Precipitation Extremes and the Impacts of Climate Change on Stormwater in Washington State

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http://www.otak.com/what/project.cfm?id=102

Figure A: Juanita Creek, in Kirkland WA, passing through an urban greenway.

1. Abstract

Estimation of precipitation extremes is critical to the design of stormwater infrastructure. The standard approach is to estimate frequency distributions of precipitation extremes for given accumulation intervals, and to design stormwater structures to withstand these storms. We examine, whether there is evidence of changes in the frequency distributions of precipitation extremes for three major metropolitan areas of Washington State: Seattle, Vancouver, and Spokane. The historical analysis is based on hourly precipitation records for gauges surrounding the three metropolitan areas for the time period 1956-2007. We analyze changes over this period through comparison of estimated frequency distributions fitted to annual maximum precipitation. Possible changes in future precipitation extremes are analyzed using two runs of the Weather Research and Forecast (WRF) regional climate model, using ECHAM5 and CCSM3 to generate boundary conditions, for the time periods 1970-2000 and 2020-2050. Annual maximum precipitation from the model output was analyzed for 1 hour to 10 day durations for simulations in the Seattle area, which were downscaled and bias corrected to be equivalent to point observations at Seattle-Tacoma International Airport. The downscaled and bias corrected hourly precipitation sequences were used as input to the HSPF hydrologic model, from which simulated annual maximum discharge for several urban streams was analyzed for the two periods. Both regional climate model simulation run pairs show a predominance of increases in extreme precipitation, although there are decreases for one of the models at the shortest accumulation intervals. As the magnitude of the projected changes differs substantially between the two models, so do projected changes in flood peaks.


http://picasaweb.google.com/andy.ritchie/MeadowbrookFlood3December2007

Figure B: Thornton Creek in Seattle, WA flooding in 2003

2. Introduction and Background

Typically, urban stormwater infrastructure is designed to manage the runoff from “design” rainfall events of specified duration (e.g., 24 hours) and return period (e.g., 100 years), or from the projected discharge of a particular flow recurrence (e.g.., the 25-year flood) without reference to the precipitation that produced it. Historical management goals for urban stormwater have emphasized safe conveyance, with more recent attention also being given to the consequences of increased streamflows on the physical and biological integrity of downstream channels. Future changes to climate that may alter precipitation intensity or duration would likely have consequences for urban stormwater discharge, particularly where stormwater detention and conveyance facilities were designed under assumptions that no longer apply. The social and economic impact of increasing the capacity of stormwater facilities, or the disabling of key assets because of more severe flooding, could be substantial.

This study thus addresses the following questions:

- What are the historic trends in precipitation extremes across Washington State?
- What are the projected trends in precipitation extremes over the next 50 years in the state’s urban areas?
- What are the likely consequences of future changes in precipitation extremes on urban stormwater infrastructure?

Prior studies provide a good methodological starting point for identifying the most likely consequences of climate change on stormwater infrastructure, along with an initial list of potentially useful adaptation measures. Their greatest shortcoming, however, lies uniformly in their rudimentary characterization of the precipitation regimes that drive the responses (see also Trenberth et al., 2003; Kirschen et al., 2004). Our report seeks to bridge this gap between presumptive, but poorly quantified, future climate-change and the acknowledgment that infrastructure adaptation is generally less costly and disruptive if necessary measures are undertaken well in advance of anticipated changes. We have approached this task both by analyzing the variability in historical precipitation extremes across Washington State and by utilizing higher resolution regional climate model results than have been previously possible to characterize future projections of precipitation extremes. We process these results in a bias correction and statistical downscaling procedure to provide forcings to an urban streamflow prediction model, thus evaluating the implications of the simulated precipitation extremes for urban flooding.

