

Focus Area: Lower Willamette and Columbia

Research Questions:

- How anomalous was 2015?
- What is the effect of climate change and river management?

Long (100 y+) records are needed.

Strategy:

1. Archival Research,
1850-present
2. Data Analysis
3. Statistical model



Archival T_w Research

January 1862.			
Date	High Water Time	Low Water Time	Remarks
	10 m Lat Dec	10 m Lat Dec	
1 st A.M	8 40 13 05		Put sheet in motion at 8 30 A.M.
	9 A.M	8 23 1 95	
2 nd A.M	2 15 11 28		
	A.M	7 41 5 58 Staff 1'g higher	Temp. 7 - 33°
	9 A.M	1 28 12 65	
	9 A.M	9 5 2 55	
3 rd A.M	3 4 11 15		
	A.M	8 37 5 30	
	9 A.M	2 21 11 90	
	9 A.M	9 36 2 65	

Astoria: 1853-1876

NOAA & US
National Archives

Most of these old records have been forgotten.

A few years ago, while researching historic tides, I found many 19th century water temperature records

These daily data have never been analyzed.

However, invaluable for teasing apart climate and local human effects.



Lower Willamette Records

STATION:		Portland, Oregon		Month: July		1882	
DATE	TIME	RIVER OBSERVATIONS		TEMPERATURE OF WATER RIVERS, LAKES, AND STREAMS		WIND	CLOUDS
		STAGE	CHARGE	1 P.M.	4 P.M.	8 P.M.	12 M.
July 1	A.M.	1.2	0.7	64°	64°	64°	64°
2	A.M.	1.2	0.8	64°	64°	64°	64°
3	A.M.	1.2	0.9	64°	64°	64°	64°
4	A.M.	1.2	1.0	64°	64°	64°	64°
5	A.M.	1.2	1.1	64°	64°	64°	64°
6	A.M.	1.2	1.2	64°	64°	64°	64°
7	A.M.	1.2	1.3	64°	64°	64°	64°
8	A.M.	1.2	1.4	64°	64°	64°	64°
9	A.M.	1.2	1.5	64°	64°	64°	64°
10	A.M.	1.2	1.6	64°	64°	64°	64°
11	A.M.	1.2	1.7	64°	64°	64°	64°
12	A.M.	1.2	1.8	64°	64°	64°	64°

Portland, 1882

US Signal Service Records, 1881-1890

PORTLAND OR U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU							
Report of River Rainfall Station at Portland, Oregon, on the Willamette River Drainage Area for the month of July, 1942							
Time of observation 7:30 A.M. Flood stage 15. Warning stage 15							
REMARKS, SPECIAL OBSERVATIONS, ETC. STAGES, ETC. River Temperature							
RIVER		PRECIPITATION					
DATE	STAGE	CHARGE	TIME OF BROOKING	TIME OF ENDING	AMOUNT	SNOW ON GROUND IN INCHES	STATE OF WEATHER
1	2	3	4	5	6	7	8
1	12.1	-0.7					
2	11.3	-0.8					
3	11.0	-0.3					
4	10.8	-0.2					
5	10.5	-0.3					
6	10.7	+0.2					
7	10.5	-0.2					
8	10.3	-0.2					
9	10.2	-0.1					
10	10.2	0.0			0.37		
11	10.0	-0.2			0.02		
12	10.0	0.0					
13	10.3	+0.3					
14	10.2	-0.1			0.75		
15	10.1	-0.1			0.22		
16	10.1	0.0			0.10		
17	9.8	-0.3					
18	9.5	-0.3					
19	8.9	-0.6					
20	8.7	-0.2					
21	8.8	+0.1					
22	8.9	+0.1					
23	8.8	-0.1					
24	8.6	-0.2					
25	8.8	+0.2					
26	8.7	-0.1					
27	8.8	+0.1					
28	8.8	0.0					
29	8.4	-0.4					
30	7.7	-0.7					
31	7.3	-0.4					
32	7.3	-0.4					
33	7.8	/			0.96	0.0	
34	7.6	/					
35	7.6	/					
5 days until .01 in more							
Elevation of zero 11.3 ft. N.P.S. 11.9 ft.							
CONDITION OF RIVER AT GAGE							

Weather Bureau Records, 1941-1961

→ Big concatenation effort



RIVER READINGS
Stage of Water in the Willamette River Each
Day During the Year 1890.

