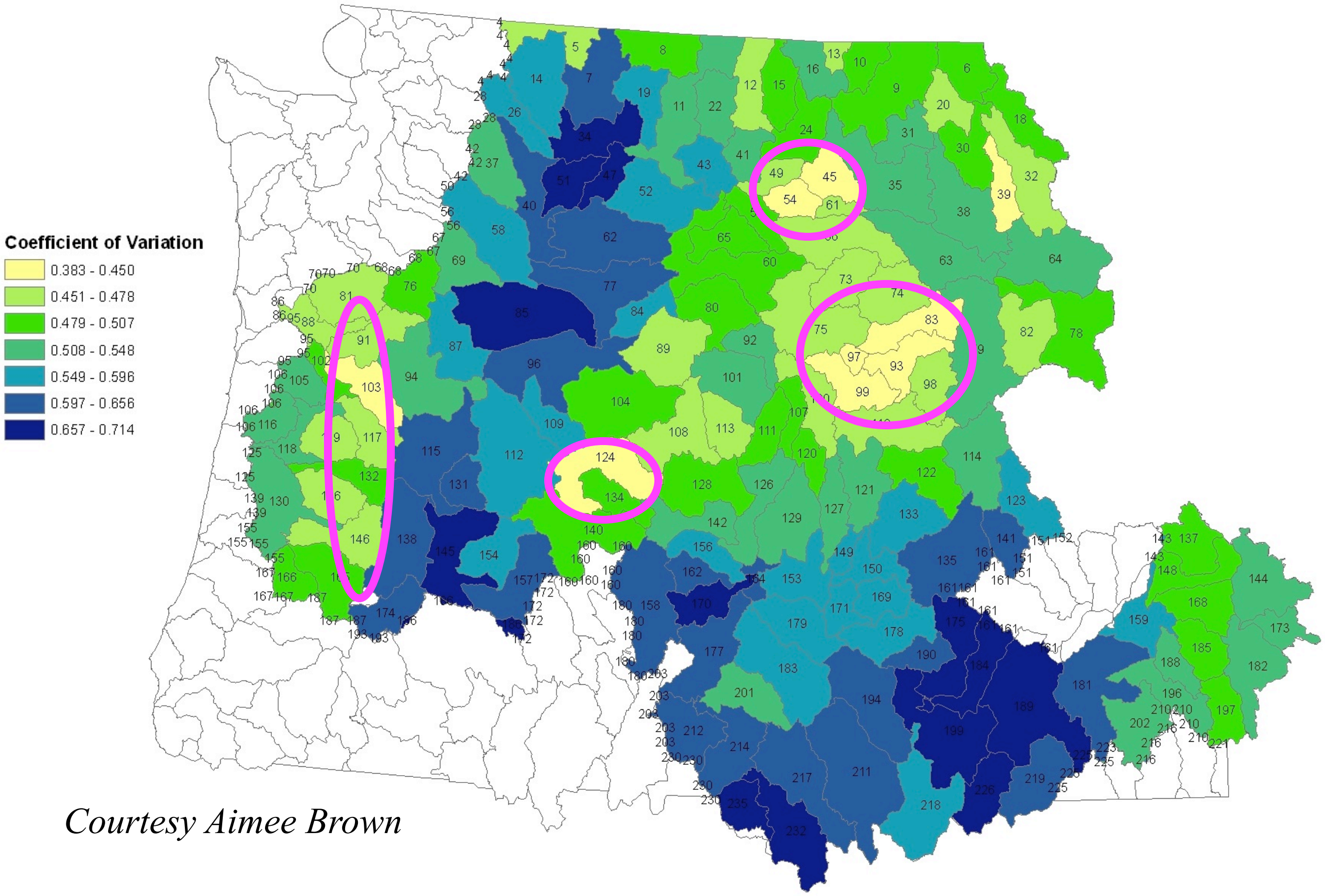


Projected Precipitation Change by 2099





US Columbia River Basin Coefficient of Variation for Nov-Mar Precipitation, 1970-2008



