Precipitation extremes and flooding: Evidence of nonstationarity and hydrologic design implications

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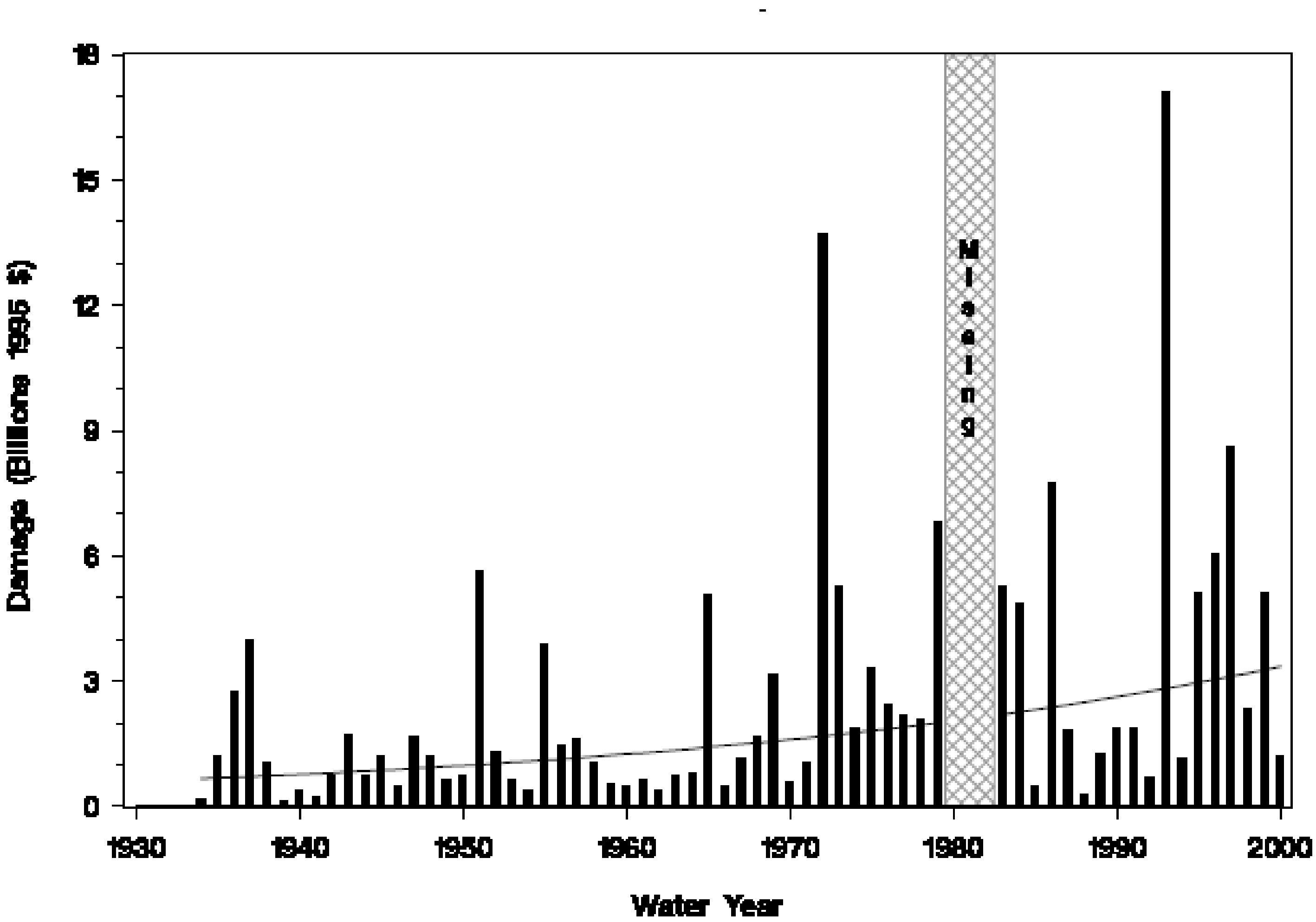
Total U.S. flood damages, 1934-2000



from Pielke et al., 2000

What causes a flood?

- Heavy precipitation
- Antecedent soil moisture and/or snow
- Interaction of storm characteristics (geometry, duration, intensity) with catchment geometry and characteristics (topography, channel network density, geology/soils)
- Storm orientation and movement relative to catchment/channel orientation

Other important flood characteristics

- Hydrologists usually think in terms of the annual maximum flood, which is the series of the largest floods each year (usually their peak discharge)
- Bankfull capacity corresponds roughly to 2-year return period (median annual maximum flood), which also is very roughly the mean annual flood
- Damages due to “floods” below bankfull capacity usually are minimal; damages increase rapidly (sometimes characterized as a power law) above bankfull discharge
- Flood risk is usually estimated by fitting a probability distribution to the annual maximum series, this distribution may be extrapolated to the T-year (e.g., 100-year, often used for flood plain planning) flood
- The T-year return period precipitation event (of specified duration) generally doesn’t cause the T-year flood (due to factors indicated above)

Extreme precipitation should be increasing as the climate warms

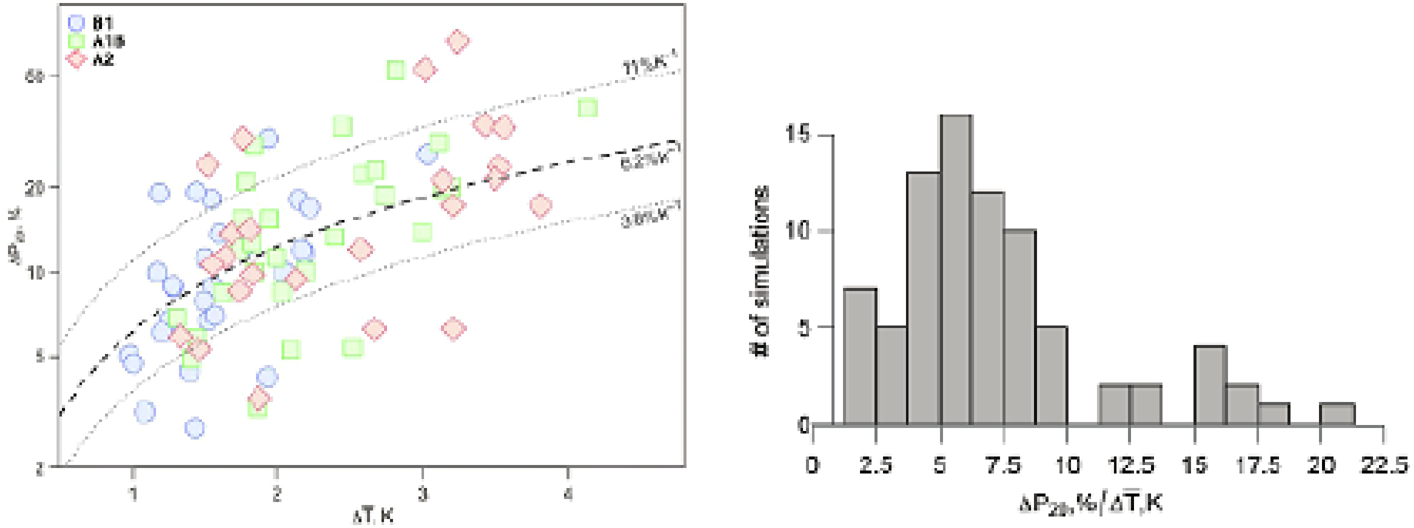
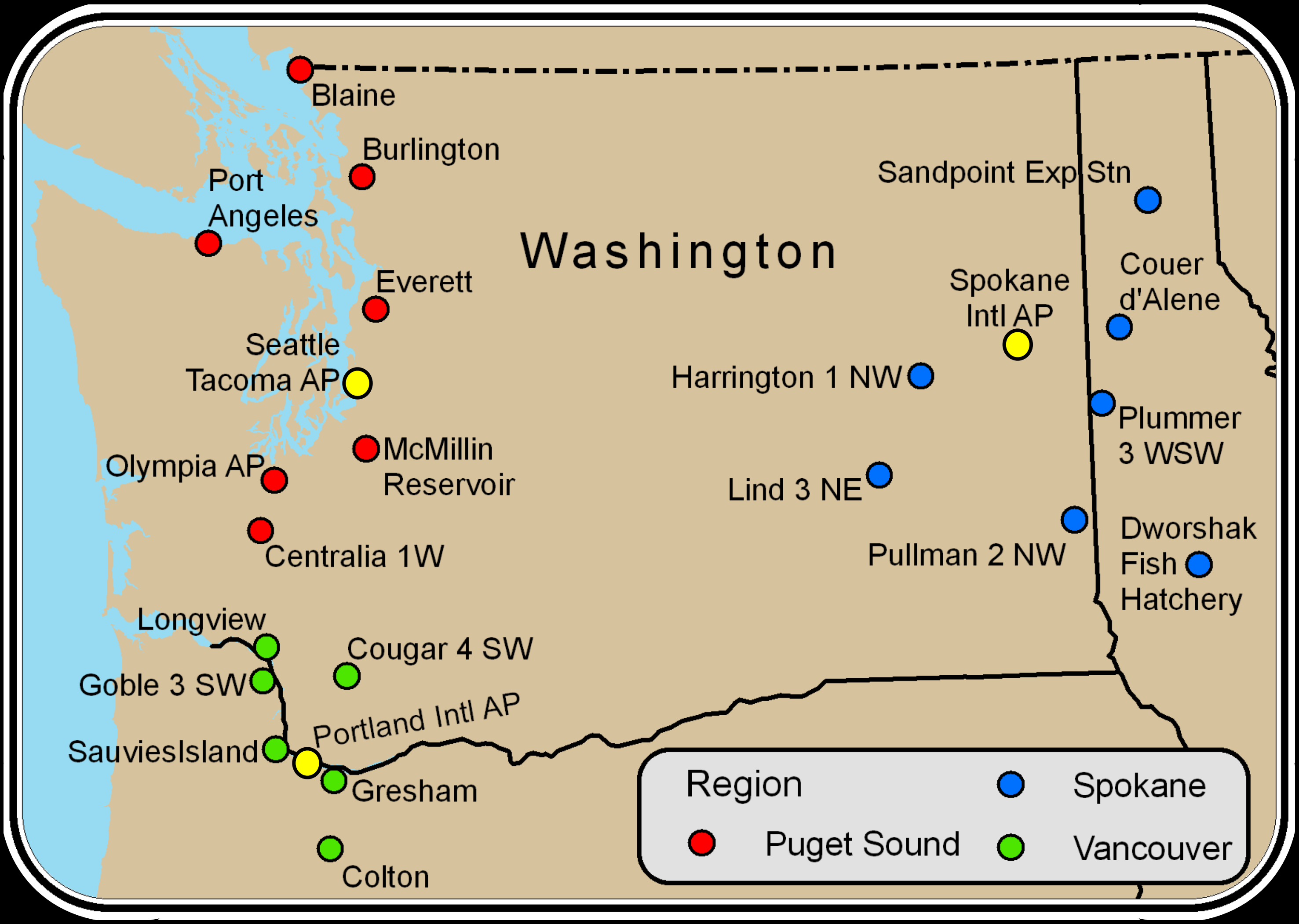


