

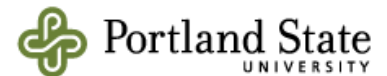


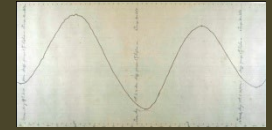
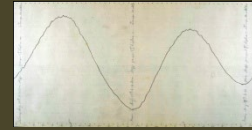
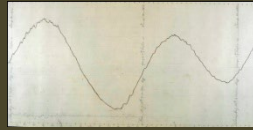
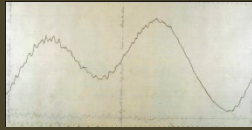
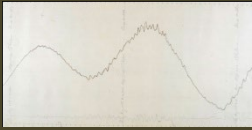
2015:
The new
normal?

Water temperature shifts on the Willamette River since 1850



Stefan Talke, David Jay, and Heida Diefenderfer

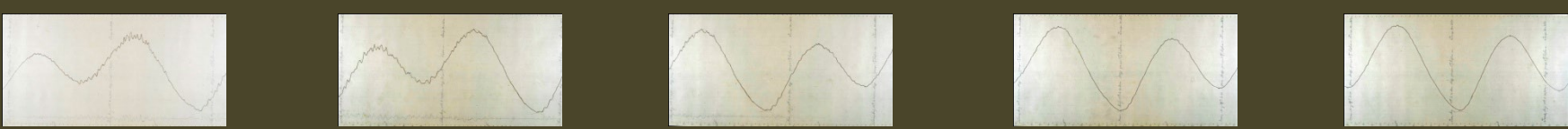




Big Picture Questions

1. The **Columbia and Willamette Rivers** were different in the past. But **how different was T_w** ?
2. Are **engineered alterations, climate change, or both** causing **trends**?
3. Based on the **past**, what can we **learn** for the **future**?
4. Today's **focus**: An **empirical/statistical** look at **water temperature**





Step 1: Lost and forgotten Tw records rediscovered

STATION: Portland, Oregon ; Month: July, 1882.

DATE	RIVER OBSERVATIONS				TEMPERATURE OF WATER				WIND				CLOUD							
	Depth of water, feet and inches (ft. in.)				RIVER, LAKE, AND OCEANS (ft.)				Direction and force				Upper							
July 1	+	26.0	-0.6		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 2	+	26.0	-0.2		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 3	+	26.0	-0.4		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 4	+	26.0	-0.2		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 5	+	26.0	-0.3		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 6	+	26.0	-0.1		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 7	+	26.0	-0.1		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 8	+	26.0	-0.3		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 9	+	26.0	-0.3		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 10	+	26.0	-0.3		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 11	+	26.0	-0.4		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0
July 12	+	26.0	-0.6		72.0	65.0	62.0	60.0	27.0	30.0	35.0	38.0	42.0	45.0	48.0	50.0	52.0	55.0	58.0	60.0

Portland, 1882

US Signal Service Records, 1881-1890

Form No. 1066-M-0-1 U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU PORTLAND OR
 Report of River Rainfall Station at Portland Oregon 7-47 on the
Willamette River Drainage Area for the month of July 1947
 Time of observation 7:30 A.M. Flood stage 8 Warning stage

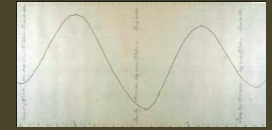
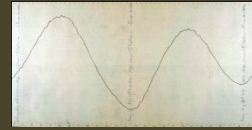
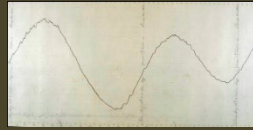
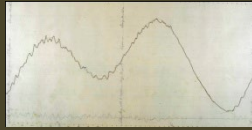
DATE	RIVER		PRECIPITATION				STATE OF WEATHER	REMARKS, SPECIAL OBSERVATIONS, CRUST STAGES, ETC.
	GAUGE	CHANGE	TIME OF BEGINNING	TIME OF ENDING	AMOUNT	SNOWFALL IN INCHES		
1	12.1	-0.7						64°
2	11.3	-0.8						64°
3	11.0	-0.3						69°
4	10.8	-0.2						71°
5	10.5	-0.3						74°
6	10.7	+0.2			T			75°
7	10.5	-0.2						74°
8	10.3	-0.2						74°
9	10.2	-0.1						74°
10	10.2	0.0			0.37			72°
11	10.0	-0.2			0.92			72°
12	10.0	0.0						72°
13	10.3	+0.3						72°
14	10.2	-0.1			0.75			72°
15	10.1	-0.1			0.22			71°
16	10.1	0.0			0.10			70°
17	9.8	-0.3						69°
18	9.5	-0.3						68°
19	8.9	-0.6						69°
20	8.7	-0.2						70°
21	8.8	+0.1						70°
22	8.9	+0.1			T			70°
23	8.8	-0.1						71°
24	8.6	-0.2						72°
25	8.8	+0.2						72°
26	8.7	-0.1						73°
27	8.8	+0.1			T			73°
28	8.8	0.0						74°
29	8.4	-0.4						74°
30	7.7	-0.7						73°
31	7.3	-0.4						73°
Sum	298.8				0.96	0.0		5 days with .01 or more
Avg	9.6							Elevation of zero 115 ft. N.P.S. 11.9 ft.

Portland, 1942

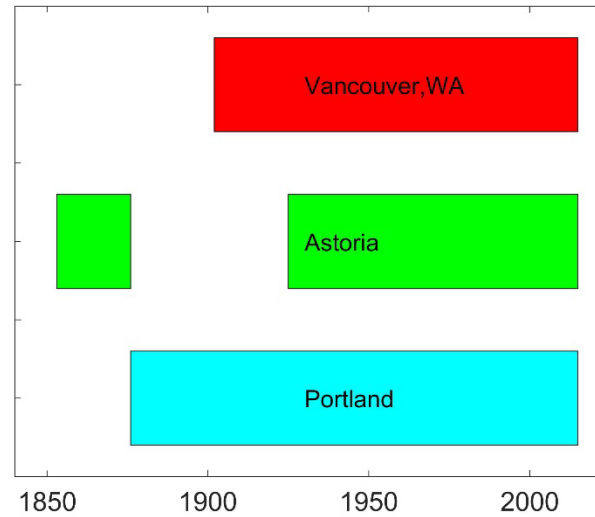
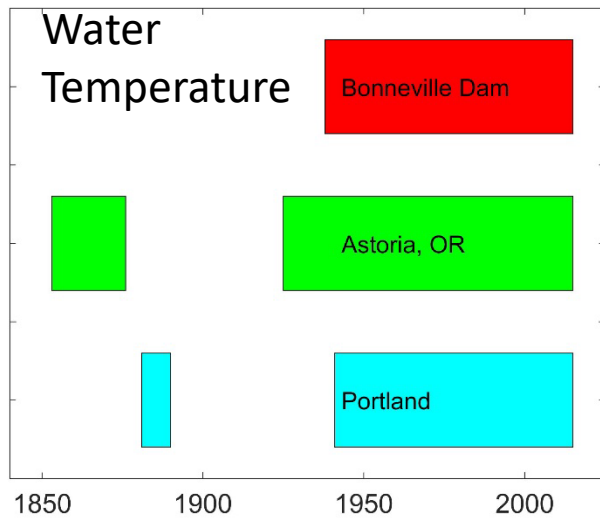
BEST AVAILABLE RECORD