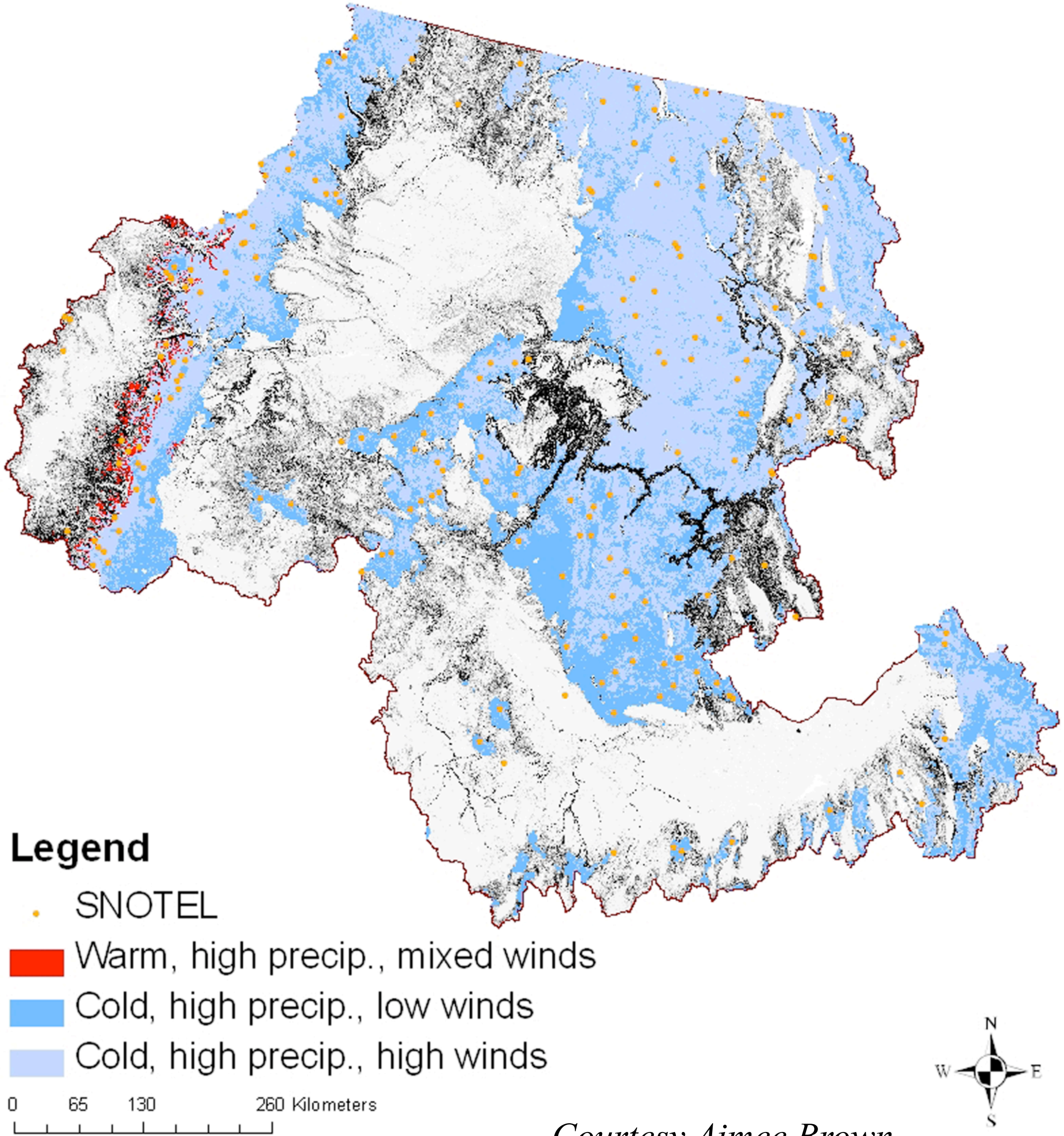
Courtesy Aimee Brown

Question: Will those watersheds with historically low variability of winter precipitation be less resilient?

Ecosystem resilience and management resilience are both important.

Will some watersheds move to the tail of winter precip. distribution?
Will some watersheds experience a tipping point?