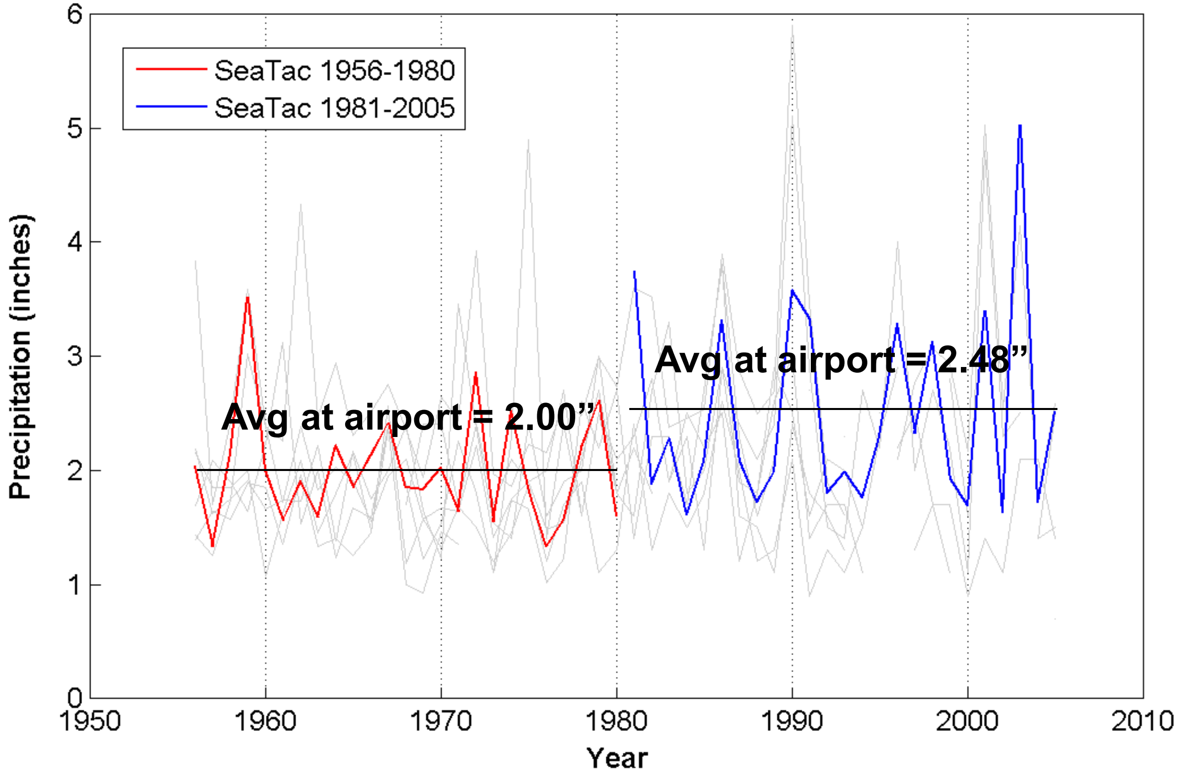
Figure 4.10: Relative changes in 20-yr return values averaged over the global land area of annual 24-h precipitation maxima (Δ*P*20) as a function of globally averaged changes in mean surface temperature for B1, A1B, and A2 global emissions scenarios, with results pooled from 14 GCM runs and for 2046–65 and 2081–2100 relative to 1981-2000. In the left panel, the pooled results are shown along with the median slope of 6.2%/°C and the 15th and 85th percentiles (dashed and dotted lines, respectively). The right panel shows the results as a histogram. Replotted from Kharin et al (2007; Figure 16).

Is extreme precipitation increasing?