3. Historical Analysis - Methods

The *Regional frequency analysis*, a technique adapted from the regional L-moments method of Hosking and Wallis (1997) was used to evaluate changes in rainfall extremes over the period 1956–2005 for a wide range of frequencies and durations. The precipitation frequency analysis analyzed the annual maximum series for aggregates of hourly precipitation ranging from one hour to ten days for the three major urban areas in Washington State: the Puget Sound, Vancouver, and Spokane regions. A frequency distribution was fit to the time series of annual precipitation maxima from a set of stations within each region. Data originated from the National Climatic Data Center (NCDC) hourly precipitation archives. Stations selected for the analysis are shown in Figure C and listed in Table A. The minimum requirement for inclusion was a reported period of record of 40 years, with minimal missing data. Annual maximum precipitation depths for multiple durations were identified for each station and combined into pools in order to calculate regional L-moment parameters (Hosking and Wallis 1997, Fowler and Kilsby 2003) These parameters were then used to fit data to Generalized Extreme Value (GEV) distributions and to generate regional growth curves. Uncertainty bounds about the GEV distributions were provided. Statistical significance for differences in the entire distribution was found by using the Wilcoxon rank sum test with a two-sided significance level of 0.05.

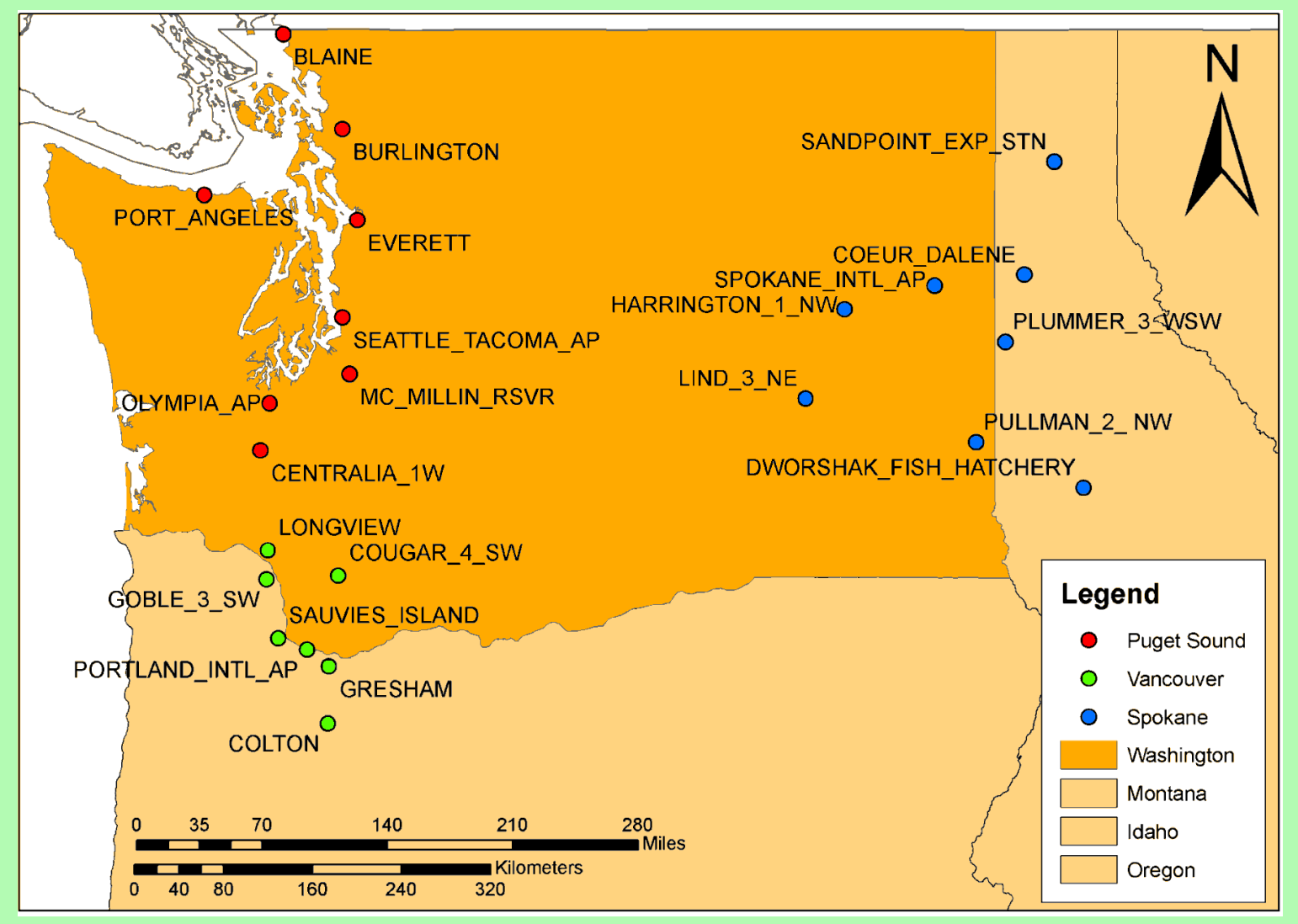

Figure C: Locations of the stations used in the regional frequency analysis.