Weather Bureau Records, 1941-1961

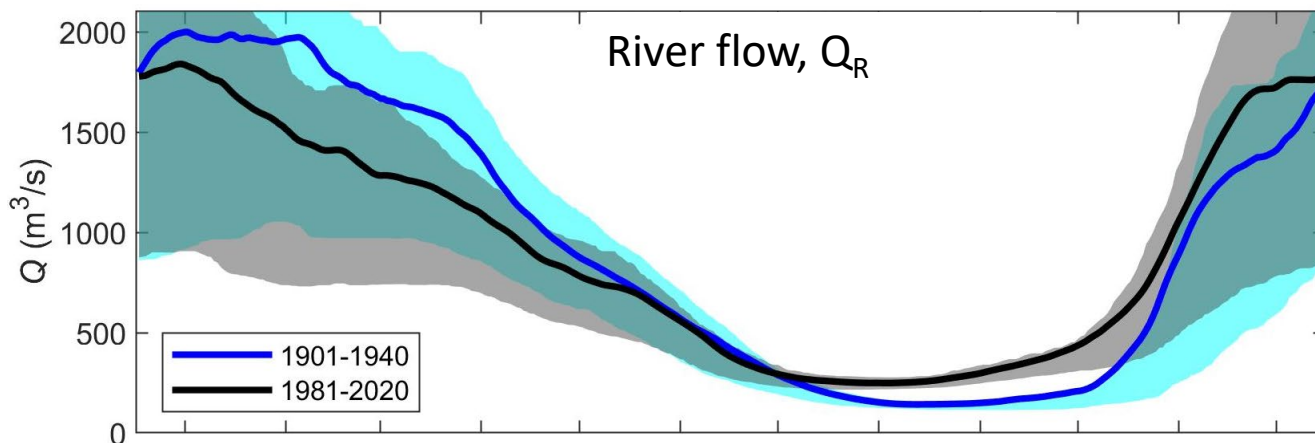
→ Big concatenation effort



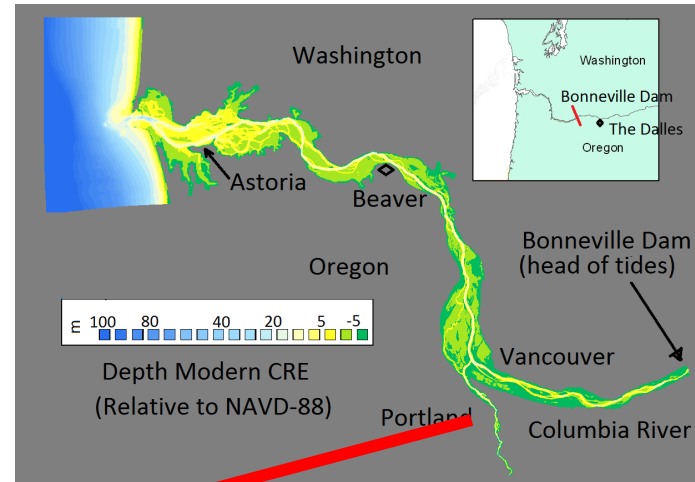
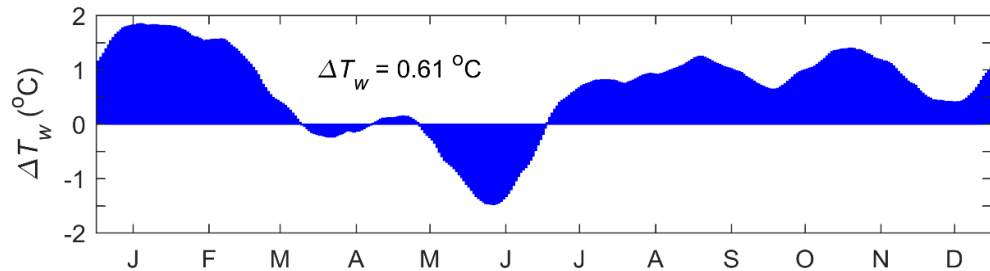
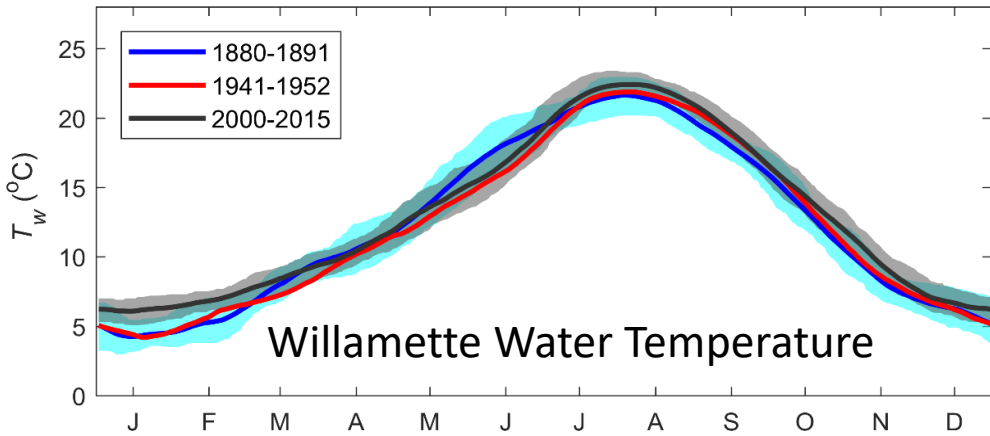
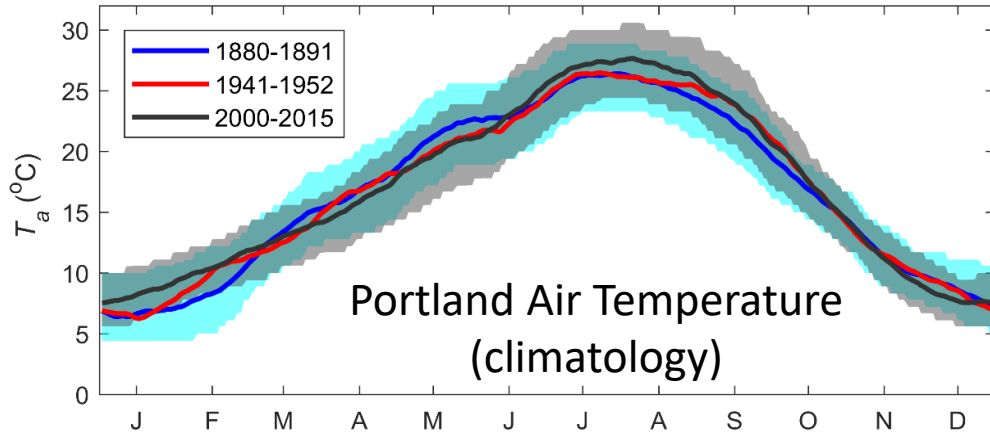
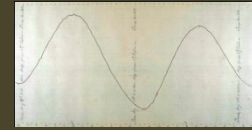
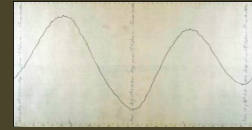
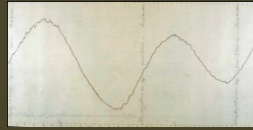
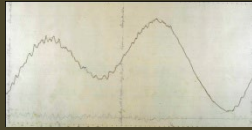
Data Summary: Flow (Q_R), T_w and WL



Water Level
(can be used to
estimate river
flow)



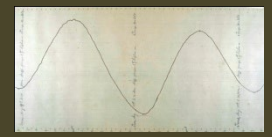
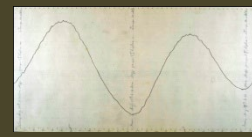
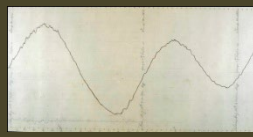
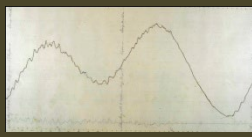
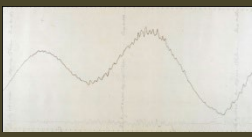
Available since
1880s



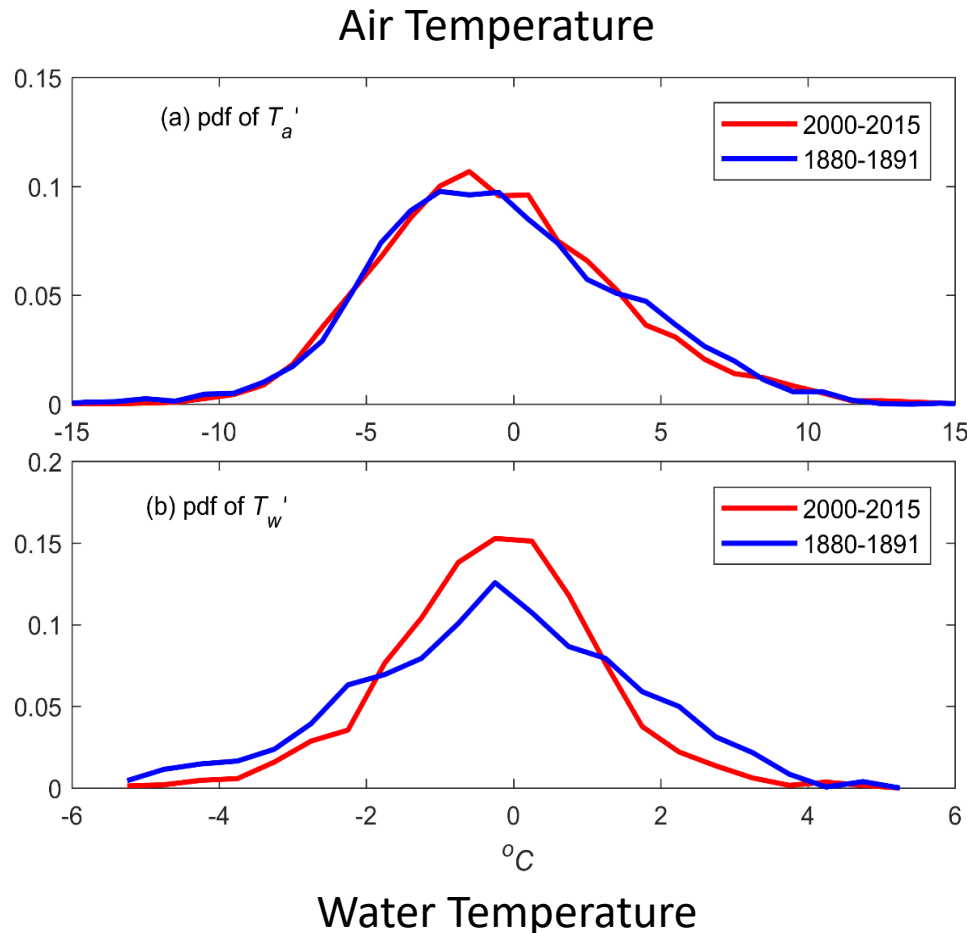
Little change between 1880 and 1940 decades

Modern measurements are **1-2°C higher** than historically, *except spring and Nov/Dec.*

A combination of reservoirs and climate change post 1950 is responsible. But what?