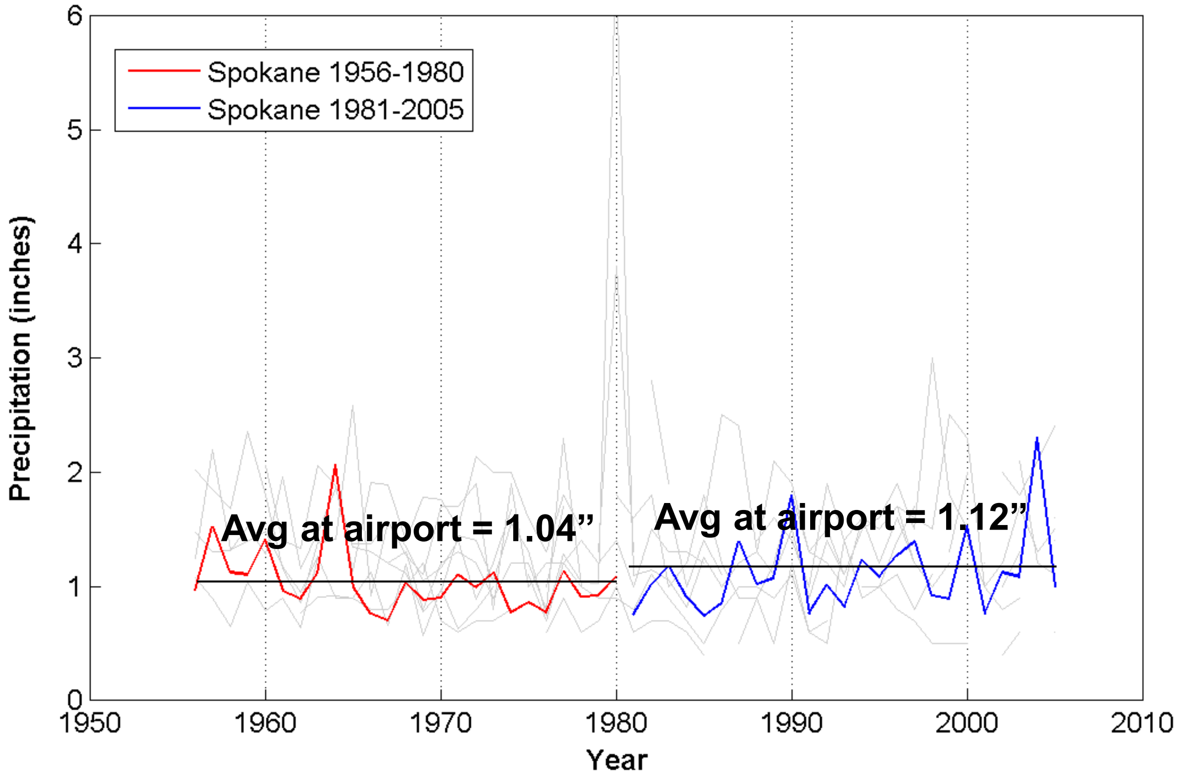
Study Locations



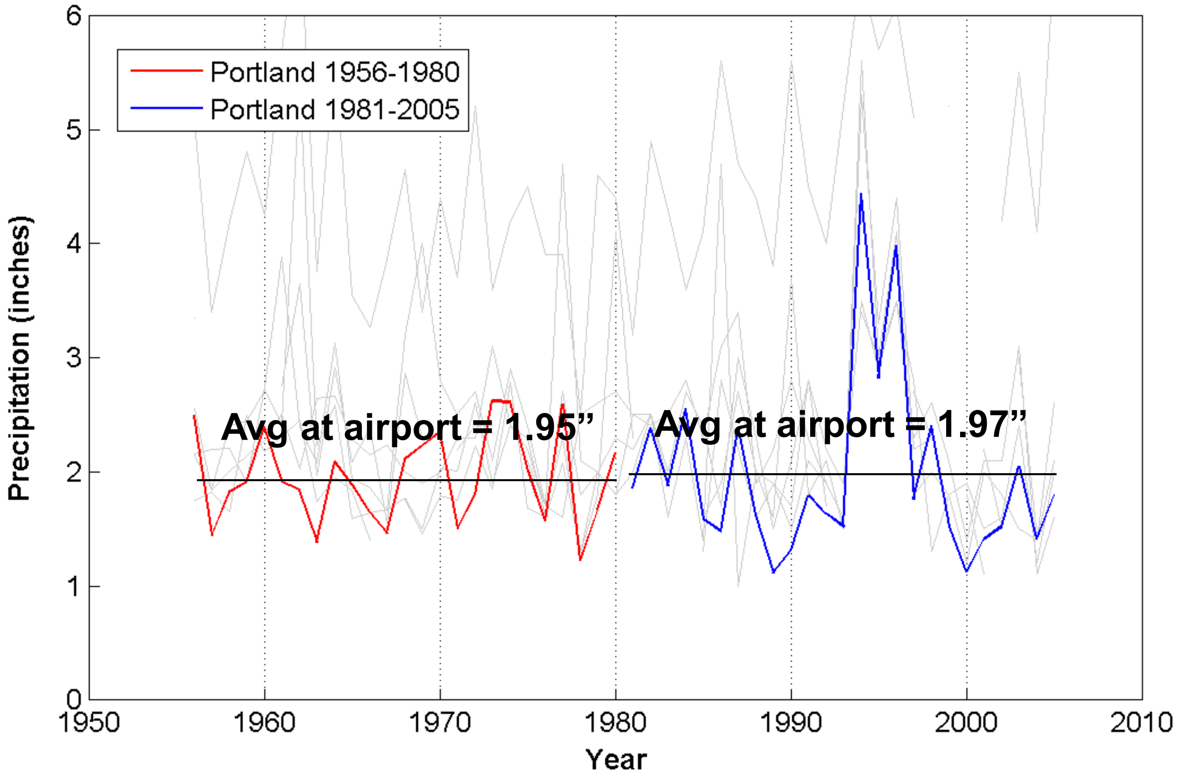
24-Hour Annual Maxima at SeaTac



24-Hour Annual Maxima at Spokane



24-Hour Annual Maxima at Portland



Regional Frequency Analysis

Principle:

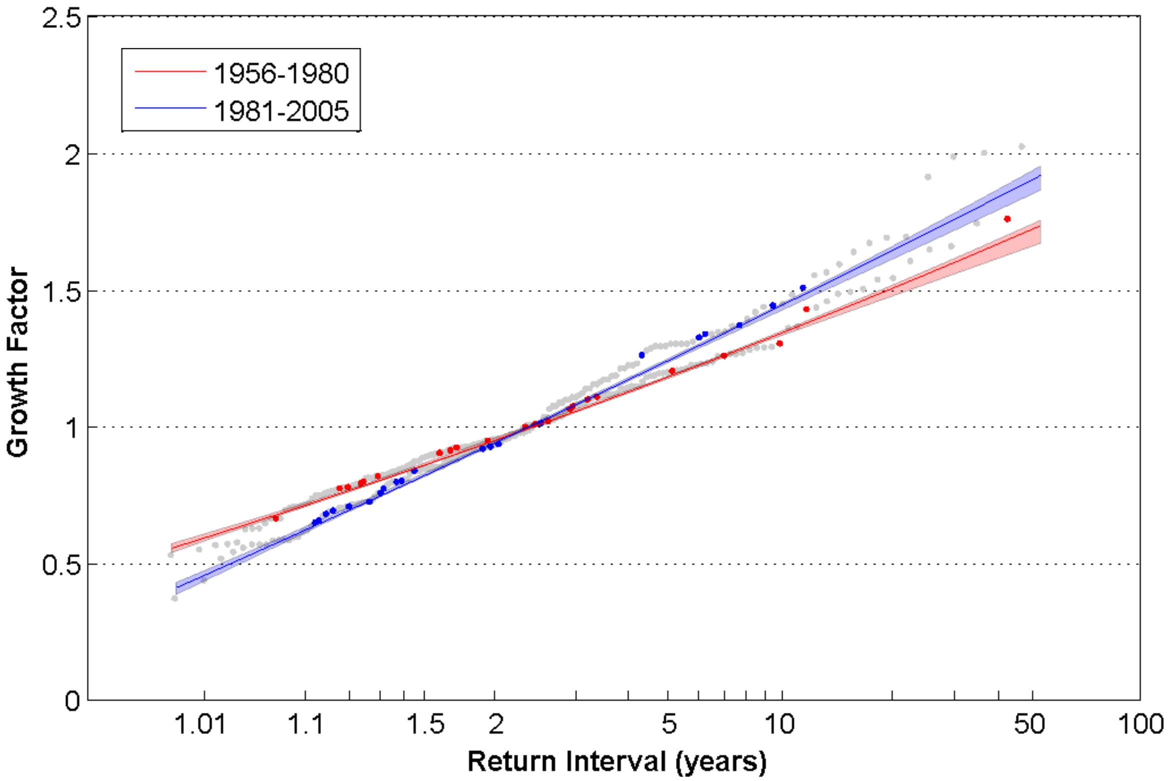
- Annual precipitation maxima from all sites in a region can be described by common probability distribution after site data are divided by their at-site means.
- Larger pool of data results in more robust estimates of design storm magnitudes, particularly for longer return periods.