Region	Station	State	Co-op ID	Reported Period	# of Years Removed	Sample Size
Puget Sound	Blaine	WA	729	1949–2007	7	52
	Burlington	WA	986	1949–2007	5	54
	Centralia 1W	WA	1277	1968–2007	3	37
	Everett	WA	2675	1949–2007	4	55
	McMillin Reservoir	WA	5224	1949–2007	14	45
	Olympia AP	WA	6114	1949–2007	8	51
	Port Angeles	WA	6624	1949–2007	13	46
	Seattle Tacoma AP	WA	7473	1949–2007	16	59
Spokane	Couer d'Alene	ID	1956	1949–2007	20	39
	Dworshak Fish Hatchery	ID	2845	1967–2007	1	40
	Harrington 1 NW	WA	3515	1962–2007	5	41
	Lind 3 NE	WA	4679	1949–2007	5	54
	Plummer 3 WSW	ID	7188	1949–2007	12	47
	Pullman 2 NW	WA	6789	1949–2007	6	53
	Sandpoint Exp Stn	ID	8137	1960–2007	5	43
	Spokane Intl AP	WA	7938	1949–2007	0	59
Vancouver	Colton	OR	1735	1949–2007	2	57
	Cougar 4 SW	WA	1759	1949–2007	3	56
	Goble 3 SW	OR	3340	1949–2007	2	57
	Gresham	OR	3521	1949–2007	9	50
	Longview	WA	4769	1955–2007	10	43
	Portland Intl AP	OR	6751	1949–2007	0	59
	Sauvies Island	OR	7572	1949–2007	1	58

Table A: Stations used in the regional frequency analysis.


http://blog.oregonlive.com/breakingnews/2007/12/06/

Figure D: Google images showing Interstate 5 at Chehalis before the flood paired with stills from video shot on December 4, 2007.