US Portion of the Columbia River Basin

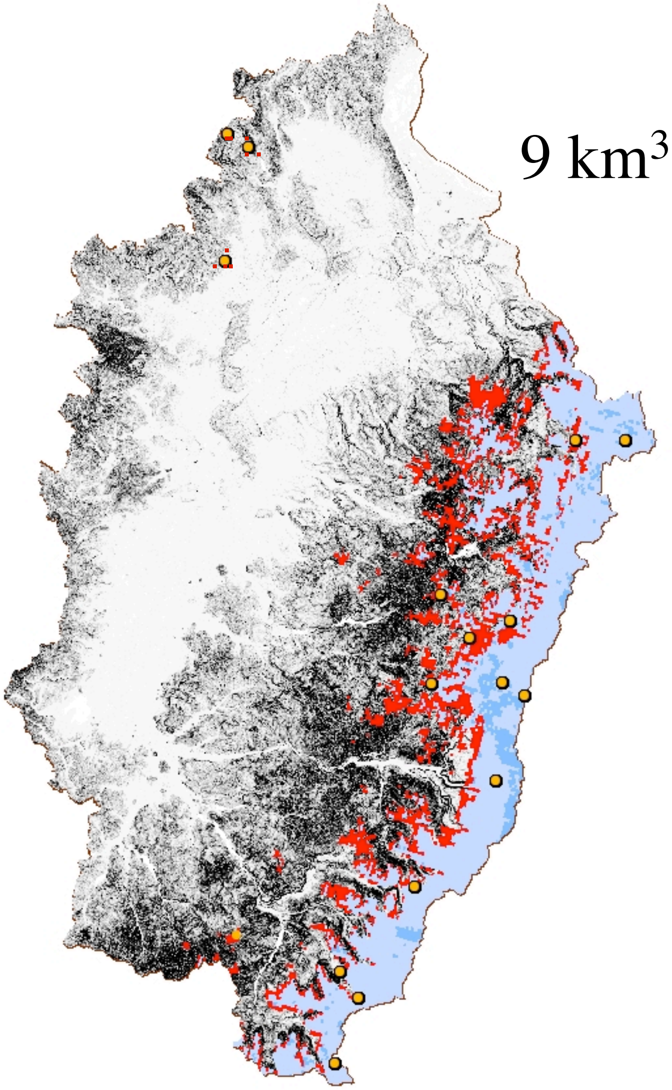


Courtesy Aimee Brown

At-Risk Snow:

- A 2^{o}C winter warming is projected to cause some winter precipitation to fall as rain rather than snow
- Impacts vary across the Columbia River Basin but greatest impacts are for snow at lower elevations in the Western Cascades

Willamette Basin: Projected 25% decrease in snow-covered area for a 2°C warming



9 km^3 of water

Courtesy Aimee Brown

<u>At-Risk Snow:</u>

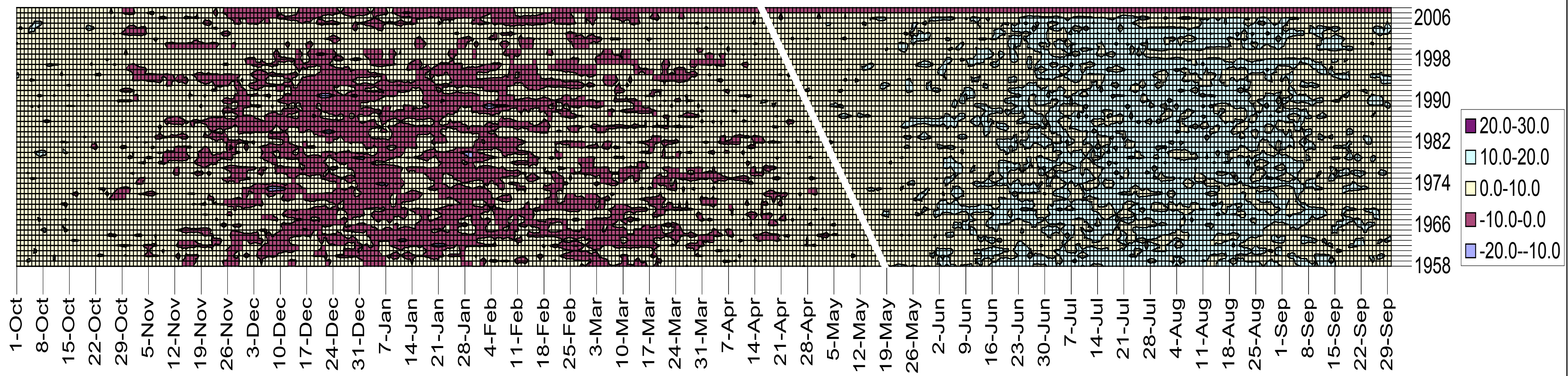
- Willamette River Basin, Oregon would see the greatest impact; 70% of Oregon's population.