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	23	17	10	-57	116	183	181	78	48	29	26	32
2	23	182	14	50	124	178	130	78	46	34	25	32
3	17	207	22	58	134	172	129	78	46	31	22	29
4	17	267	22	58	139	168	127	74	42	24	14	26
5	17	267	46	61	149	167	126	74	39	20	27	14
6	15	291	62	69	162	161	126	67	39	12	24	13
7	Frozen	279	16	77	172	187	176	56	25	11	22	-0.5
8	"	253	90	79	177	184	183	57	26	10	24	-15
9	22	217	97	83	182	180	171	54	26	11	29	-11
10	27	174	94	83	190	148	124	53	30	11	12	-07
11	25	131	87	79	183	128	119	52	32	10	13	-03
12	25	104	51	79	189	146	117	52	31	15	13	24
13	32	86	73	71	202	148	115	53	31	28	15	24
14	25	75	74	67	204	145	113	54	23	22	17	31
15	32	69	67	65	206	143	111	55	24	22	21	32
16	29	69	52	59	207	145	108	55	32	27	22	38
17	28	74	52	64	207	142	107	55	32	26	31	39
18	27	67	64	67	207	143	104	55	32	31	26	37
19	27	67	73	67	207	145	102	52	31	25	16	52
20	25	57	81	72	205	149	102	52	32	28	28	22
21	25	53	81	75	208	141	96	50	23	19	24	21
22	27	51	78	75	207	137	92	52	21	15	23	24
23	35	49	79	75	207	137	94	46	16	10	28	22
24	42	52	81	76	202	137	86	43	14	11	28	26
25	51	40	81	77	199	136	82	39	18	15	12	24
26	51	30	82	83	197	133	85	40	21	19	17	31
27	63	30	71	87	195	132	78	43	23	21	17	30
28	59	20	71	91	185	131	71	45	24	22	20	30
29	70	67	99	102	181	77	48	31	26	24	24	30
30	94	63	108	101	181	77	49	32	25	23	25	35
31	107	57	105	105	78	49	26					

River Stage measurements

Form No. 1006.—Met'l.

PORTLAND OR

DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

6-1894

MONTHLY METEOROLOGICAL RECORD OF RIVER STATIONS

Taken at Portland Oregon, during June, 1894, at 2^o P.M.,
75th meridian time, or 11:24 A.M., local time, on the Willamette River.