4. Bias Correction & Projected Stream flow - Methods

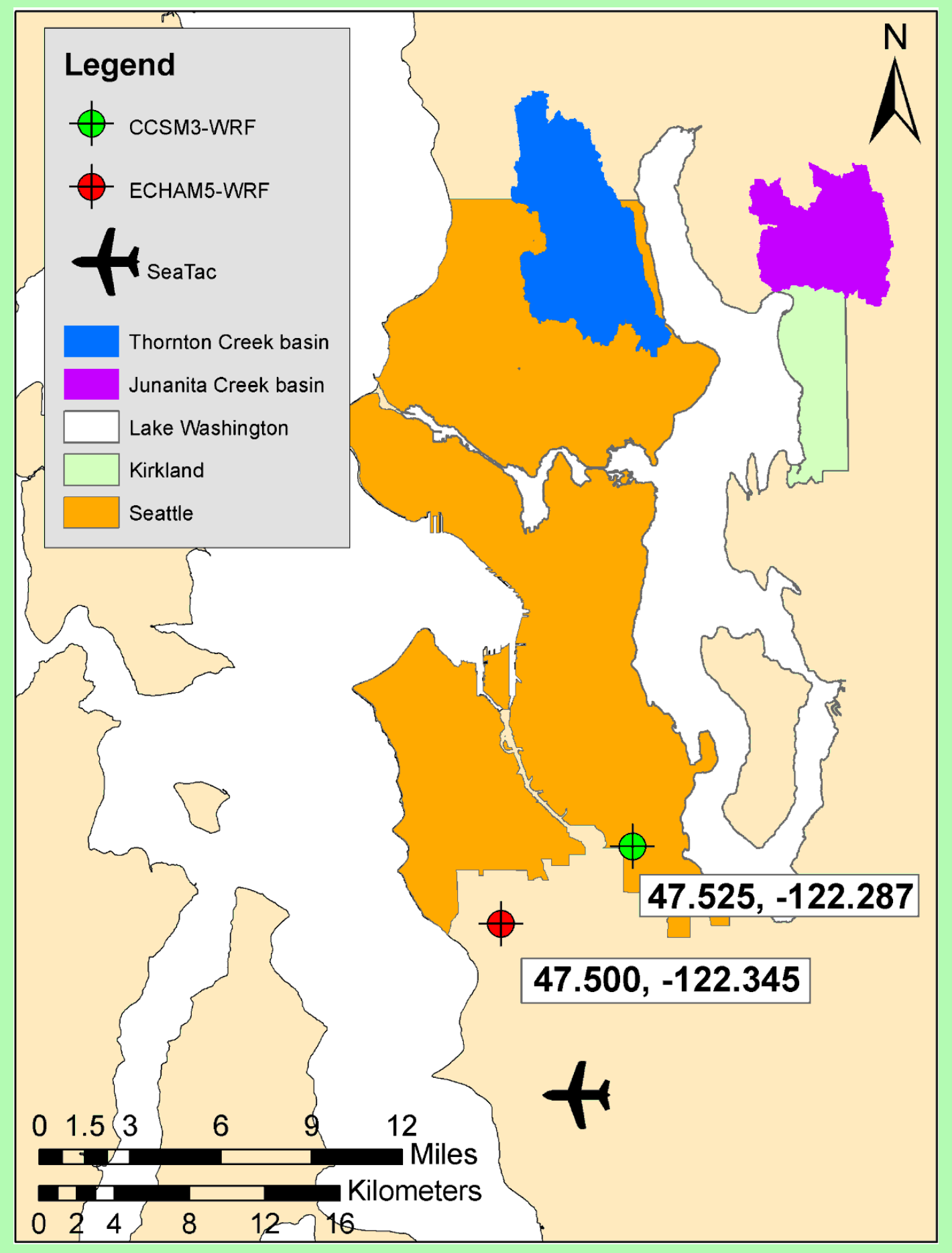

Figure E: Locations of the two gridpoints used for BCSD shown in relation to SeaTac Airport and the Thornton and Juanita Creek watersheds.

Two global climate models (Table B) simulated hourly precipitation data for the time periods 1970–2000 and 2020–2050. Simulations for both periods were bias-corrected and statistically downscaled to a selected point. The resulting sequence of hourly precipitation was then used as input to a hydrological model to simulate urban runoff extremes.

Bias Correction: Wood et al. described the framework that was used to perform the bias correction (BCSD). For this analysis we focused on only one region of Washington State, the central Puget Sound region, and we bias-corrected the simulated data at the monthly level. The bias correction procedure is based on probability mapping as described by Wilks (2006) . The monthly data for grid nodes were thus corrected so that they had the same probability distributions as the observed data from Seatac airport, which was the same data used in the historical analysis described above. (See references for detailed explanation.)

Hydrologic simulation: We analyzed two Seattle-area watersheds, Thornton Creek and Juanita Creek, because they encompass physical and land-use characteristics typical of the central Puget Lowland (Figure E). The Thornton Creek watershed is Seattle’s largest creek basin, with approximately 28.7 km² (11.1 mi²) of mixed commercial and residential land use. Juanita Creek is a mixed-land-use 7.4 km² (2.8 mi²) watershed that drains into the eastern shore of Lake Washington. Hydrologic simulations of streamflows in these two watersheds were generated by the Hydrologic Simulation Program-Fortran (HSPF; Bicknell et al., 1996) . HSPF is a lumped-parameter model that simulates discharge at user-selected points along a channel network from a time series of meteorological variables. The BCSD precipitation data from the RCM grid points were used as input to HSPF to predict streamflows in both the Thornton and Juanita Creek watersheds.

Table B: Summary of emission scenarios, GCMs, and downscaling parameters used for this study.
[1] A2 simulations performed by Pacific Northwest National Laboratories
[2] A1B simulations performed by UW-CIG

IPCC Emissions Scenario	Global Circulation Model (GCM)	Regional Climate Model (RCM)	RCM grid spacing for Washington State simulation	Lat-Long Coordinates of RCM output used in for hydrologic modeling	
A2[1]	CCSM3	WRF	20 km	47.525°N	122.287 °W
A1B[2]	ECHAM5	WRF	36 km	47.500 °N	122.345°W

5. Results and Conclusions

Results are summarized as three key conclusions:

1. ***Historical precipitation extremes have generally increased over the last 50 years, particularly in the Puget Sound region and to a lesser extent in the Spokane region.*** Existing drainage infrastructure designed using mid-20th century rainfall records may already be subject to a rainfall regime that differs from its design standard in these areas. For all but the shortest durations, however, precipitation extremes have declined in the Vancouver region *(see Figure F and Table C for summary results).*

The summarized results in Table C present the average of changes in design storm magnitudes across all recurrence intervals, which are generally of the same magnitude of change seen in the 2-year events. Sample GEV distributions (in Figure F) for the 5-day annual maxima indicate the variability of change within a single storm duration. Based on these spatially variable results, anticipating uniform responses in the patterns of future rainfall across all of Washington State are unwarranted, and adaptations will need to be region-specific.