Regional Frequency Analysis

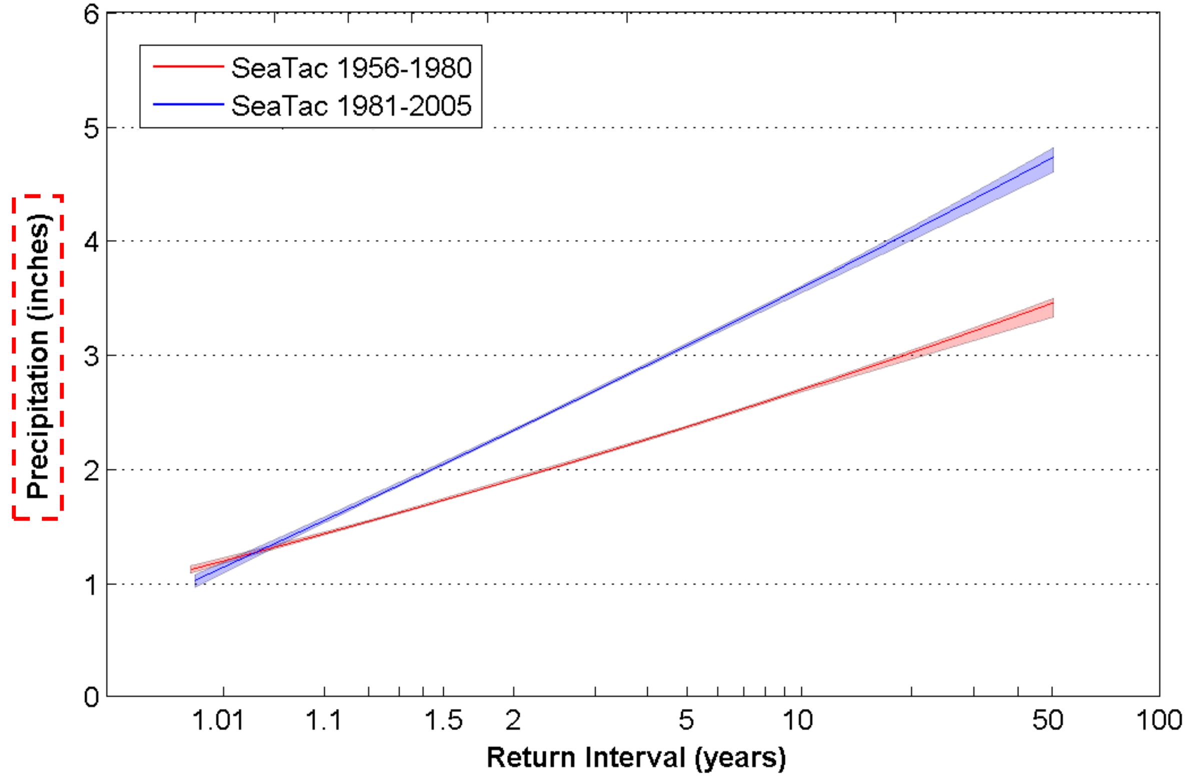
Methods:

- Annual maxima divided by at-site means.
- Regional growth curves fit to standardized data using method of L-moments.
- Site-specific GEV distributions obtained by multiplying growth curves by at-site means.
- Design storm changes calculated for various return periods.
- Sample procedure shown on following slides.

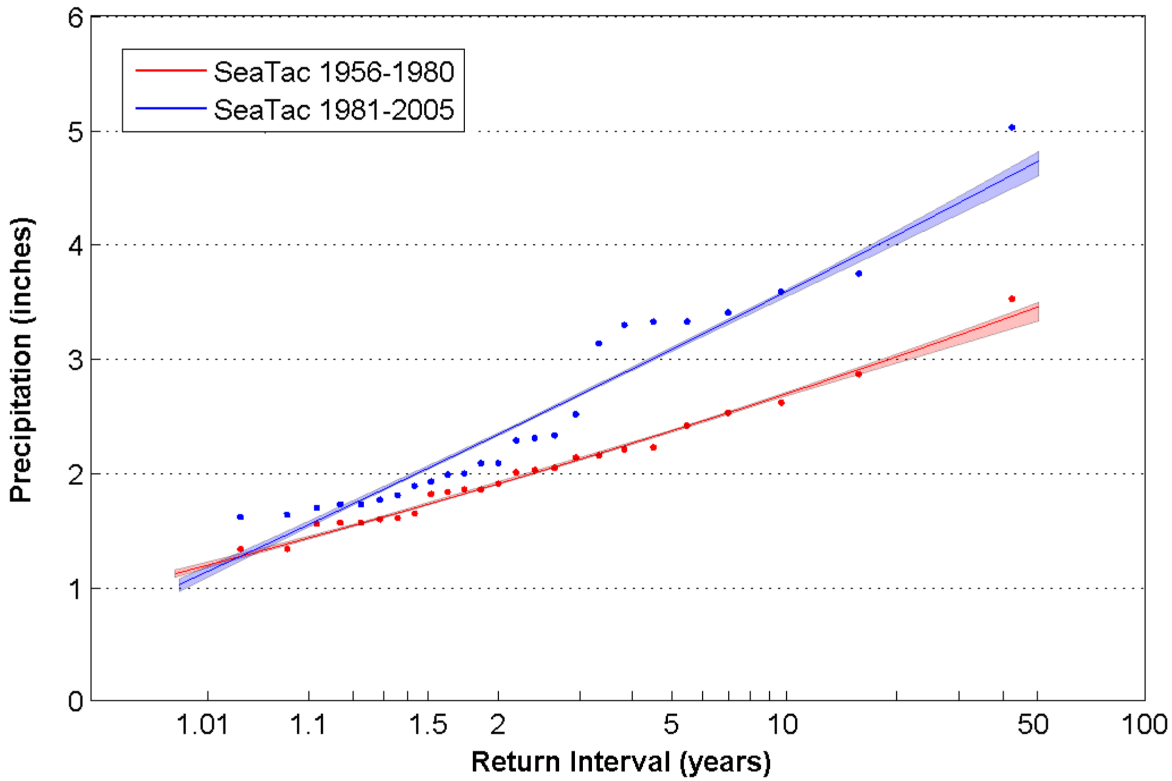
Regional growth curves fitted using method of L-moments.



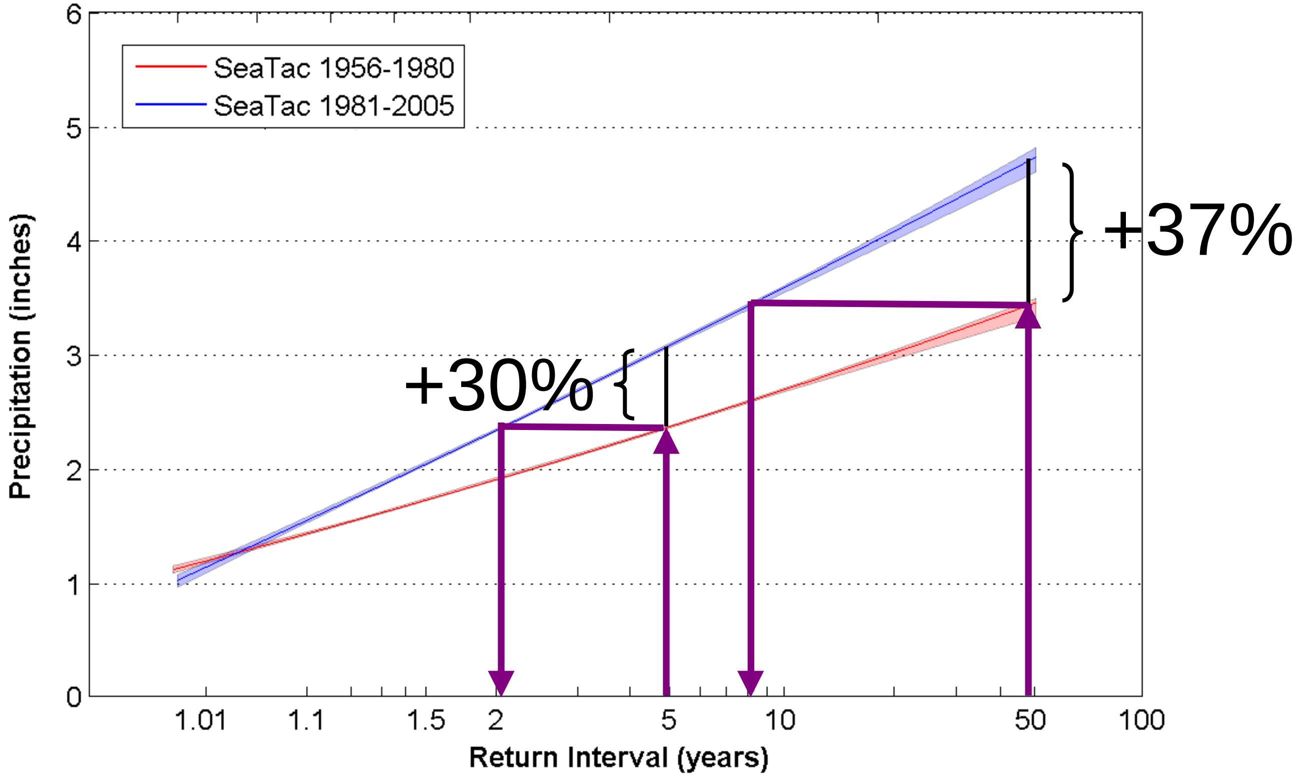
Site-specific GEV distributions obtained by multiplying regional growth curves by at-site means.