Important to look at anomalies (Δ from seasonal norm)

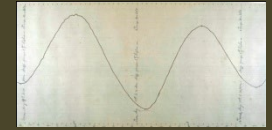
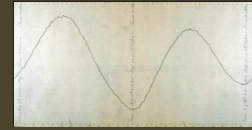
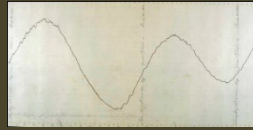
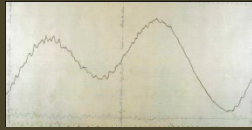


Why are the T_w extremes no bigger today?

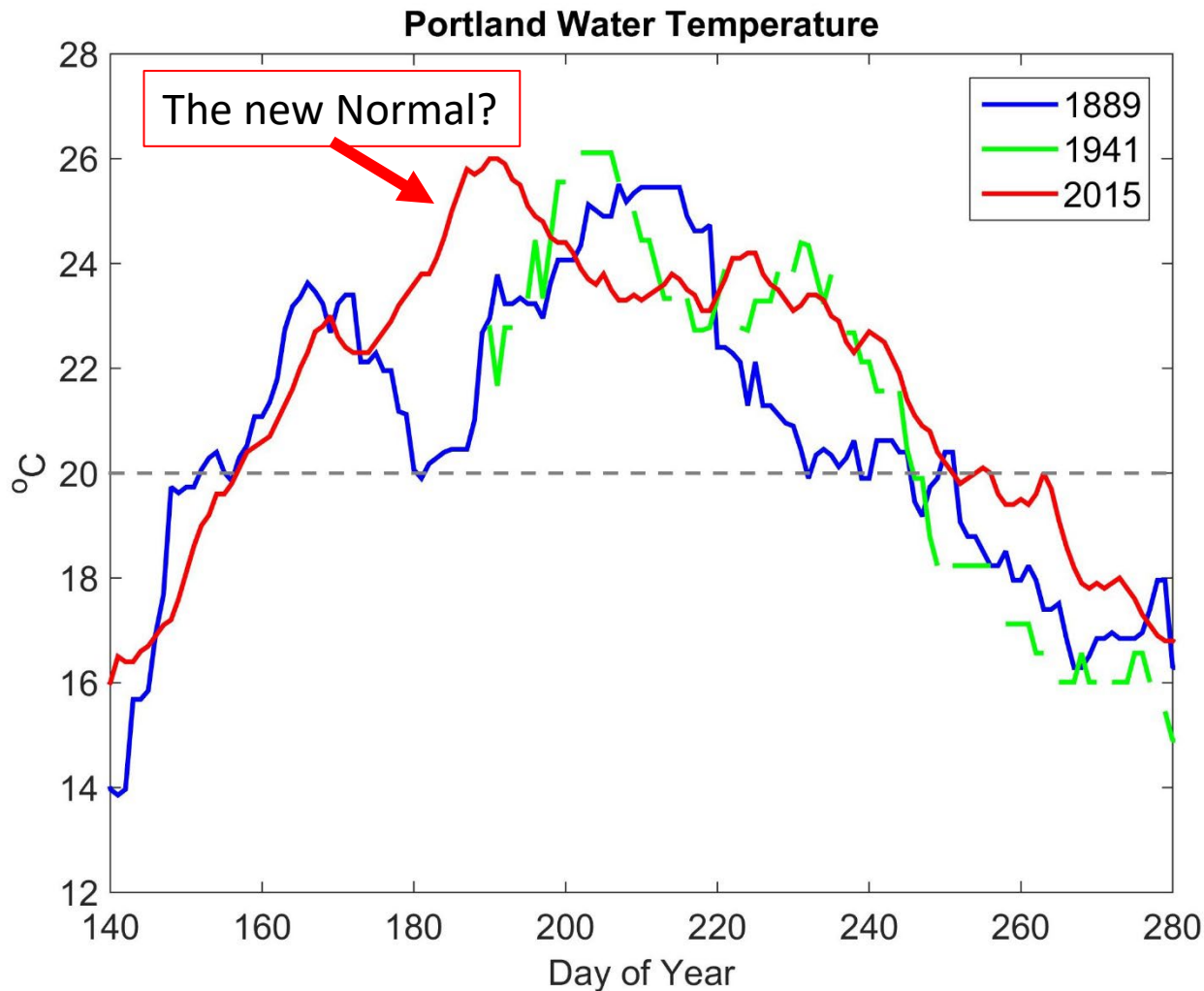
→ Air Temperature deviations from mean are similar (**Not the cause**)

→ Instead, **reservoir management** **reduced** the T_w deviation from the mean.

→ Much more common to have a +/- 4 degree T_w excursion from normal in 1800s than today



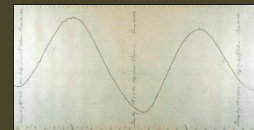
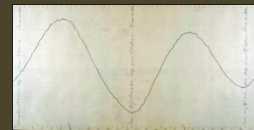
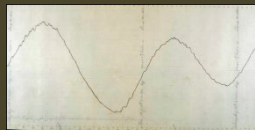
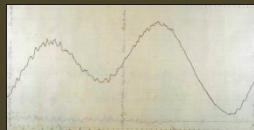
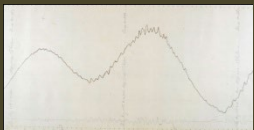
Comparison of 3 warmest T_w years on record



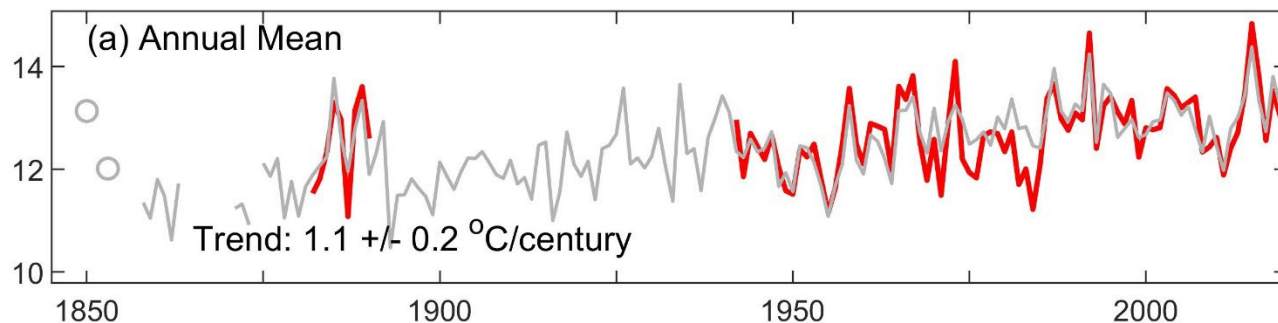
Peak T_w in 1941 and 1889 was nearly the same as 2015!!!

Why has mean T_w increased, but not maximum?

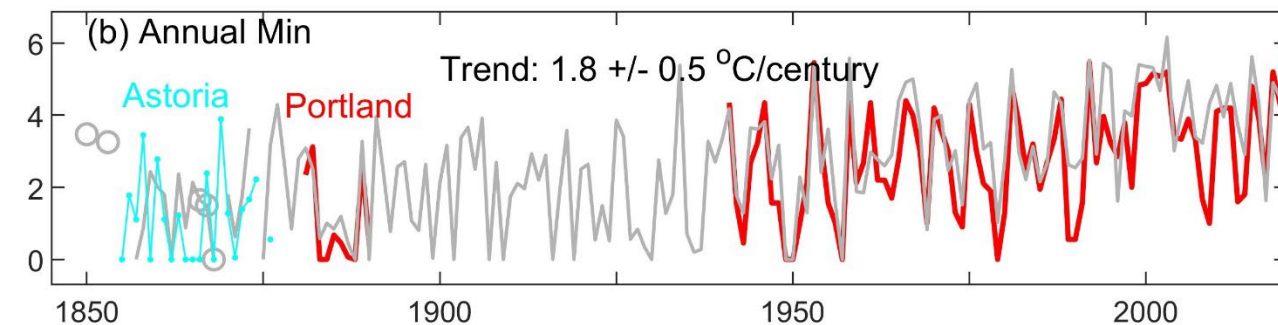
Reservoirs/flow regulation reduce T_w variability