Table C: Average changes in design storm magnitude from 1956–1980 to 1981–2005 (“2 Periods” analysis) and 1956–1965 to 1996–2005 (“5 Periods” analysis). Statistically significant changes are in bold.

	Seattle-Tacoma		Spokane		Portland	
	2 Periods	5 Periods	2 Periods	5 Periods	2 Periods	5 Periods
1-hour	+7.2%	**+28.3%**	-1.0%	**+32.4%**	**+4.4%**	**+39.9%**
2-hour	+10.0%	**+30.0%**	-5.2%	**+24.0%**	-5.3%	+8.5%
3-hour	+14.2%	+31.3%	+0.3%	+21.6%	-6.6%	+1.1%
6-hour	+12.7%	+30.8%	+0.7%	+6.8%	-8.2%	**-8.6%**
12-hour	+18.7%	+37.3%	+14.9%	+17.0%	-5.2%	**-7.9%**
24-hour	**+24.7%**	+34.8%	+6.9%	+1.2%	+1.9%	**+0.4%**
2-day	**+22.3%**	**+31.1%**	+2.9%	+0.7%	-6.6%	**-9.6%**
5-day	**+13.4%**	+16.5%	-10.1%	-17.3%	**-5.0%**	**-3.1%**
10-day	**+7.3%**	+10.2%	-3.9%	-13.1%	**-9.7%**	**-5.1%**