Probability distributions checked against original at-site annual maxima



7. Changes in design storms calculated for various return periods.



Results of Historical Analysis

Changes in average annual maxima between 1956–1980 and 1981–2005:

	SeaTac	Spokane	Portland
1-hour	+7%	-1%	+4%
3-hour	+14%	+1%	-7%
6-hour	+13%	+1%	-8%
24-hour	+25%*	+7%	+2%
5-day	+13%	-10%	-5%
10-day	+7%	-4%	-10%

* Statistically significant for difference in means at 5% significance level

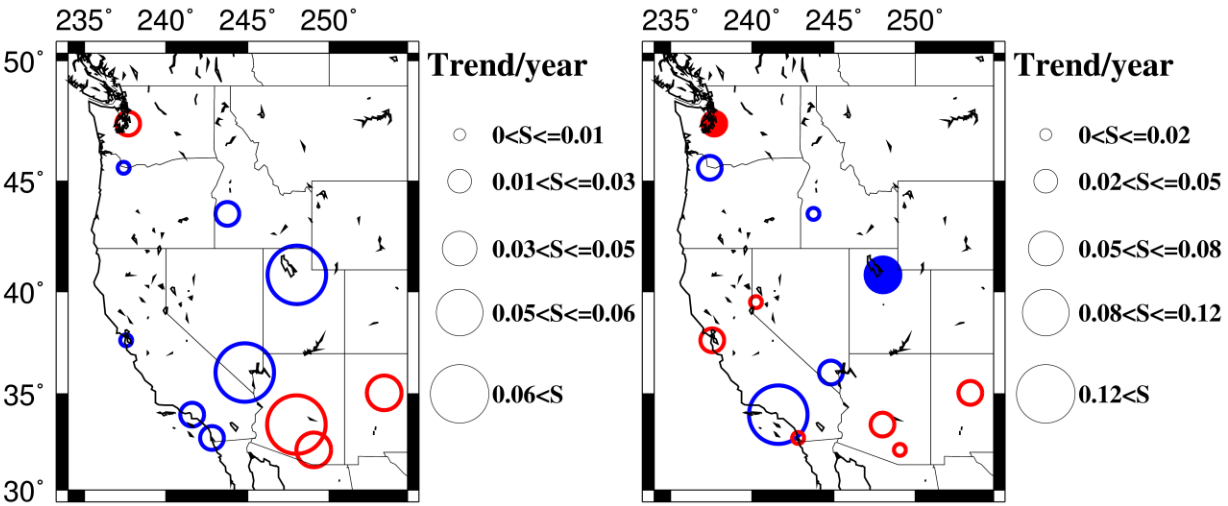
Precipitation Extreme Trends (1949-2009)

● Significant increasing (95% level)

● Significant decreasing (95% level)

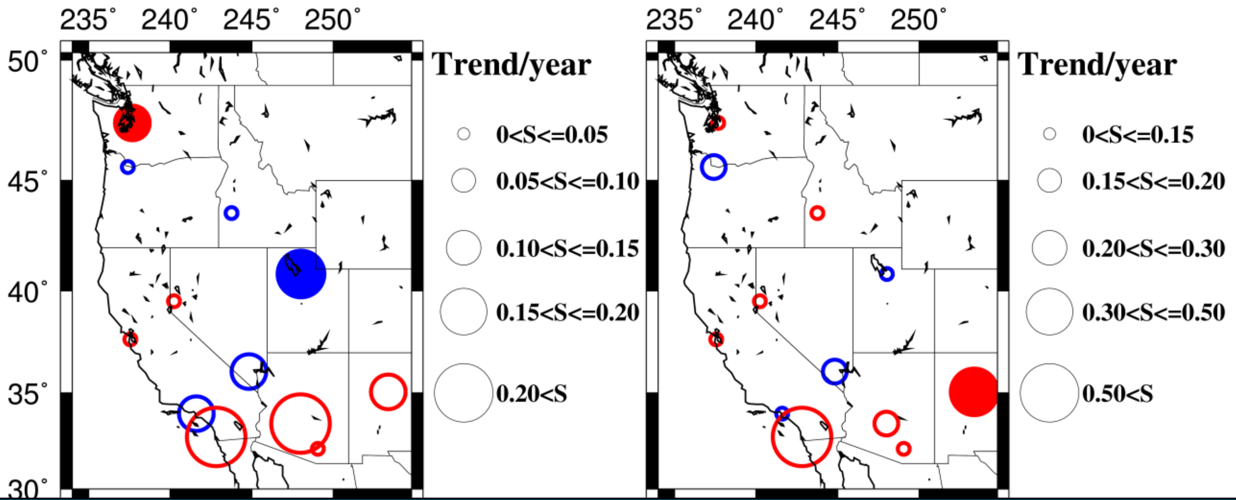
○ Increasing

○ Decreasing



(a) 3–Hour Annual Maximum

(b) 9–Hour Annual Maximum



(c) 24–Hour Annual Maximum

(d) 96–Hour Annual Maximum

Mann-Kendall trend analysis for the period of 1949-2009 (NCDC data) on precipitation extremes in major urban areas.

Are extreme floods increasing?

The Seattle Times

JANUARY 12, 2009

JANUARY FLO

When disas

routine

Crisis repeats a

disappear

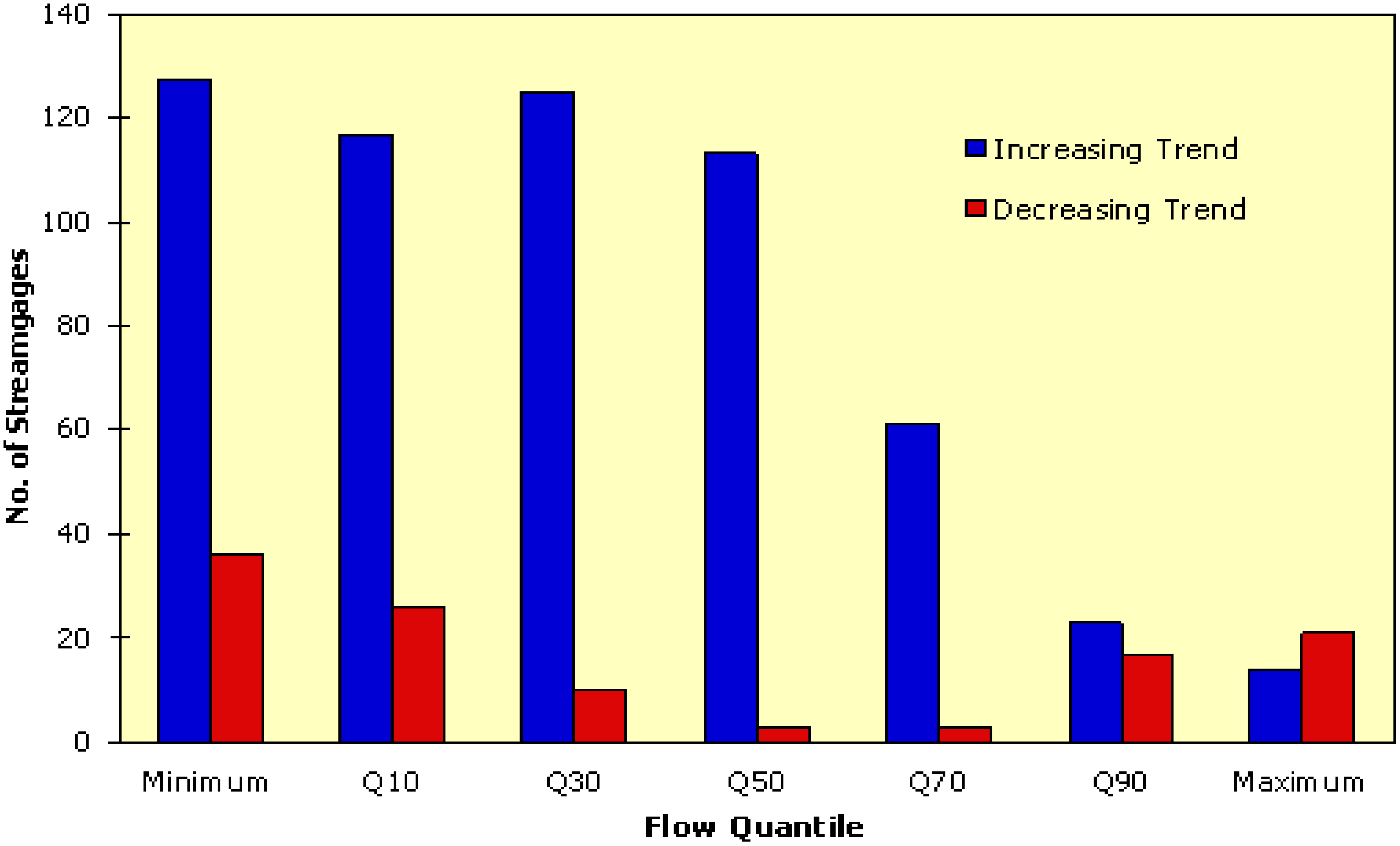
Disaster Declarations

Federal Emergency Management Agency disaster declarations in King County in connection with flooding:

January 1990
November 1990
December 1990
November 1995
February 1996
December 1996
March 1997
November 2003
December 2006
December 2007

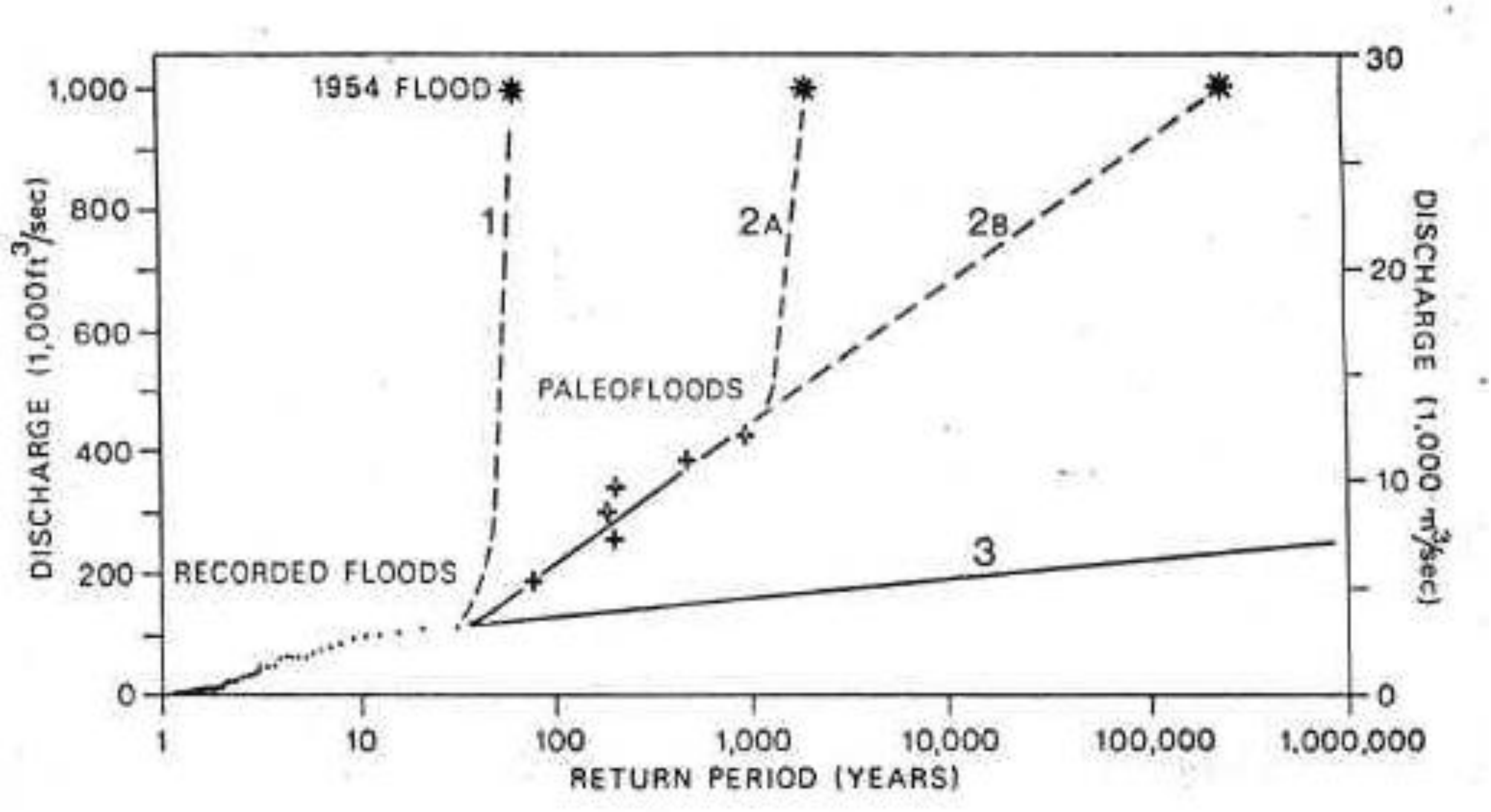
Mapes 2009

Number of statistically significant increasing and decreasing trends in U.S. streamflow (of 395 stations) by quantile (from Lins and Slack, 1999)



Issues in the historical record

Pecos River flood frequency distribution (from Kochel et al, 1988)



Future Precipitation and Streamflow Projections

Global Climate Models

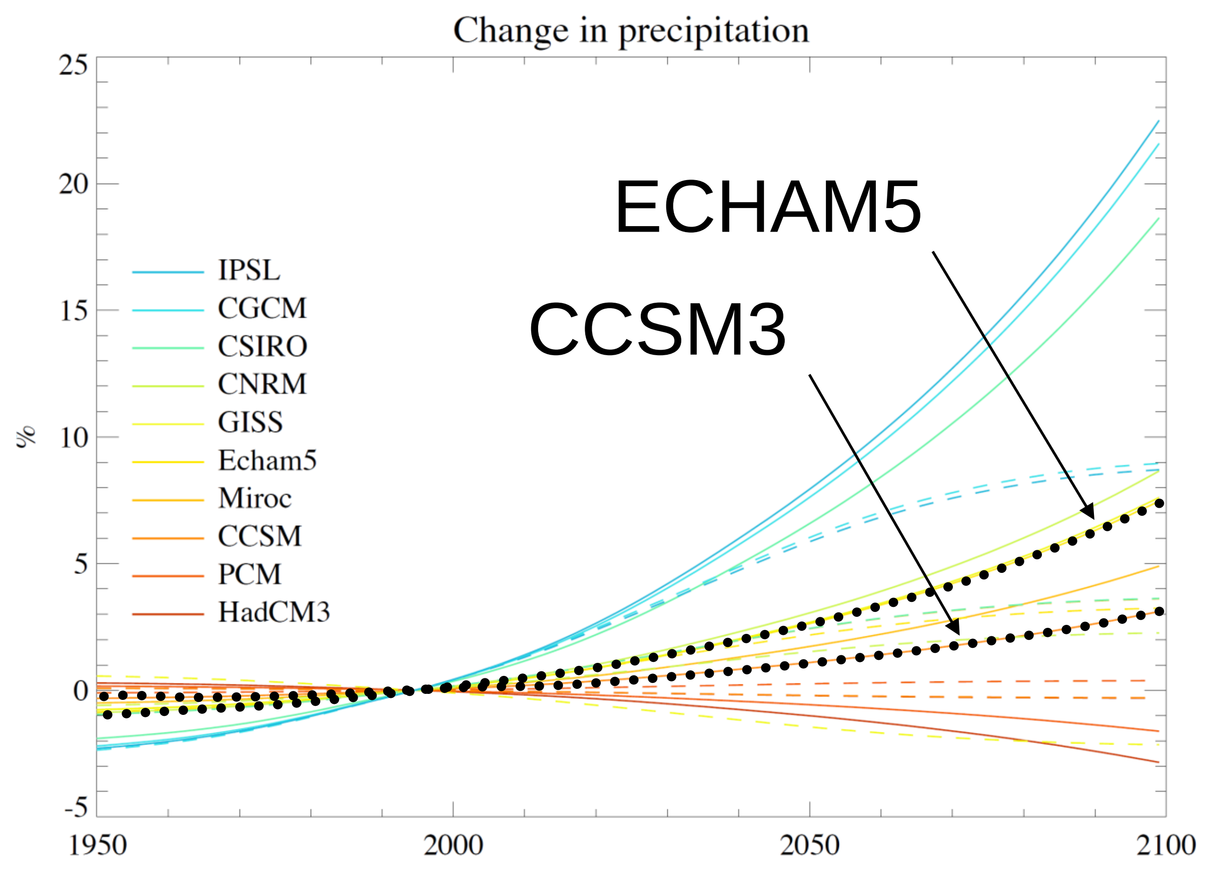
ECHAM5

- Developed at Max Planck Institute for Meteorology (Hamburg, Germany)
- Used to simulate the A1B scenario in our study