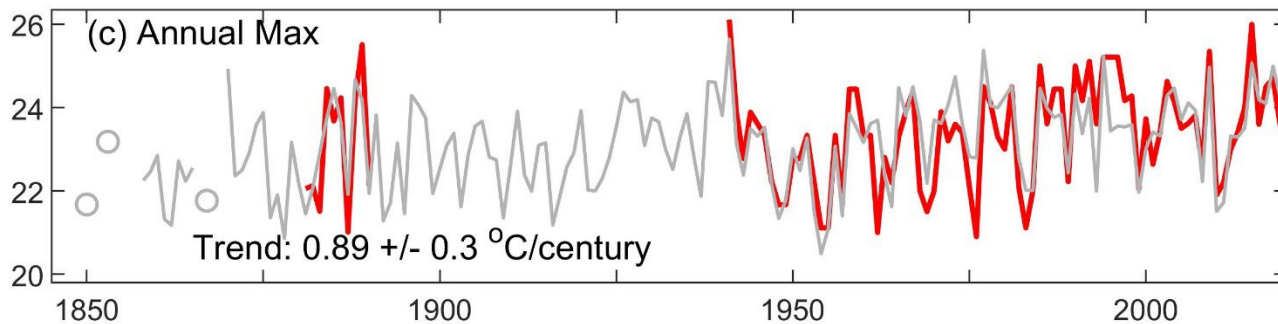
Annual Trends



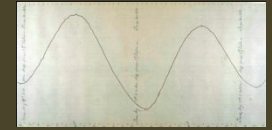
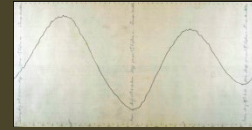
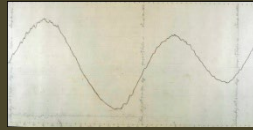
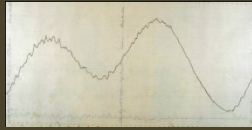
Red: Measurements
Grey: Model



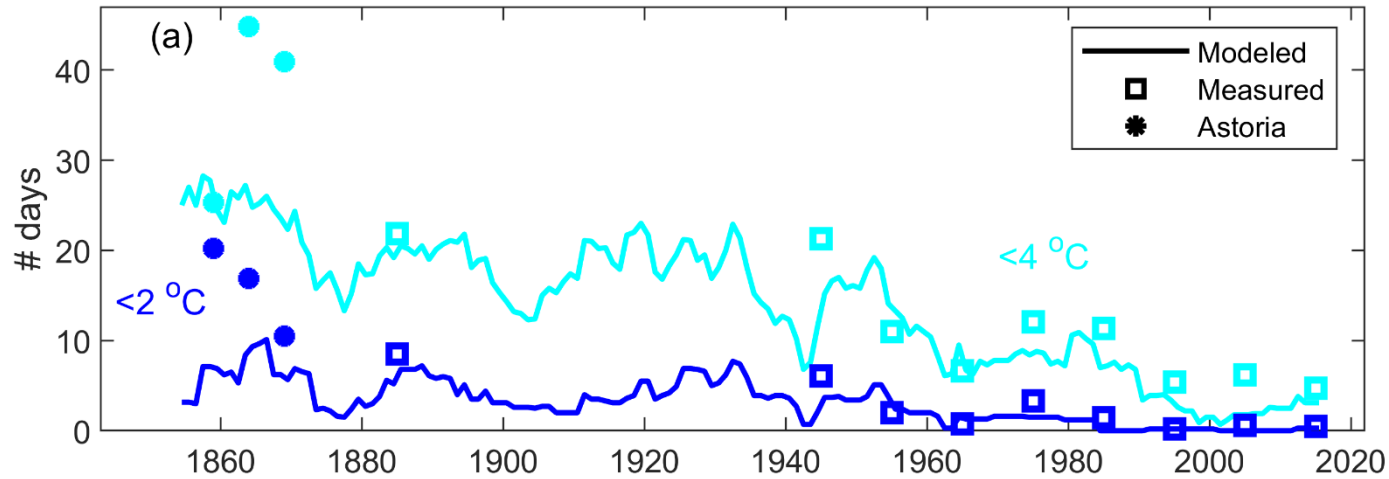
Minimum
increasing faster
than maximum!



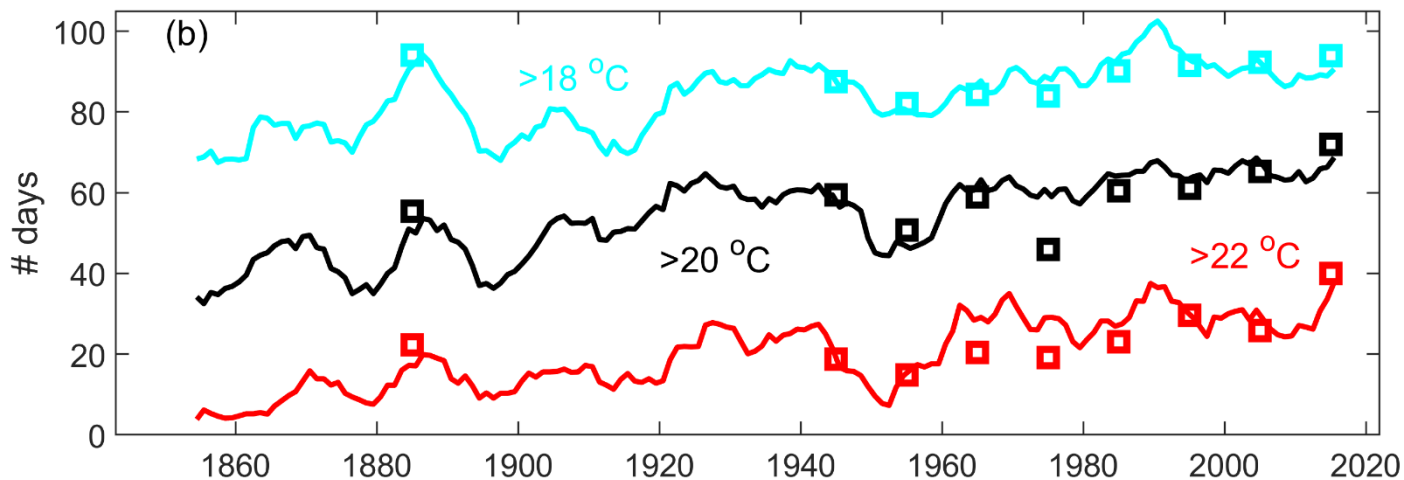
Cyan: Astoria (Columbia River, but winter I_w similar to Willamette)



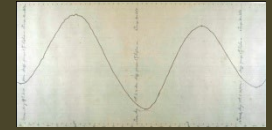
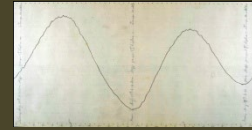
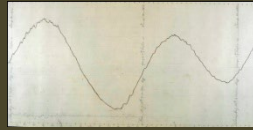
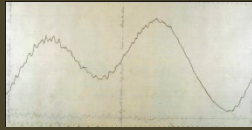
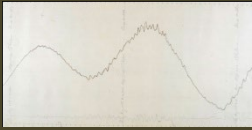
Decadal average of number of days per year over/under a threshold



River never
freezes over
any more....



About 20 days
per year more
over 20°C now



Take home messages today

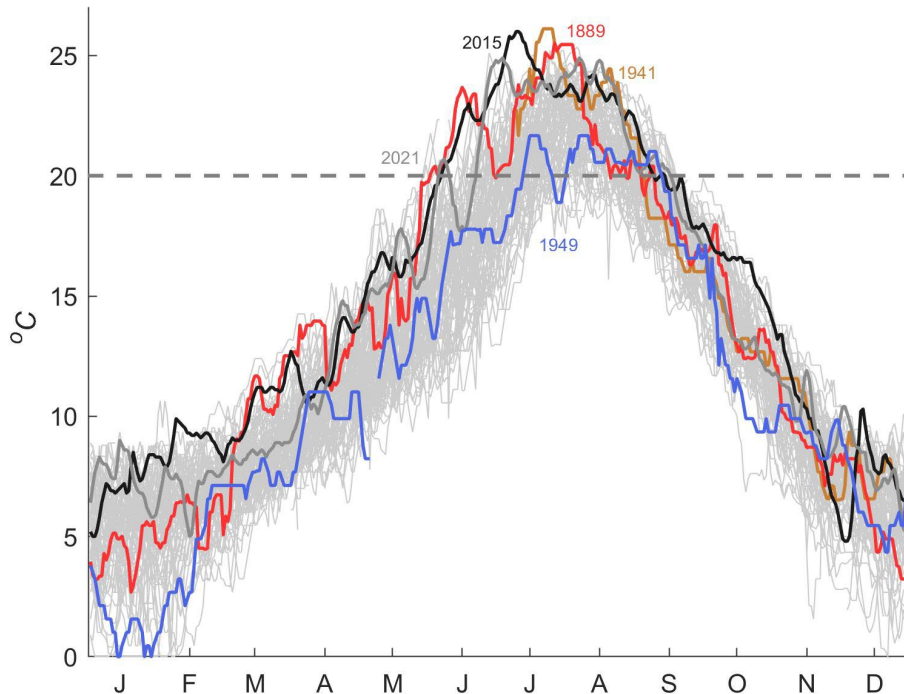
1. Mean T_w **increased nearly 2 degrees** on Willamette since 1850 (about 1.1 degrees/century), but **variability decreasing**

2. Peak T_w are about the same as in 1800s (reduced variance).

3. “Temporal” Refuges **decreasing**—number of **days T_w above 20 degrees increasing**

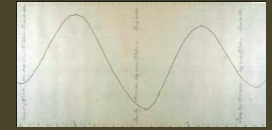
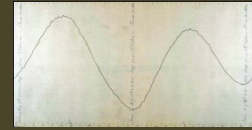
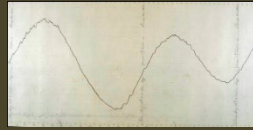
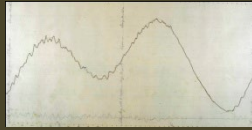
4. Statistical model on Willamette suggests roughly **70% climate effects**, 30% local effects, since 1900.