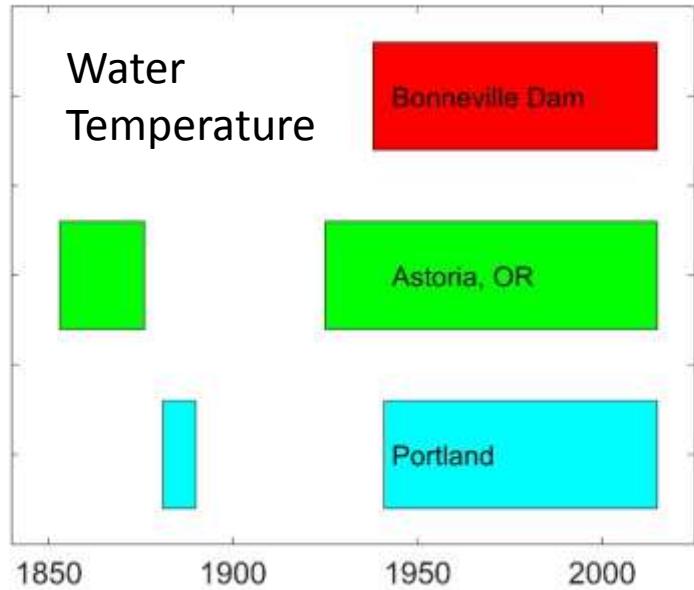
DATE	Reading of River-Gauge,		RIVER,		PRECIPITATION.		DEPTH OF SNOWFALL. Inches and tenths.	WIND, Direction, Velocity of Wind, 8 Am	CHARACTER OF WEATHER AT TIME OF OBSERVATION.	REMARKS.
	SURFACE OF WATER.		CHANGE IN 24 HOURS.		BEGAN.	ENDED.				
	Above.	Below.	ZERO OF GAUGE.	RISE.	FALL.					
	Foot and Tenths.	Foot and Tenths.	Foot and Tenths.							
1	29.6		0.6					N 2	Clear	Previous high water 28.2 July 24 1876.
2	30.1		0.5				.25	NW 4	Clear	
3	30.8		0.7				.85	SE 8	Snow	
4	31.7		0.9				.23	NW 6	Cloudy	
5	32.3		0.6					NW 3	Cloudy	
6	32.8		0.5					NW 4	Cloudy	28.7 May 5 1890, from willamette Gazette.
7	33.0		0.2				.08	NW 4	Snow	
8	32.7		0.3				.02	S 24	Cloudy	
9	32.4		0.3				.28	SW 19	Cloudy	The River was
10	32.2		0.2				.29	S 4	Cloudy	exceptionally all day of the 7 th
11	31.9		0.3				.15	SW 12	Snow	
12	31.4		0.5				.02	NW 4	Cloudy	
13	30.7		0.7					NW 4	Cloudy	
14	30.1		0.6					NW 6	Cloudy	
15	29.5		0.8					NW 8	Clear	
16	28.6		0.7				.7	S 7	Clear	
17	27.9		0.7				.10	NW 6	Cloudy	
18	27.4		0.5				.01	SW 8	Cloudy	
19	27.0		0.4					N 8	Cloudy	
20	26.7		0.3					NW 1	Cloudy	

Above: From <https://www.ncdc.noaa.gov/EdadsV2/>

Left: City of Portland Archives



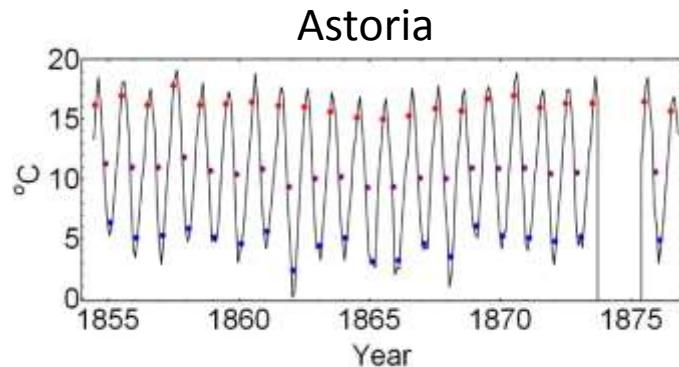
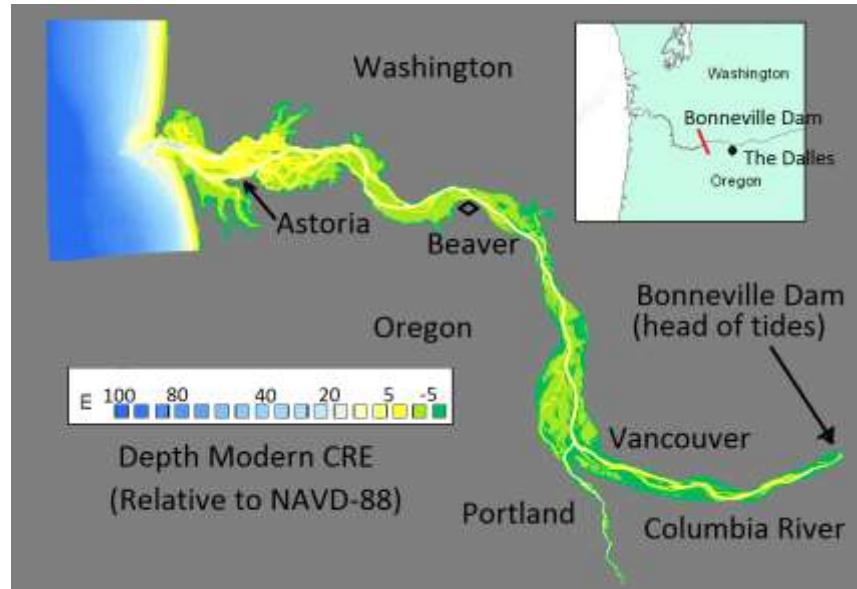
Data Recovery Synopsis