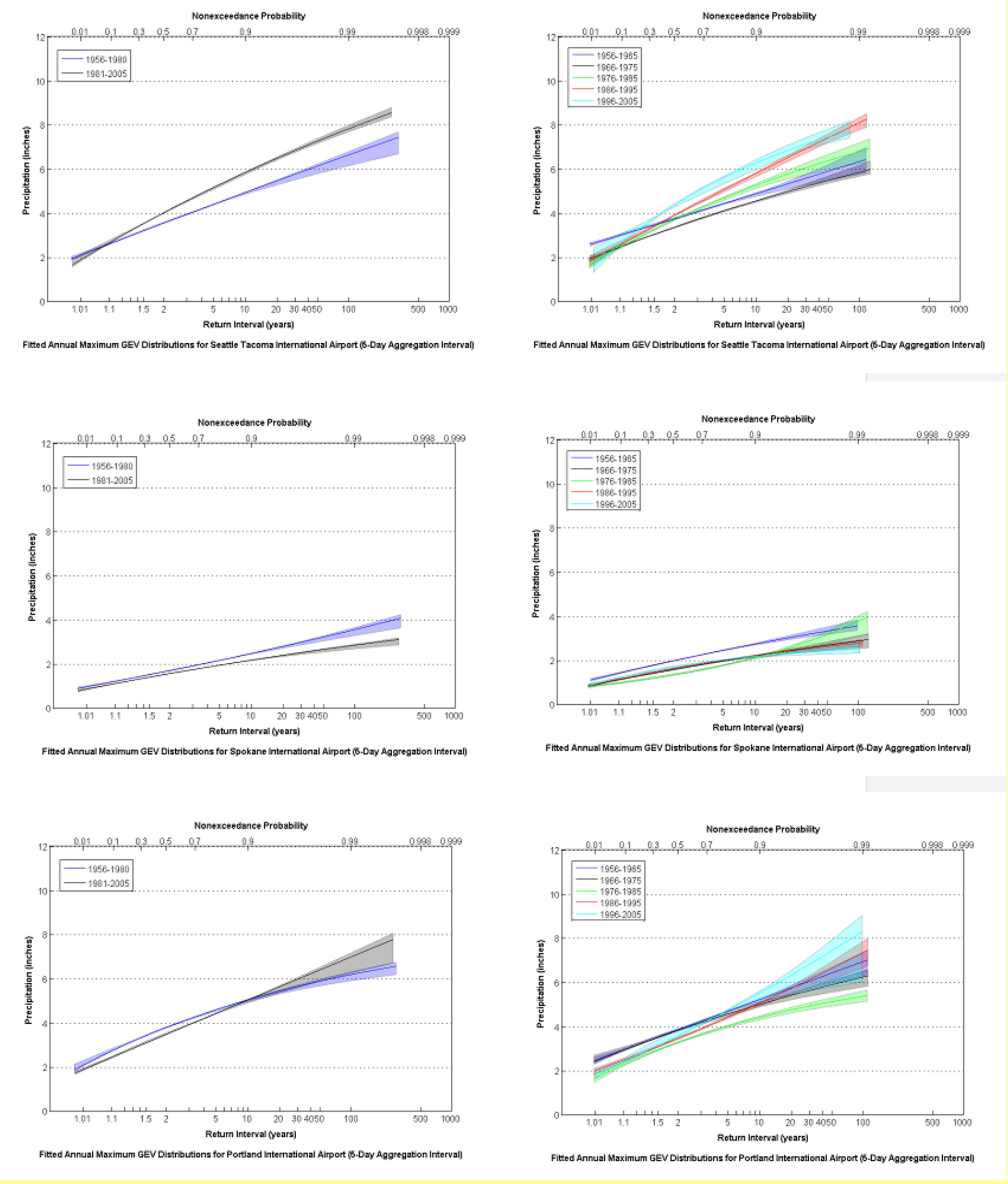

Figure F: Changes in distributions at SeaTac, Spokane, and Portland for 5-day annual maxima. Results of the 2-interval analysis are shown at left; results of the 5-interval analysis are shown at right.

2. ***Regional climate models project increases in precipitation extremes in the Puget Sound region but their predictions vary substantially.*** Differences between the underlying global climate models, and uncertainties in the downscaled model results, suggest that precipitation changes through 2050 may be difficult to distinguish from natural variability for the period of analysis. Figure G, at right, indicates that despite both models projecting increases in 2020-2050 relative to their 1970-2000 results and relative to the observed 1970-2000 record, the observed record for 1981 to 2005 is nearly as high as the largest projection in 2020-2050.

Although the historical analyses suggest that the magnitude of future increases is plausible (and, in fact, consistent with past trends), the differences between the two model predictions are sufficiently large to carry potentially significant consequences for their use in the design of stormwater facilities.