5. **Winter T_w has risen substantially.** Ecological implications?

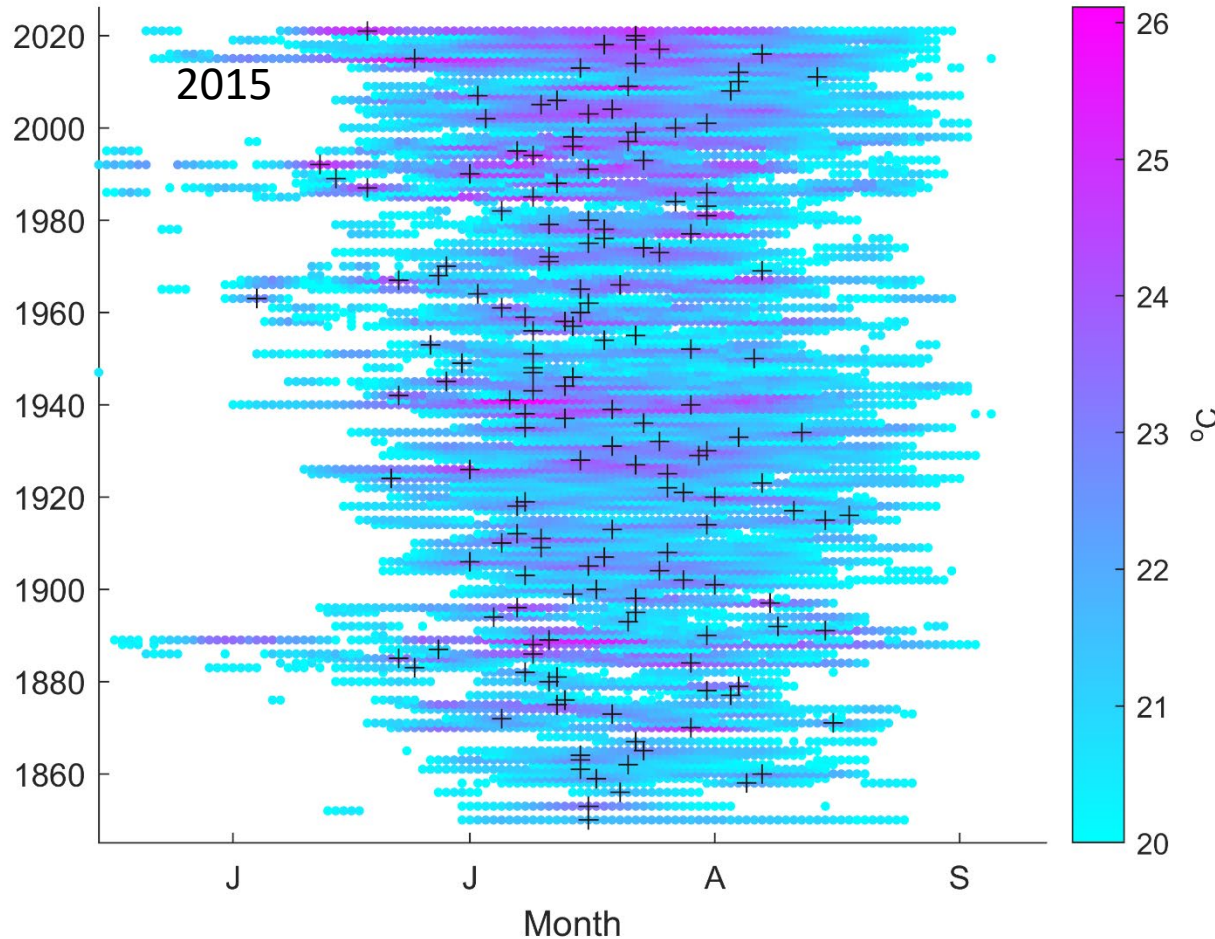


Questions?

- Talke, S. A., Jay, D. A., & Diefenderfer, H. L. (2023). Warming of the Willamette River, 1850–present: the effects of climate change and river system alterations. *Hydrology and Earth System Sciences*, 27(14), 2807-2826.
<https://doi.org/10.5194/hess-27-2807-2023>
- Scott, M. H., Talke, S. A., Jay, D. A., & Diefenderfer, H. L. (2023). Warming of the lower Columbia River, 1853 to 2018. *River Research and Applications*.
<https://doi.org/10.1002/rra.4177>



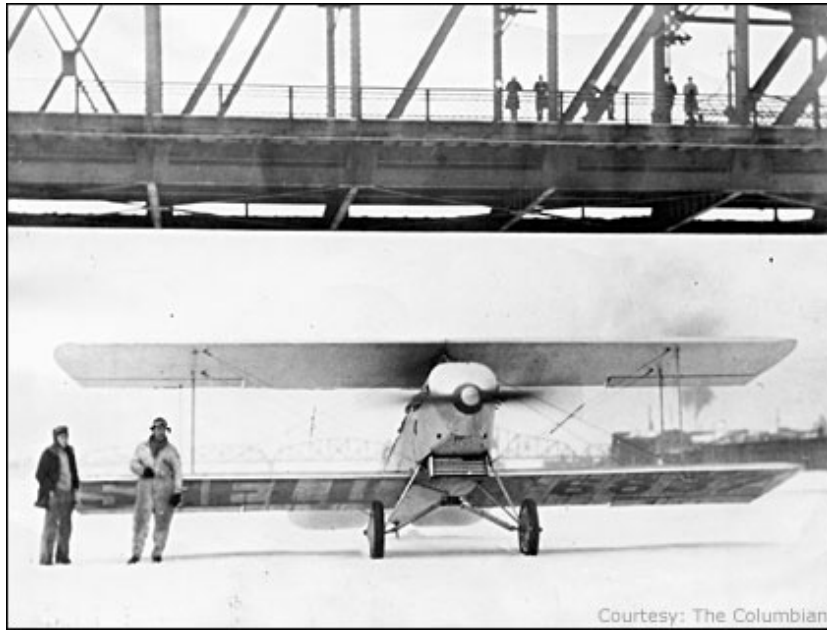
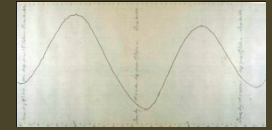
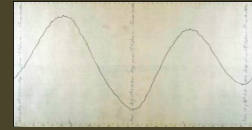
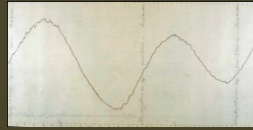
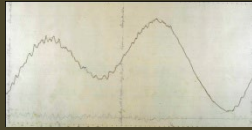
Number of days per year over 20 degrees (T_w)



A lot of variability year to year in the date T_w exceeds/dips below threshold

On average, about a 20 day increase in number of days over 20 degrees Celsius (40 per year to 60 per year).

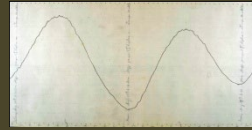
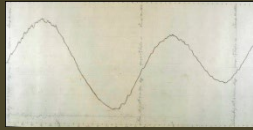
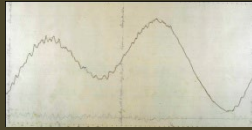
The “spread” of the 7d average above 20 degrees has changed, from about 11-80 days pre-1900 to about 35-92 today.