CCSM3

- Developed at National Center for Atmospheric Research (NCAR; Boulder, Colorado)
- Used to simulate the A2 scenario in our study

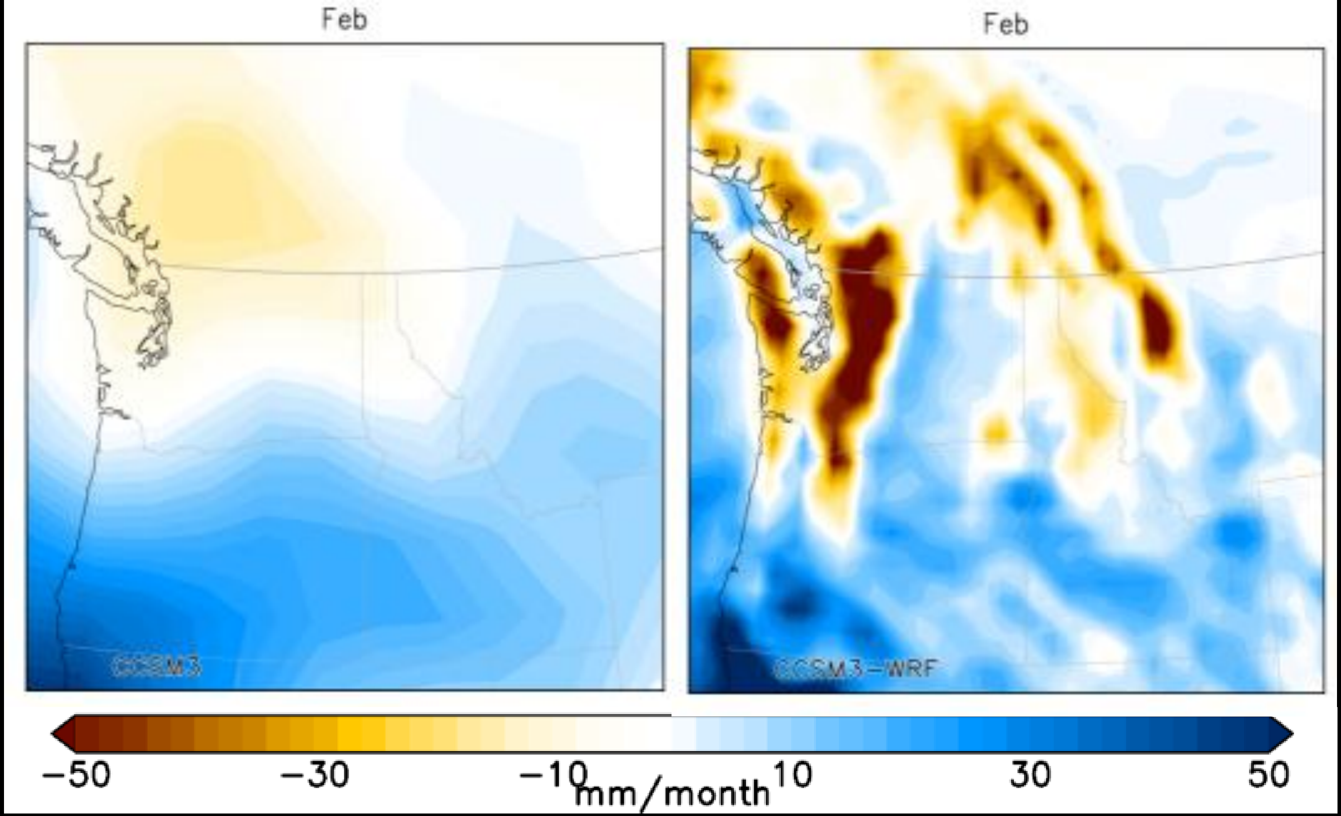
Global Climate Models



Mote et al 2005

Dynamical Downscaling

Global Model   Regional Model



Courtesy Eric Salathé

Results of Future Analysis

Changes in average annual maximum precipitation between 1970–2000 and 2020–2050:

		SeaTac	Spokane	Portland
CCSM3/ WRF	1-hour	+16% *	+10%	+11% *
	24-hour	+19%	+4%	+5%
ECHAM5/ WRF	1-hour	-5%	-7%	+2%
	24-hour	+15% *	+22% *	+2%

* Statistically significant for difference in means and distributions, and non-zero temporal trends

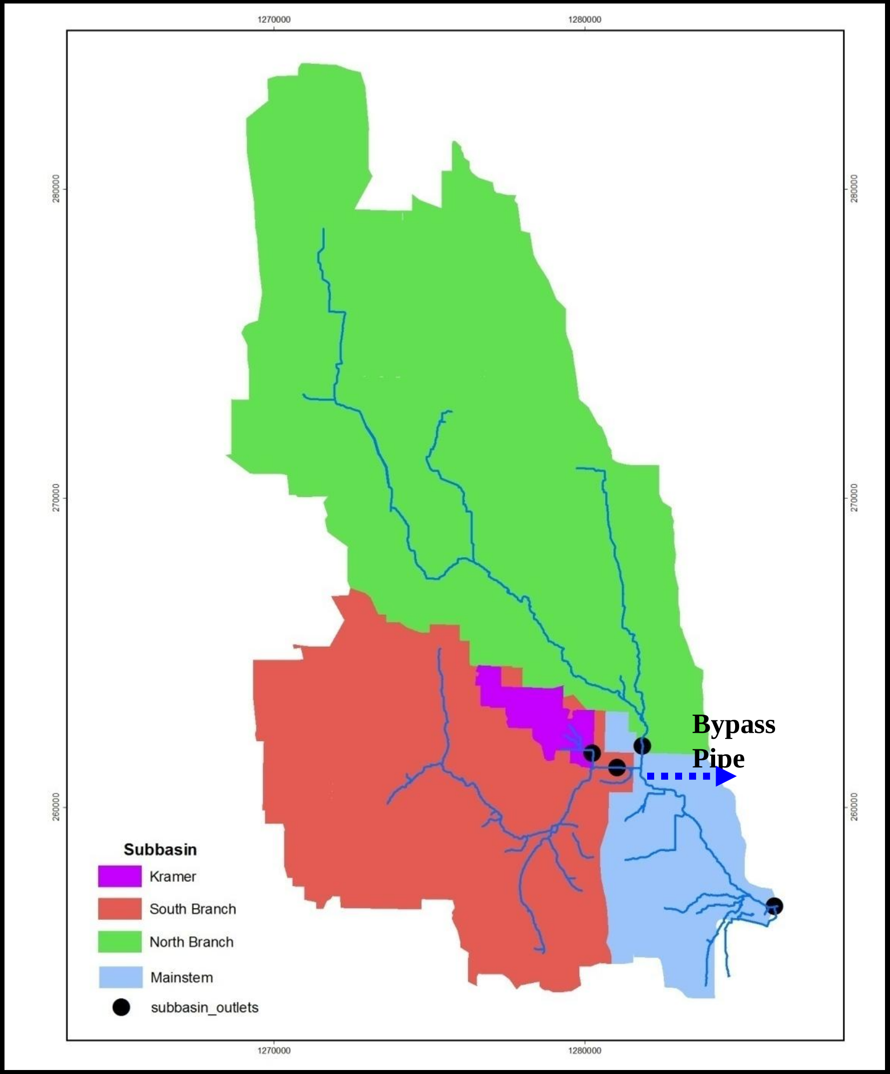
Results of Bias Correction -- SeaTac

Comparison of changes in average annual maximum between 1970–2000 and 2020–2050:

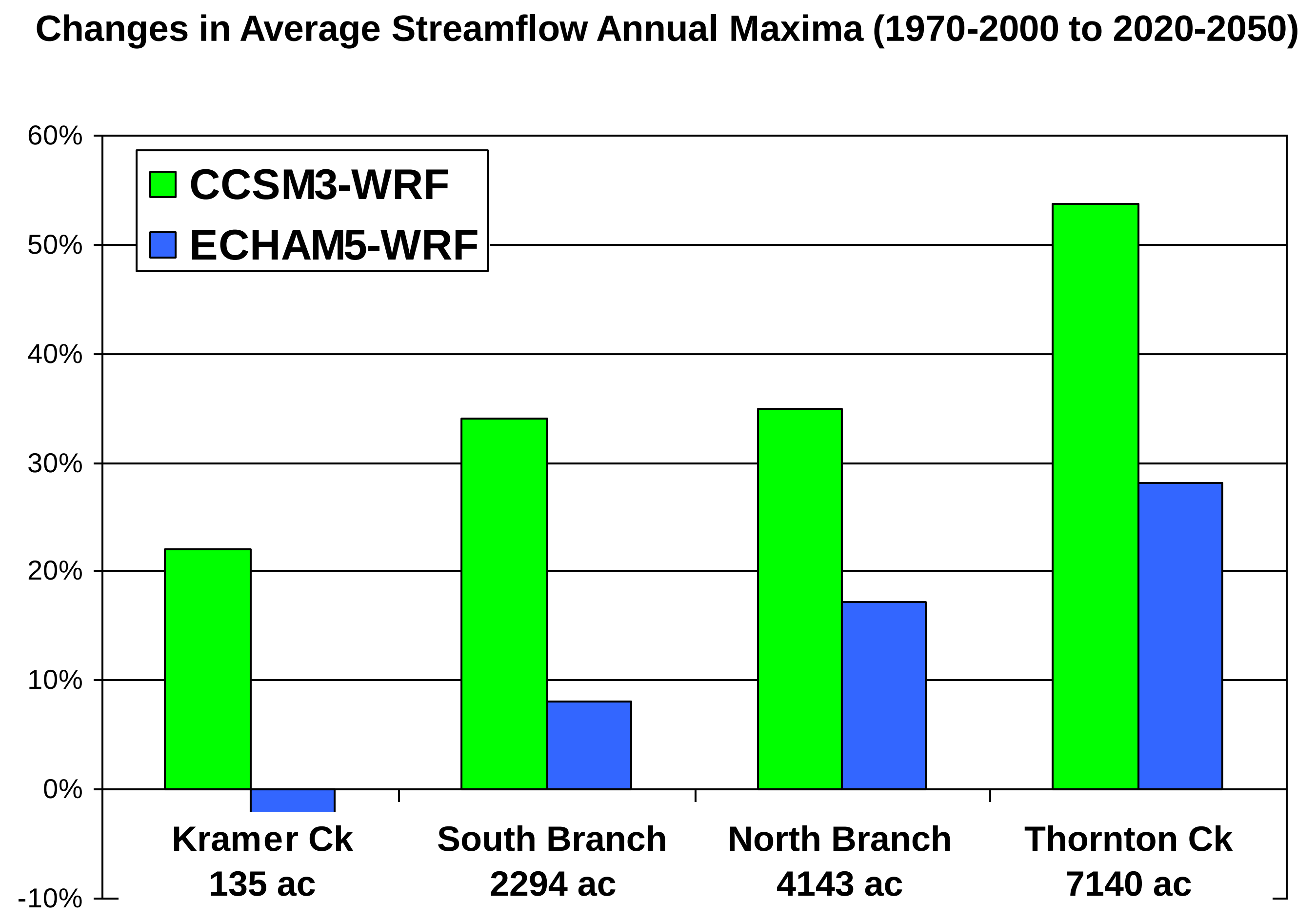
		Raw Change	Corrected Change
CCSM3	1-hour	+16%*	+14%*
	24-hour	+19%	+28%
ECHAM5	1-hour	-5%	-6%
	24-hour	+15%*	+14%*

* *Statistically significant for difference in means and distributions, and non-zero temporal trends*

Thornton Creek



Thornton Creek



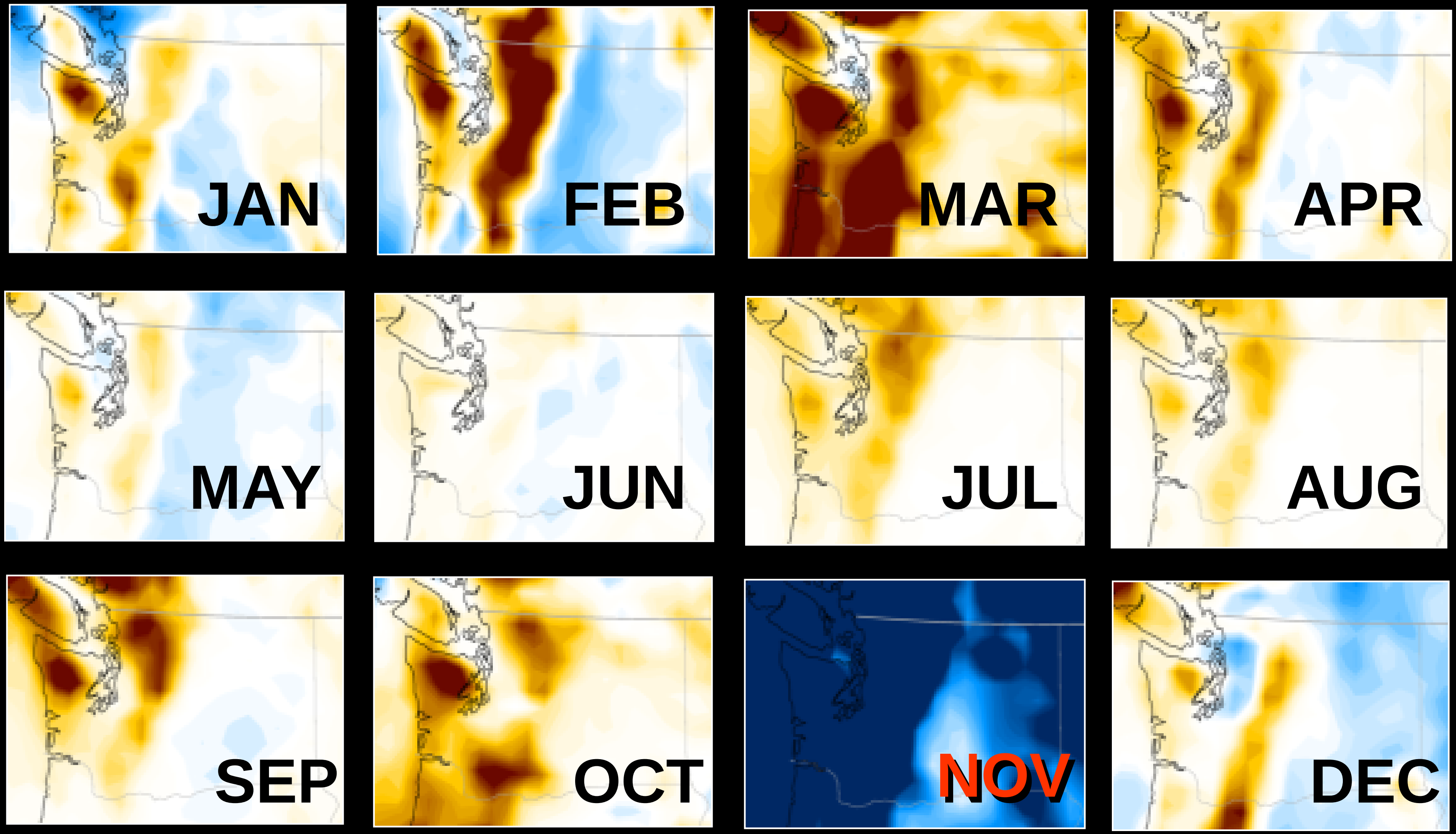
Results of Hydrologic Modeling

Changes in average annual maxima streamflow at outlet of watershed between 1970-2000 and 2020-2050:

	Juanita Creek	Thornton Creek
CCSM3	+25%*	+55%*
ECHAM5	+11%	+28%

* Statistically significant for difference in means

The November Surprise



Courtesy Eric Salathé

Concluding thoughts on extremes

- Much of the work in the climate literature on “extremes” doesn’t really deal with events that are extreme enough to be relevant to risk analysis (typically estimated from the annual maximum series)
- New design (e.g. urban) presents somewhat different issues than retrofit or re-regulation
- RCMs help to make extremes information more regionally specific, but our understanding of the ability of RCMs to reproduce observed precipitation extremes (hence bias correction) is problematic
- Extent to which RCM-derived changes in projections of extremes are controlled by GCM-level extremes is unclear
- Use of ensemble approaches is badly needed, however RCM computational requirements presently precludes this