Talke/Jay digitized: >50 station years

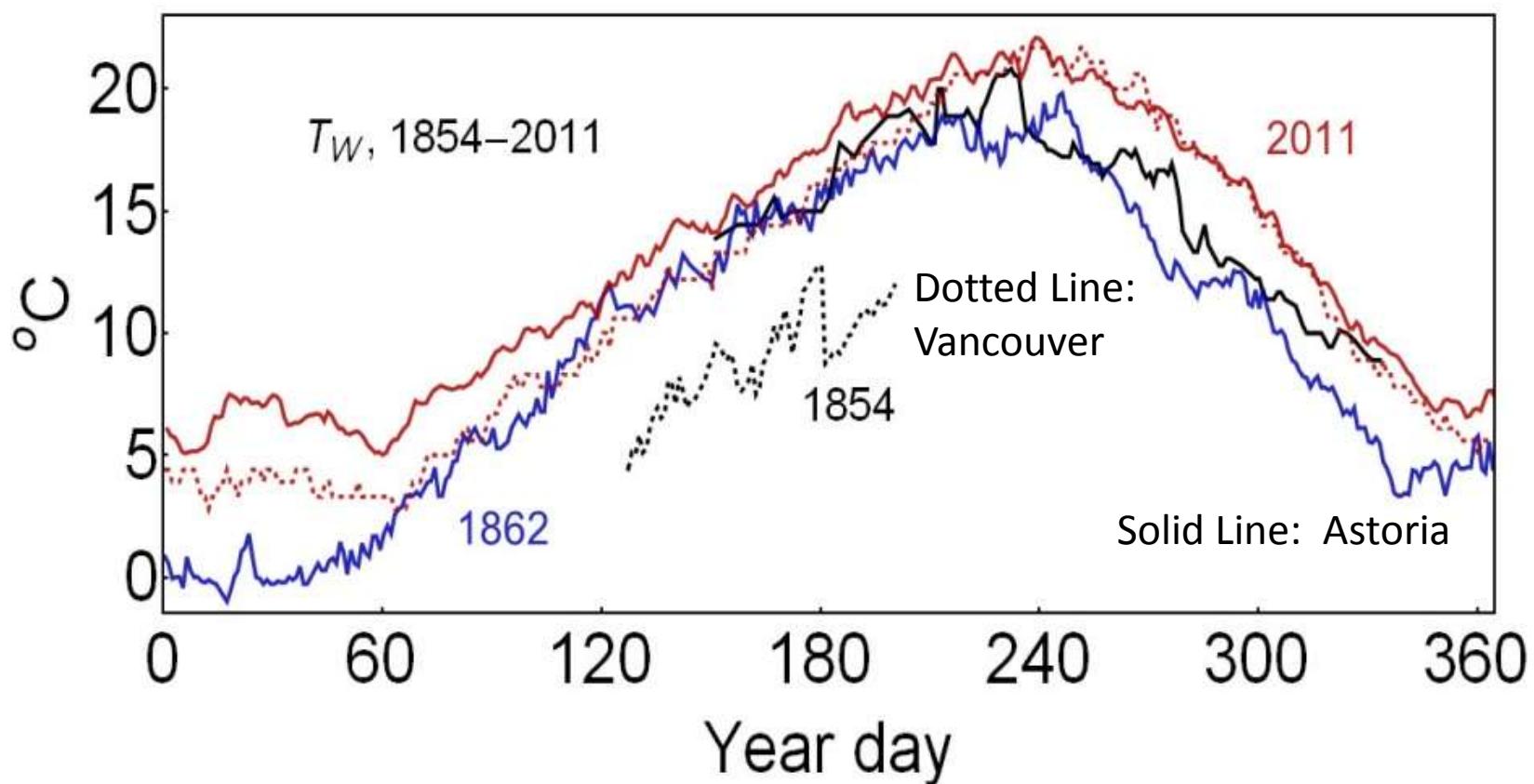
Notes:

1. Only morning temperatures analyzed.
2. Seasonal bias correction to convert morning to daily minimum Tw (0.1-0.2 degrees Celsius)
3. USGS records pre-1981 and EPA records pre-2000 required more substantial bias corrections



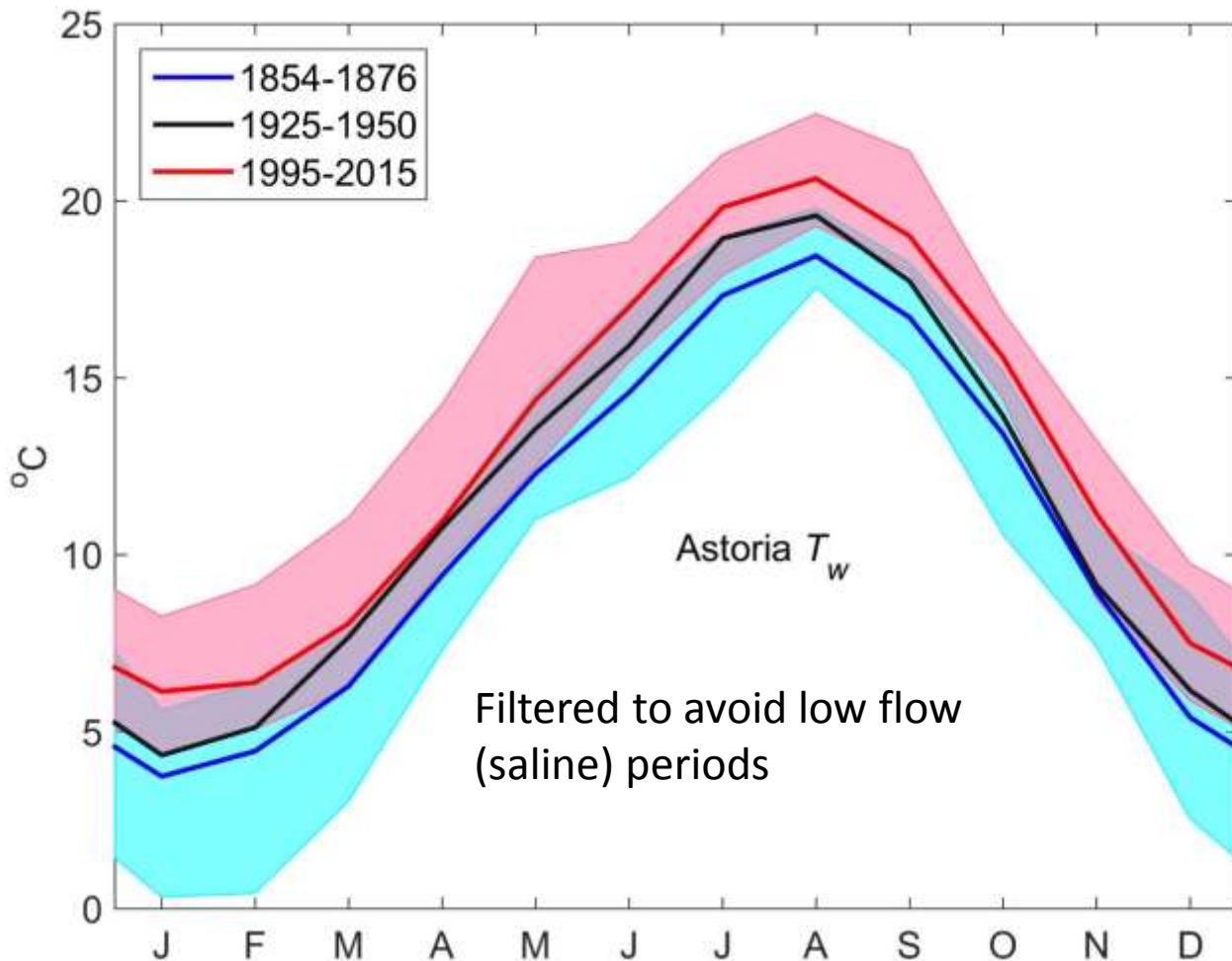


Water Temperature—Columbia Mainstem