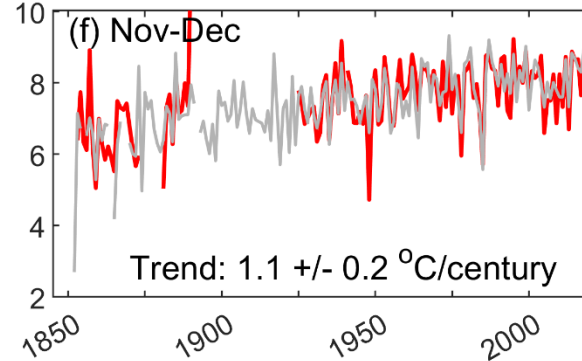
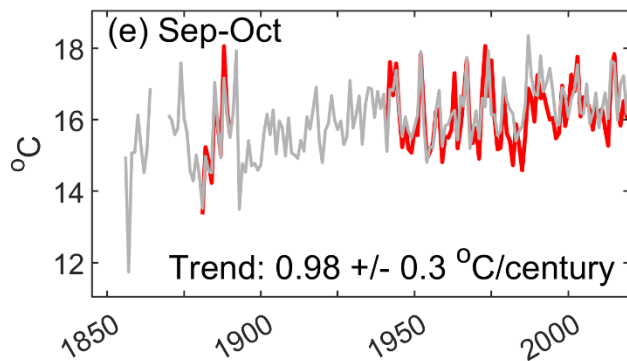
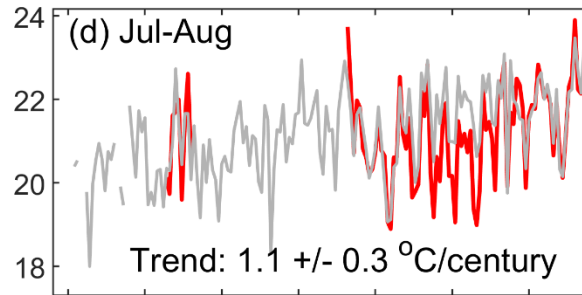
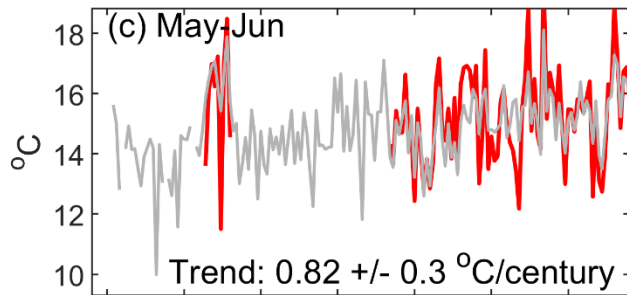
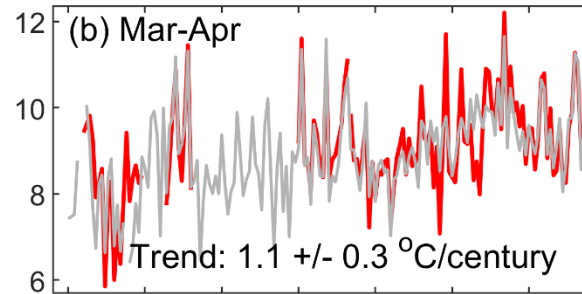
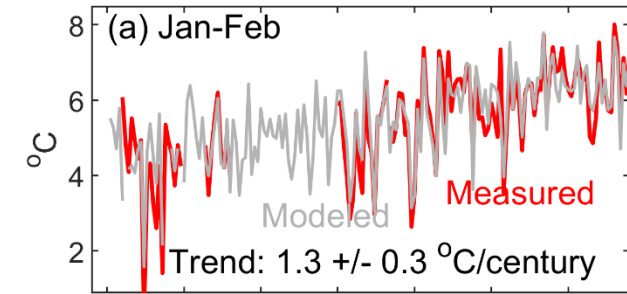
Big Picture

1. The Columbia and Willamette Rivers used to be much colder. Deep freezes that used to occur no longer do.
2. We recovered water temperature from as early as the 1850s (Astoria) and 1880s (Portland)
3. A statistical model based on river flow and daily air temperature was used to hind-cast water temperatures from 1850-present



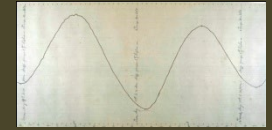
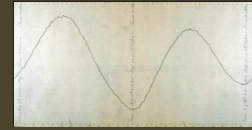
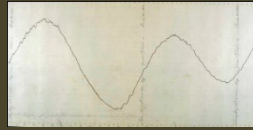
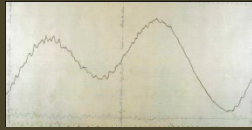


Seasonal Trends

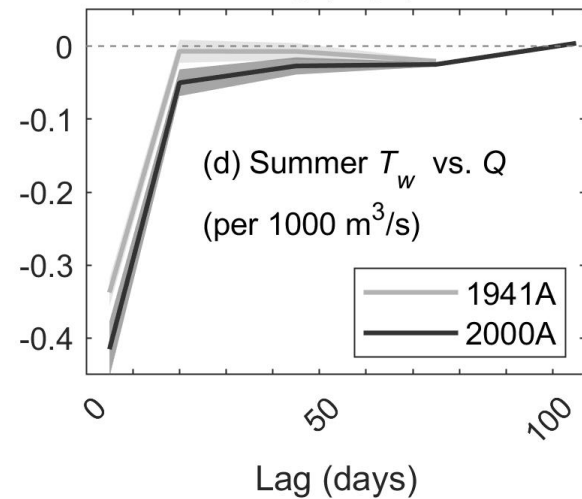
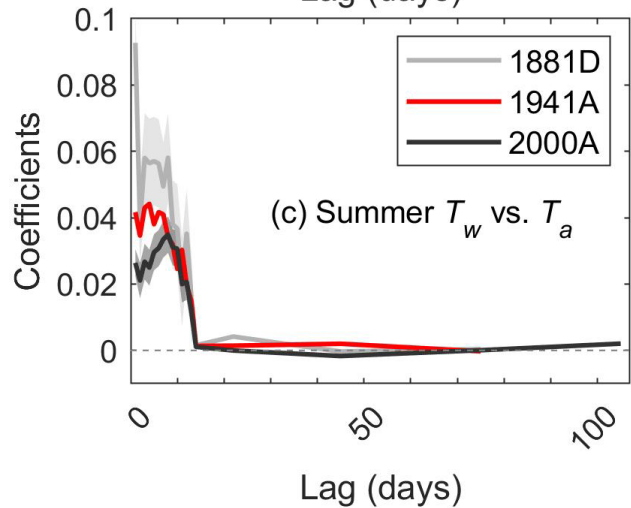
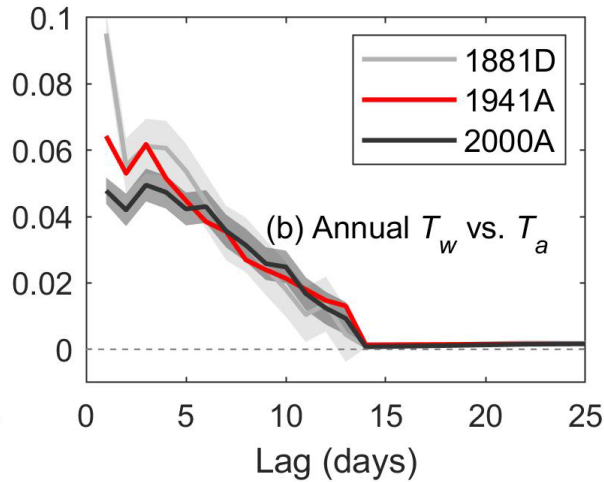
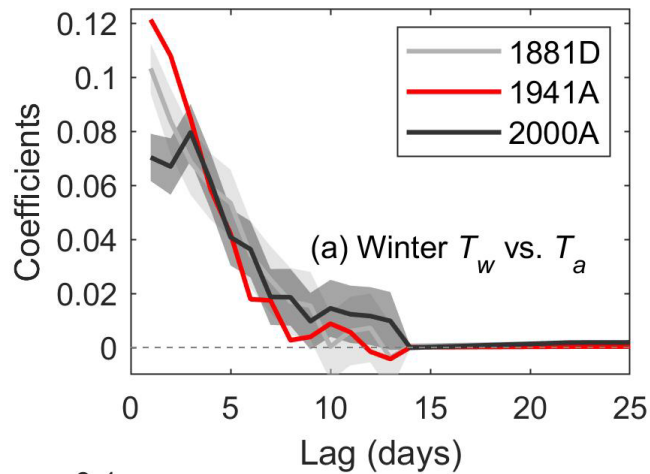


Red: Measurements
Grey: Model

Largest trend in Jan-Feb
Smallest May/June

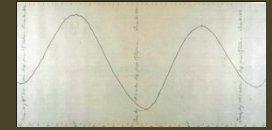
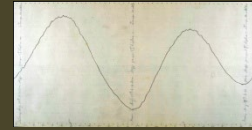
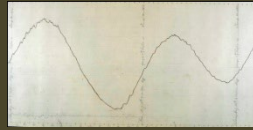
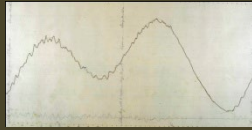


Willamette River Results: Lagged Coefficients



The lag structure for both river flow and air temperature has changed since 1880s and 1940s