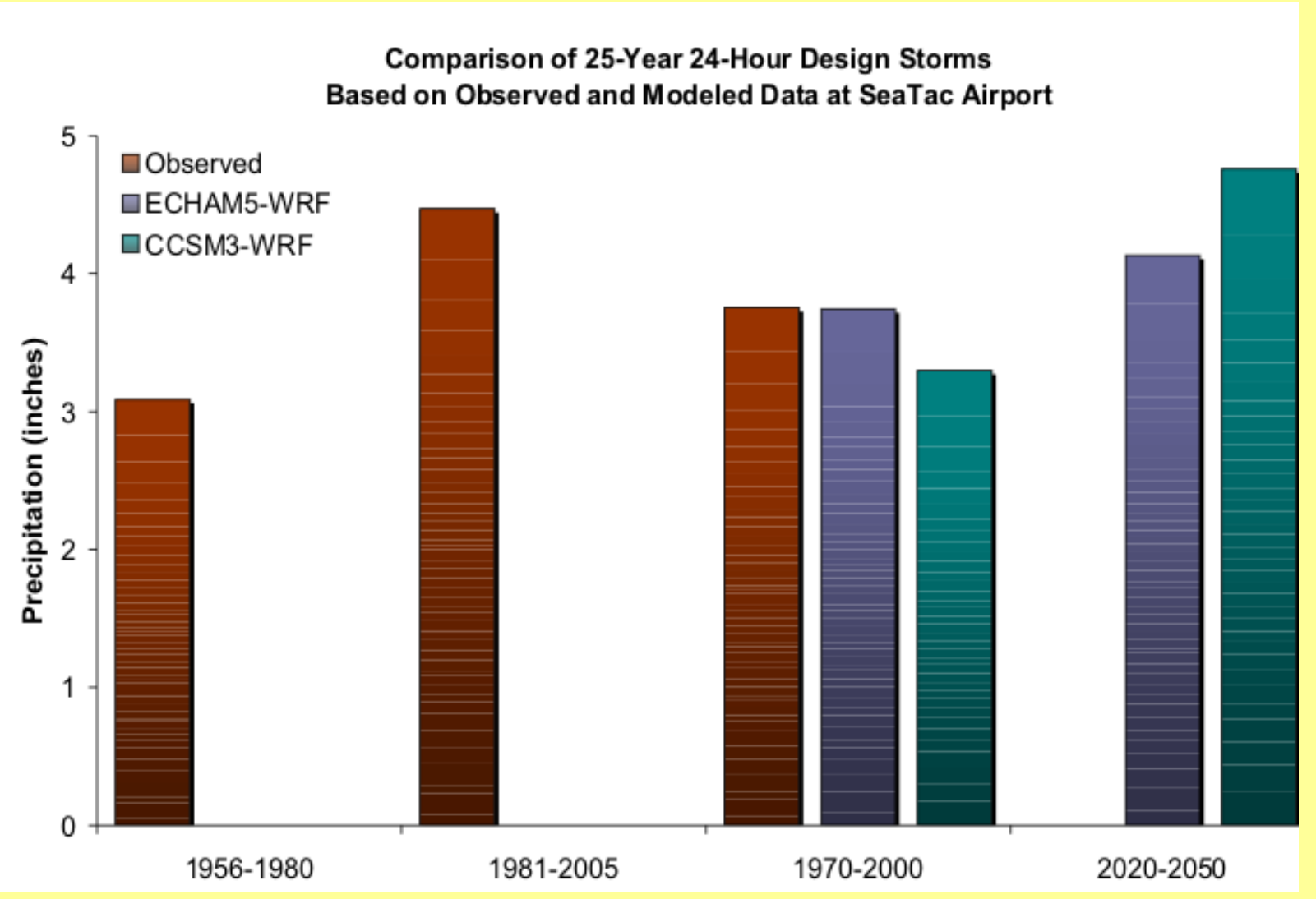

Figure G: Comparison of 25-year 24-hour design storms, based on observed and modeled rainfall data at SeaTac airport.

3. ***Hydrologic modeling of two urban creeks in central Puget Sound, driven by rainfall simulations from a regional climate model, suggest overall increases in peak annual discharge over the next 50 years.*** Magnitudes of projected changes vary widely, however, ranging from declines of 35% to increases of more than 80%, depending on recurrence interval and choice of the underlying global climate model.

Results of the hydrologic modeling (Table D and Figure H) on two urban watersheds in the central Puget Sound region affirm and extend both the broad trends and the substantial uncertainties evident in the precipitation simulations. For the largest modeled watersheds, simulations provide general agreement that peak discharges will increase, although the range of increases (15–88%, depending on the selected recurrence interval, the watershed, and the underlying GCM simulation) are much too large on which to predicate engineering designs. The comparative simulation results are even more confounding for the smaller watersheds, wherein even the net direction of change (i.e., a future increase or a future decrease) is dependent on the choice of GCM model.

Table D: Comparisons of HSPF-simulated annual maximum streamflows at the mouth of Juanita Creek, as forced by bias-corrected data for 1970-2000 and 2020-2050 from each of the two RCM runs. Biases indicated are with respect to HSPF-simulated annual maximum streamflows as forced by observed data for 1970-2000 .

Recurrence Interval (yrs)	CCSM3-WRF			ECHAM5-WRF		
	Bias with Observed (1970-2000)	Peak Flow Quantiles 2020-2050 (cfs)	Change From 1970-2000	Bias with Observed (1970-2000)	Peak Flow Quantiles 2020-2050 (cfs)	Change From 1970-2000
2	8.8%	289	+24.9%	2.7%	255	+16.8%
5	5.9%	360	+25.1%	3.9%	321	+13.7%
10	1.2%	402	+25.7%	4.3%	358	+8.5%
25	6.3%	451	+26.8%	4.5%	398	+0.4%
50	12.2%	485	+27.7%	4.4%	424	-6.1%
Average	3.9%	297	+25.7%	2.8%	260	+11.1%