<u>Monitoring:</u>

- Willamette River Basin average SNOTEL site elevation is 1132 m.
- There are no sites in the upper 1707 m of the basin, which makes up about 50% of the snow covered area.
- Highest elevation sites may experience future increases in precipitation

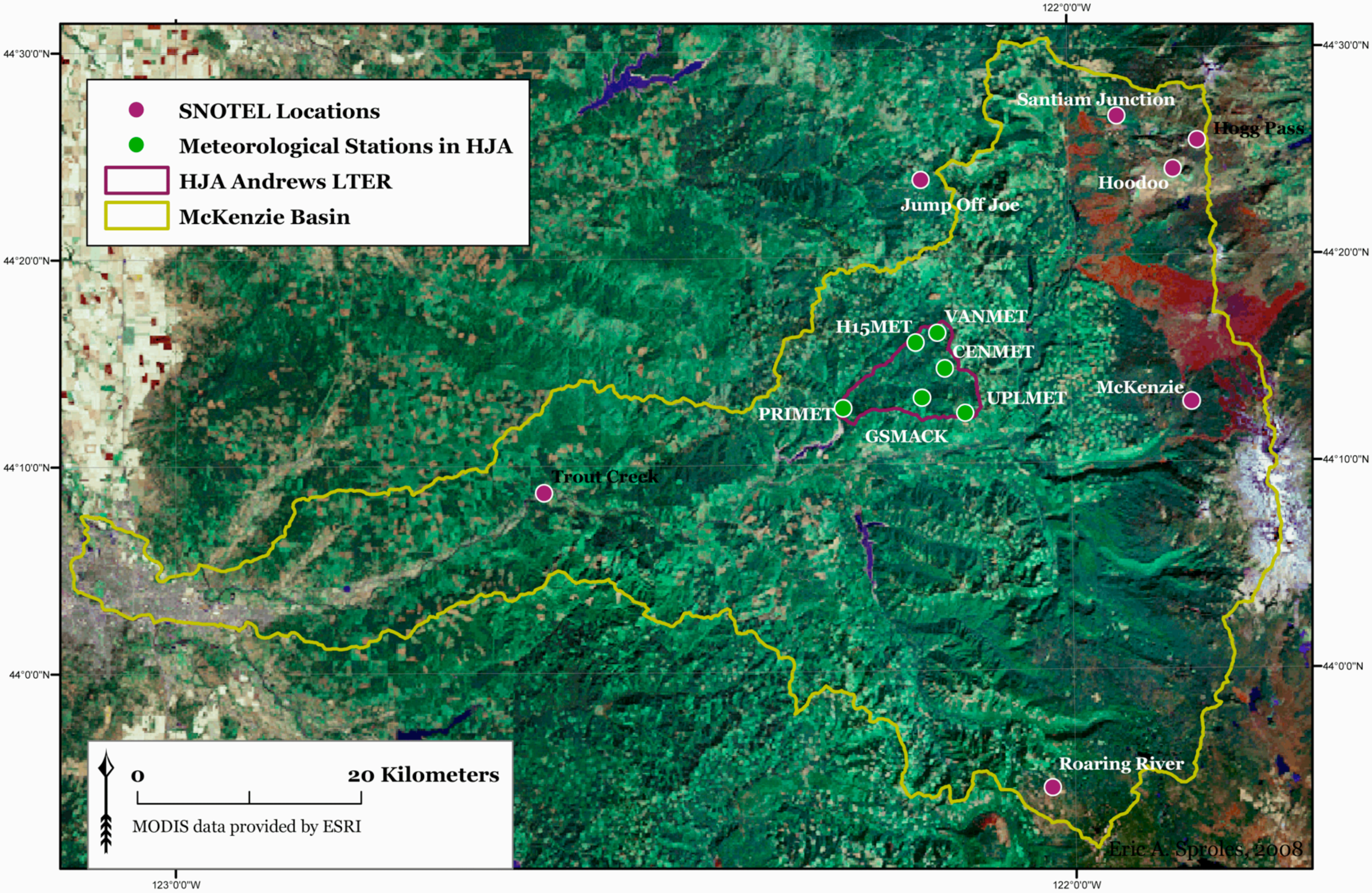
HJ Andrews Experimental Forest 1972-2006:

35 days earlier spring



What do fewer frost-free days have to do with streamflow?

Landcover of the McKenzie River Basin



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

the force generated by assembly of trans-SNARE complexes onto the two fusing membranes (Fig. 4), consistent with biochemical data (*23*). We postulate that after complexin binds to assembling SNARE complexes, its N-terminal sequence activates and clamps the force generated by SNARE-complex assembly. The N terminus of complexin might perform its activator function by pulling the complex closer to the membrane, possibly by binding to phospholipids, whereas the accessory N-terminal α-helix might clamp the complex by inserting into the space between the v- and t-SNAREs or even substituting for one of the SNAREs in the C-terminal segment of the trans-SNARE complex (*24*). Once anchored on the SNARE complex, the 40 N-terminal residues of complexin both activate and clamp SNARE complexes to control fast Ca^{2+}-triggered neurotransmitter release in a process that is conserved in all animals. Viewed in the broader picture, complexin and synaptotagmin therefore operate as interdependent clamp-activators of SNARE-dependent fusion, with synaptotagmin exploiting the activator effect of complexin and reversing its clamping function (*11*, *21*, *22*). In this molecular pas-de-deux, the functions of both proteins are intimately linked: Their phenotypes are identical both as activators and as clamps, and one does not operate without the other.

References and Notes

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19. Single-letter abbreviations for the amino acid residues are as follows: A, Ala; C, Cys; D, Asp; E, Glu; F, Phe; G, Gly; H, His; I, Ile; K, Lys; L, Leu; M, Met; N, Asn; P, Pro; Q, Gln; R, Arg; S, Ser; T, Thr; V, Val; W, Trp; and Y, Tyr.
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Supporting Online Material

www.sciencemag.org/cgi/content/full/323/5913/516/DC1
SOM Text
Figs. S1 to S14
Table S1
References

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Widespread Increase of Tree Mortality Rates in the Western United States

Phillip J. van Mantgem,[1]*†‡ Nathan L. Stephenson,[1]*† John C. Byrne,[2] Lori D. Daniels,[3] Jerry F. Franklin,[4] Peter Z. Fulé,[5] Mark E. Harmon,[6] Andrew J. Larson,[4] Jeremy M. Smith,[7] Alan H. Taylor,[8] Thomas T. Veblen[7]

Persistent changes in tree mortality rates can alter forest structure, composition, and ecosystem services such as carbon sequestration. Our analyses of longitudinal data from unmanaged old forests in the western United States showed that background (noncatastrophic) mortality rates have increased rapidly in recent decades, with doubling periods ranging from 17 to 29 years among regions. Increases were also pervasive across elevations, tree sizes, dominant genera, and past fire histories. Forest density and basal area declined slightly, which suggests that increasing mortality was not caused by endogenous increases in competition. Because mortality increased in small trees, the overall increase in mortality rates cannot be attributed solely to aging of large trees. Regional warming and consequent increases in water deficits are likely contributors to the increases in tree mortality rates.