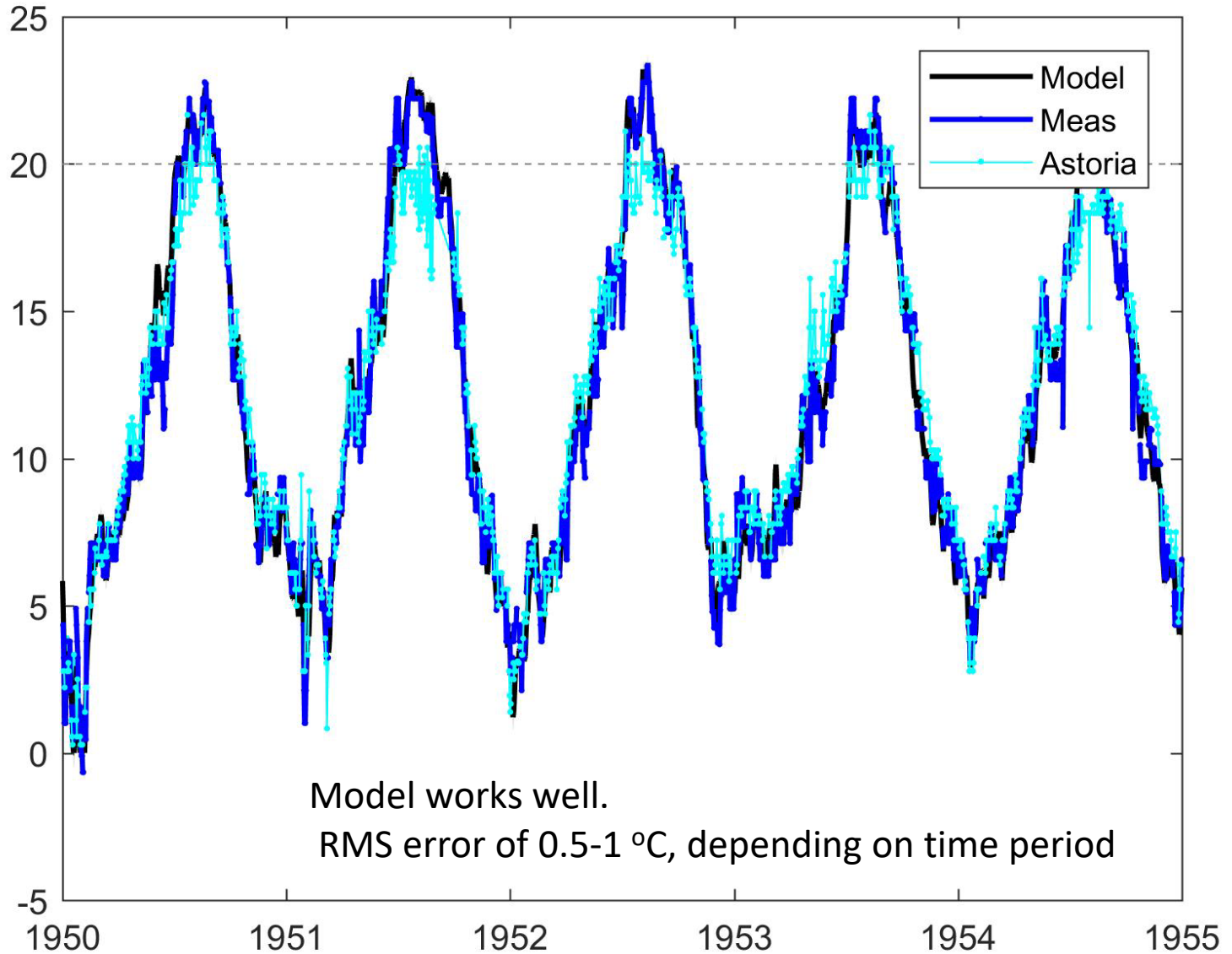
Statistically, flow important in summer but not winter

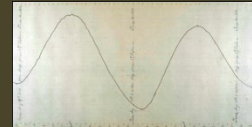
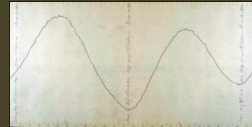
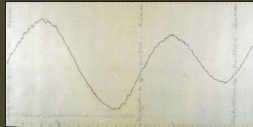
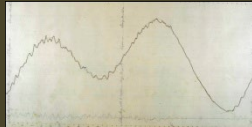
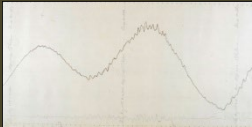


Willamette T_w Model/Measurement Comparisons

Astoria
matches
in winter

(summer
 T_w from
Columbia)

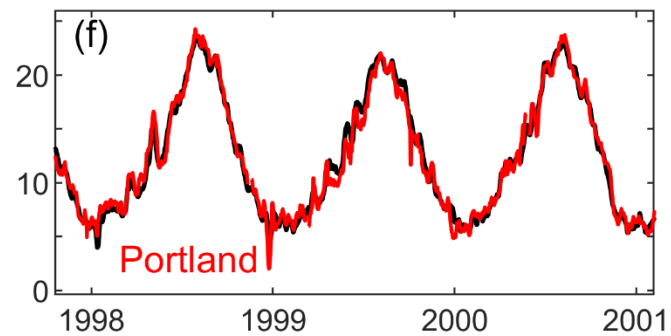
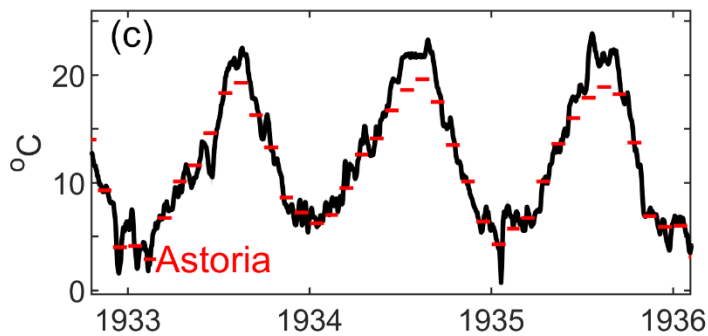
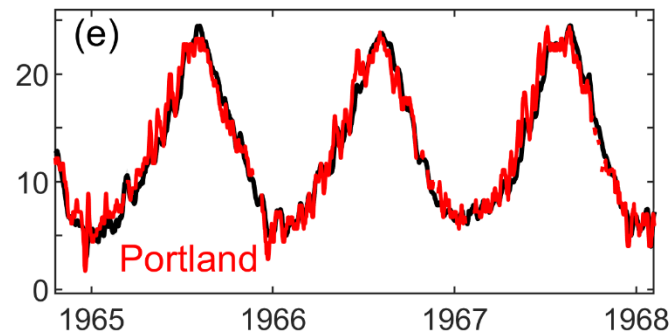
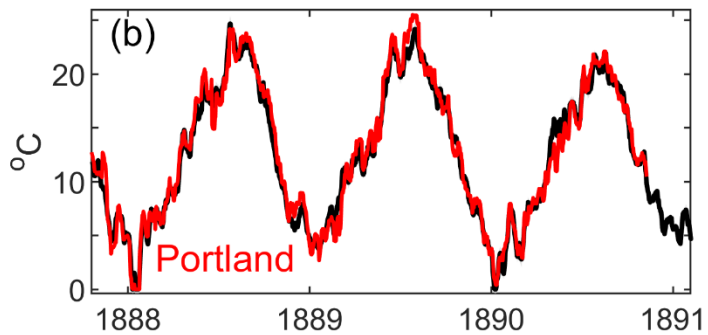
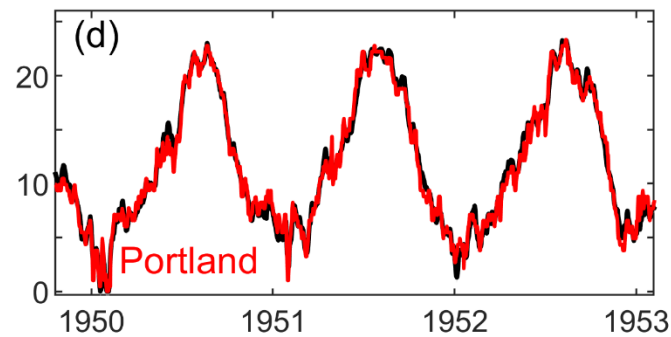
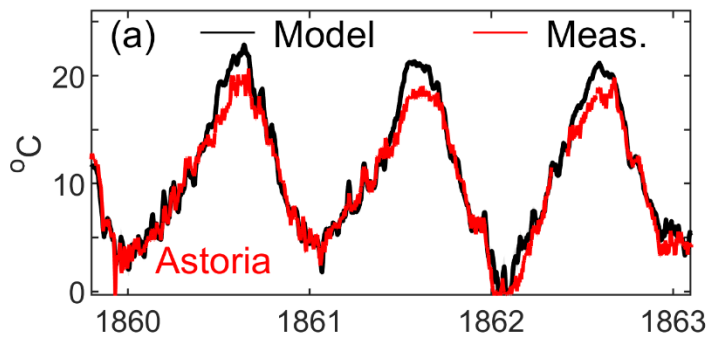