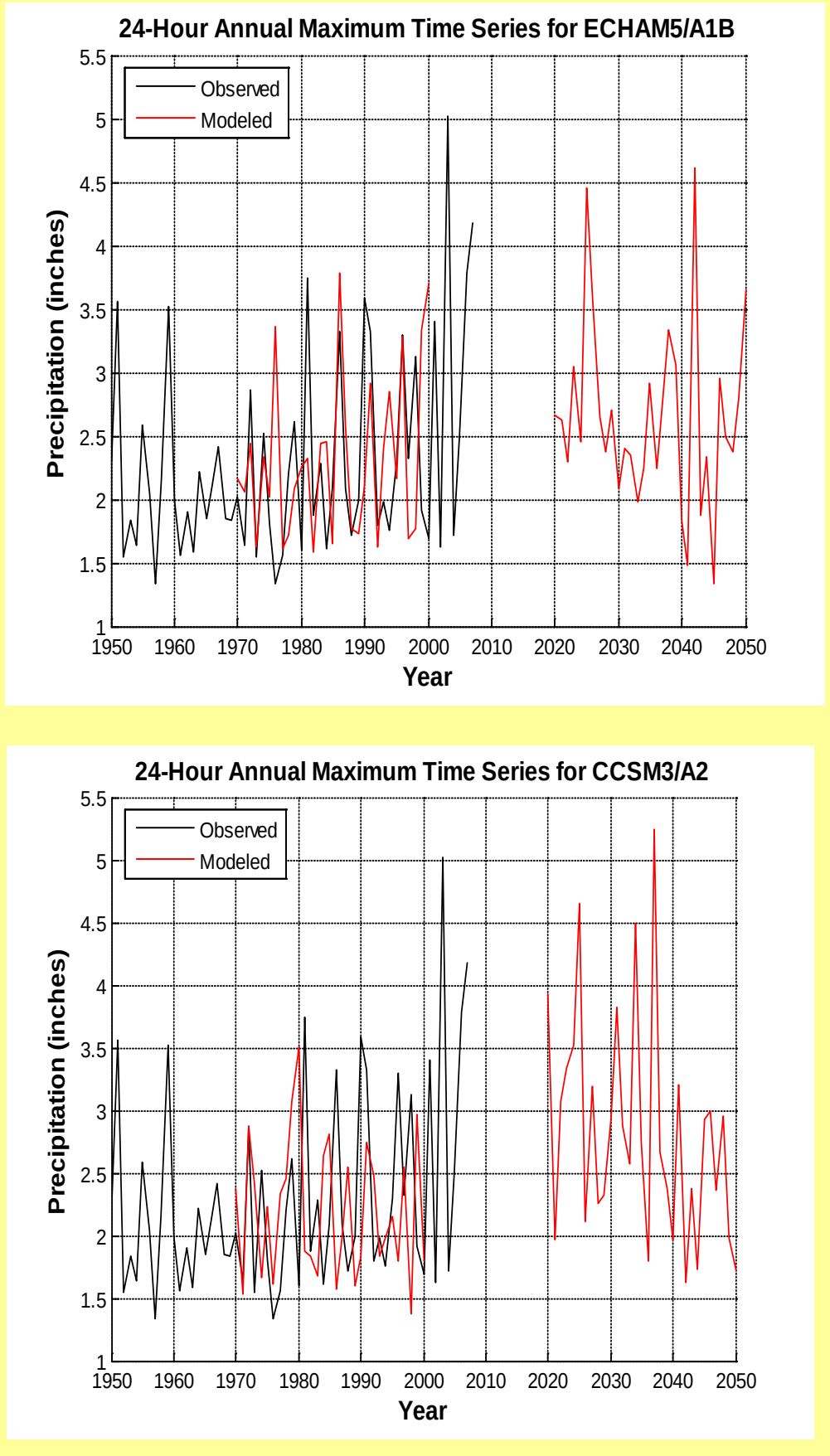

Figure H: 24-hour annual maxima resulting from the bias-corrected data plotted on top of 24-hour annual maxima resulting from the observed data at SeaTac. As shown, the range and means of the simulated data generally match those of the observed data for the historic period (1970-2000).

Conclusions

This exploration found locally discernable and significant signals in data towards a precipitation regime of increasing intensity. However, given that this analysis is based on just two GCMs, it is at most suggestive not definitive. To acquire a more complete understanding of how precipitation extremes will change in the future, additional model simulations and extension of the regional frequency analysis to the future simulated data would provide more robust results and conclusions.

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