As key regulators of global hydrologic and carbon cycles, forests are capable of contributing substantial feedbacks to global changes (*1*). Such feedbacks may already be under way; for example, forest carbon storage may be responding to environmentally driven changes in global patterns of tree growth and forest productivity (*2*–*4*). Recent warming has been implicated as contributing to episodes of forest dieback (pulses of greatly elevated tree mortality), such as those mediated by bark beetle outbreaks in western North America (*5*, *6*). Yet little effort has gone toward determining whether environmental changes are contributing to chronic, long-term changes in tree demographic rates (mortality and recruitment). Changes in demographic rates, when compounded over time, can alter forest structure, composition, and function (*7*). For example, a persistent doubling of background mortality rate (such as from 1 to 2% $year^{-1}$) ultimately would cause a >50% reduction in average tree age in a forest, and hence a potential reduction in average tree size. Additionally, changing demographic rates could indicate forests approaching thresholds for abrupt dieback. Yet spatially extensive analyses of long-term changes in tree demographic rates have been limited to tropical forests, where mortality and recruitment rates both have increased over the past several decades, perhaps in response to rising atmospheric CO_2 concentrations, nutrient deposition, or other environmental changes (*2*, *8*). Comparably extensive analyses have not been conducted in temperate forests.

We sought to determine whether systematic changes in tree demographic rates have occurred recently in coniferous forests of the western United States, and if so, to identify possible causes of those changes. Although the western United States has witnessed recent episodes of forest dieback related to bark beetle outbreaks or combinations of drought and outbreaks (*5*, *6*), most forested land continues to support seemingly healthy forests that have not died back (*9*). To minimize transient dynamics associated with stand development and succession, we limited our analyses to data from repeated censuses in undisturbed forest stands more than 200 years old (*10*). Old forests contain trees of all ages and sizes (*11*, *12*), and any large, persistent changes in demographic rates over a short period (such as a few decades) are likely to be consequences of exogenous environmental changes (*2*, *13*). In contrast, in young forests rapid demographic changes can sometimes result largely from endogenous processes (such as self-thinning during stand development) (*14*), potentially obscuring environmentally driven changes.

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[1]U.S. Geological Survey, Western Ecological Research Center, Three Rivers, CA 93271, USA. [2]USDA Forest Service, Rocky Mountain Research Station, Moscow, ID 83843, USA. [3]Department of Geography, University of British Columbia, Vancouver, British Columbia V6T 1Z2, Canada. [4]College of Forest Resources, University of Washington, Seattle, WA 98195, USA. [5]School of Forestry and Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ 86011, USA. [6]Department of Forest Science, Oregon State University, Corvallis, OR 97331, USA. [7]Department of Geography, University of Colorado, Boulder, CO 80309, USA. [8]Department of Geography, Pennsylvania State University, University Park, PA 16802, USA.

*These authors contributed equally to this work.

†To whom correspondence should be addressed. E-mail: pvanmantgem@usgs.gov (P.J.V.); nstephenson@usgs.gov (N.L.S.)

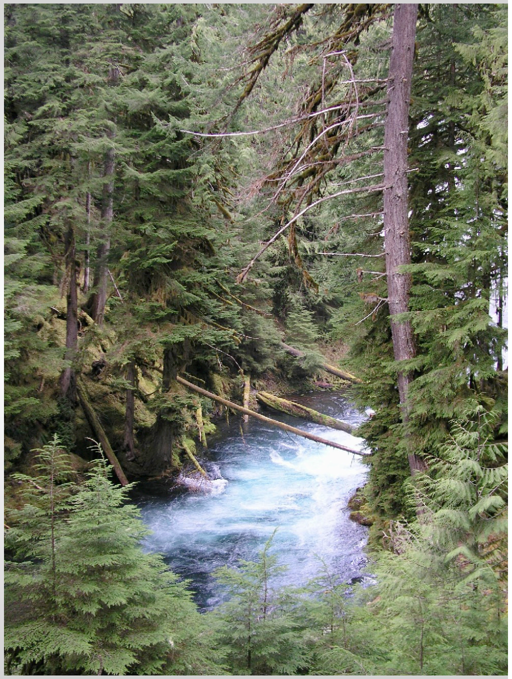
‡Present address: U.S. Geological Survey, Western Ecological Research Center, Arcata, CA 95521, USA.

Trees need water too.

An example of climate change impacts on a Cascadian watershed in western Oregon

1. Spring is coming over one month earlier than in 1958 (more frost free days)
2. Plants and trees have a longer growing period
3. Spring streamflow has decreased
4. Summer soil moisture may have decreased
5. Tree mortality rate has increased

- What will be the future responses to climate change?
- How will we know of the real magnitude of change if we aren't able to make the right measurements in the right places?



Questions?