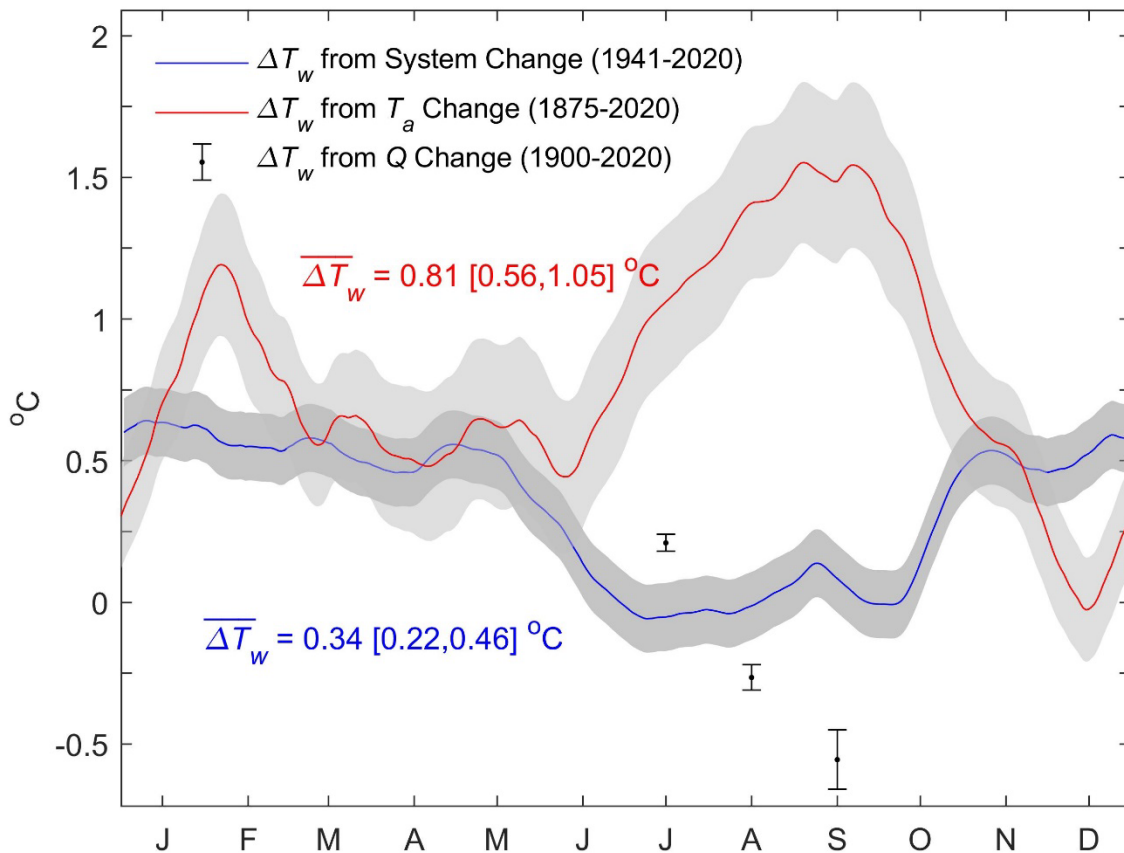
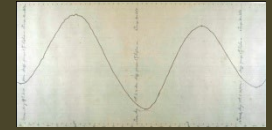
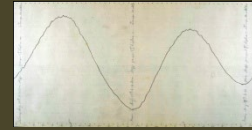
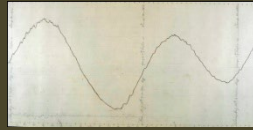
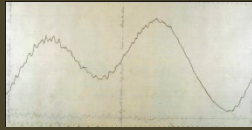
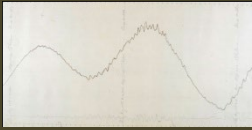


More Willamette T_w Model/Measurement Comparison: Time Series

Astoria
matches
in winter

(summer
 T_w from
Columbia)

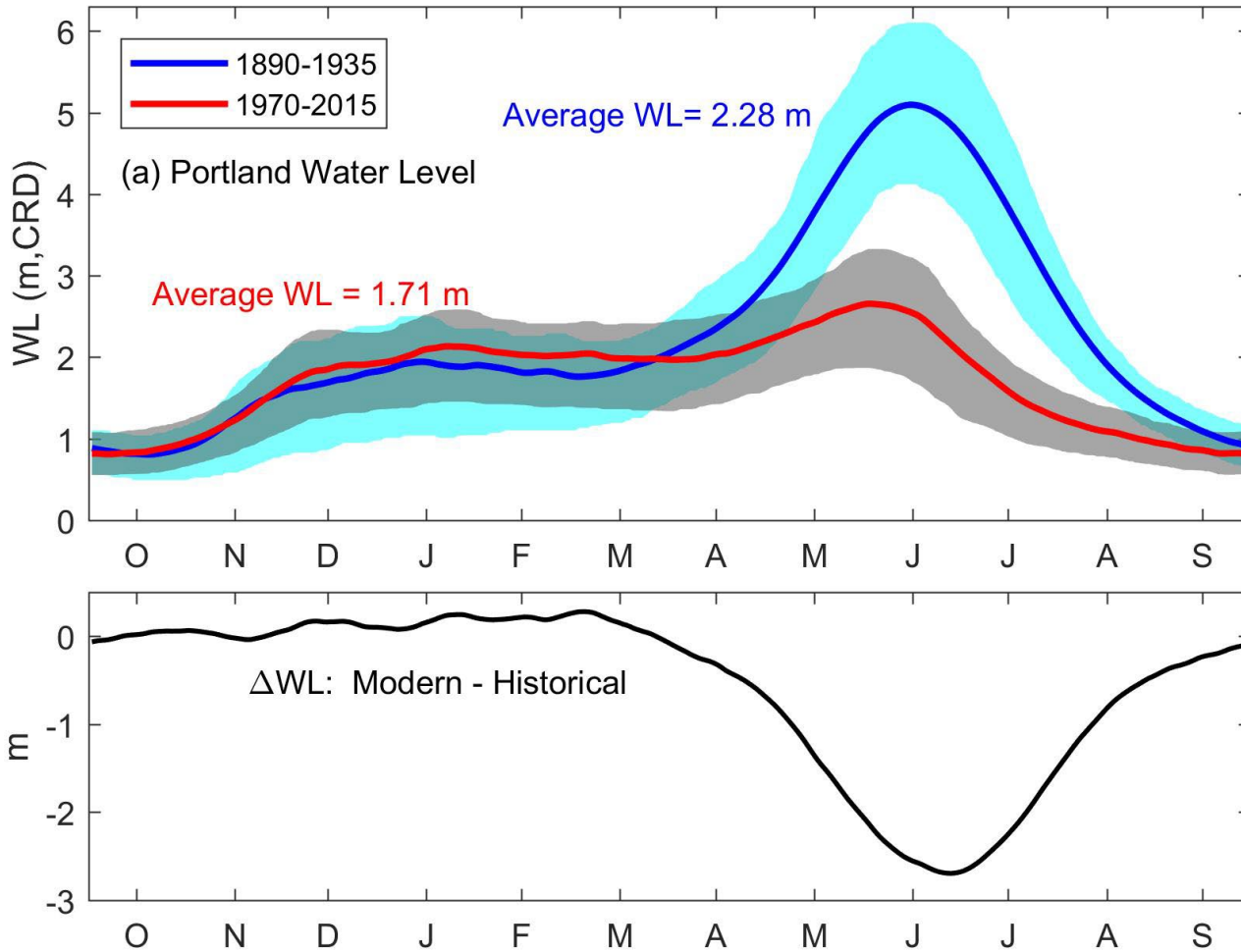
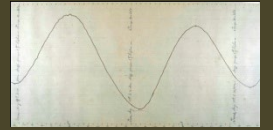
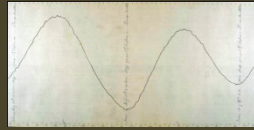
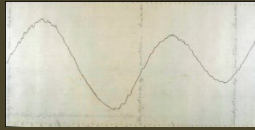
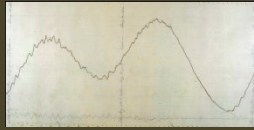
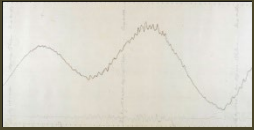




Attribution Analysis:

- Landscape changes, reservoir system, and other system changes caused a **roughly 0.5-0.6 °C increase in T_w from November to May** over last 100 years.
- Climate change and other factors increasing T_a are correlated with **1.5 °C increase in T_w from mid-August to mid-October**. Also significant **Winter increase**.
- T_w is reduced by flow releases in July-September.

Take home: About 30% local, 70% climate.
But... significant non-linear interactions likely.



Water level patterns:

Historical vs. Modern

(fill is 25-75%)

Note: In Dec-March, Water level is 20-30cm higher

During May-July, WL is 2-3m lower