Water Temperature Astoria: Climatology



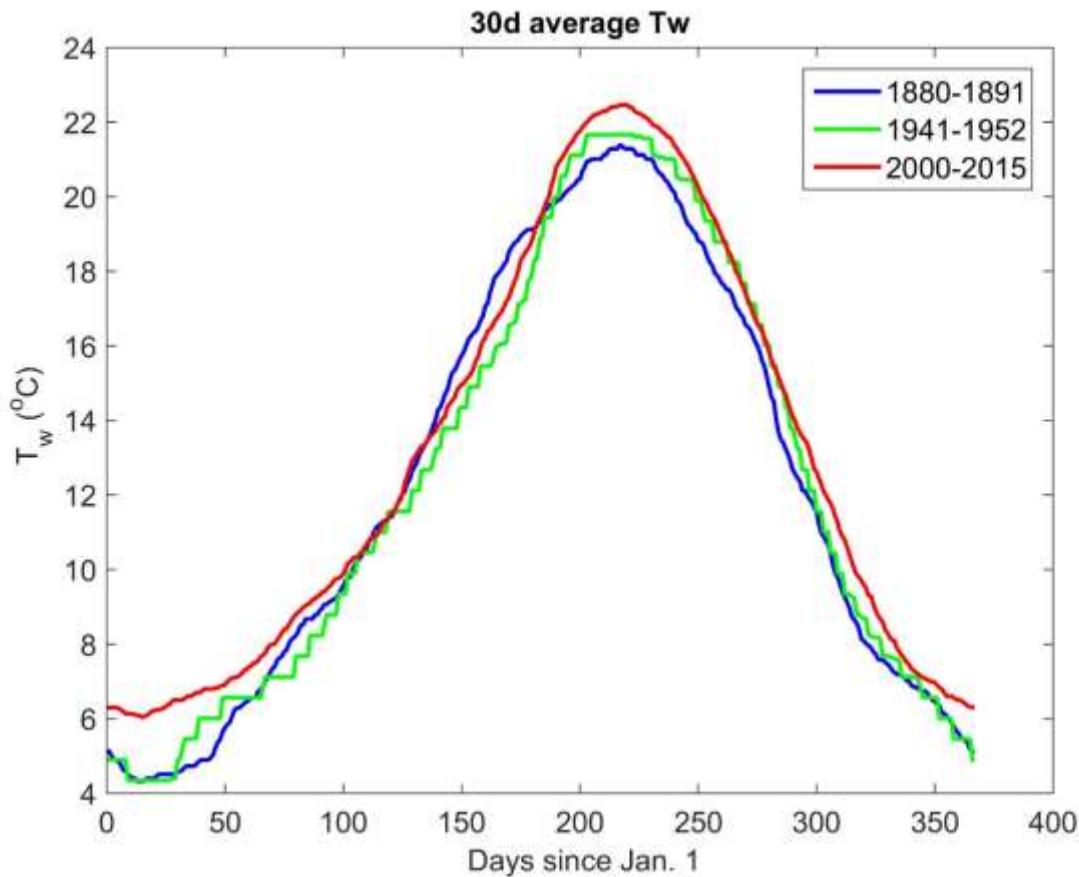
Columbia River Water
Temperature $\sim 2\text{ }^{\circ}\text{C}$ larger
now than in past, on
average

Density measurements
1925-1980 show that
salinity intrusion was
much less historically
than today.

→ Historical Astoria
measurement was a river
measurement



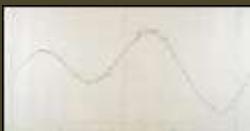
Lower Willamette River (Portland) Climatology



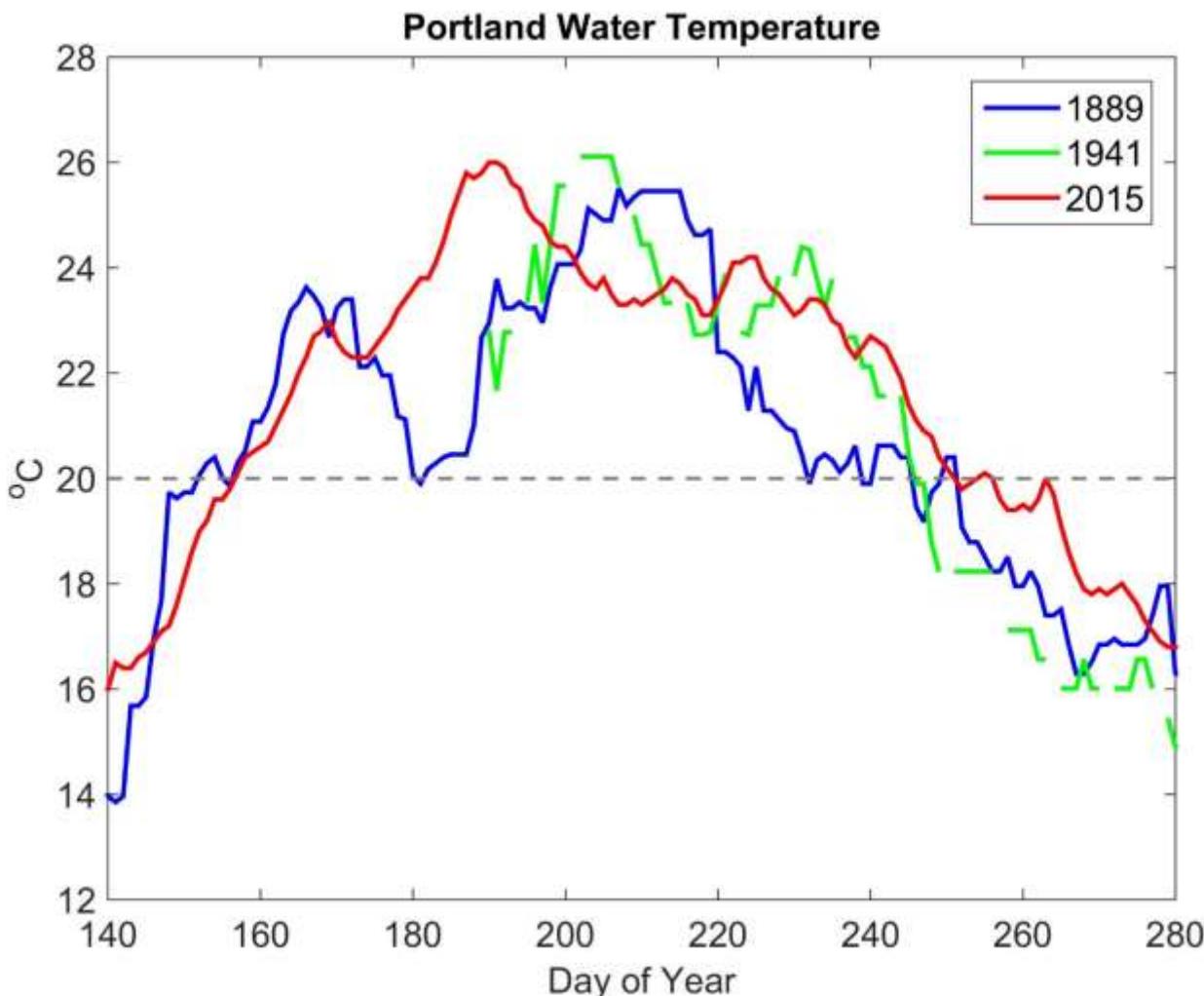
Little Change in climatology between 1880 and 1952

Modern measurements are **1-2 degrees higher** than historically, *except spring*

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

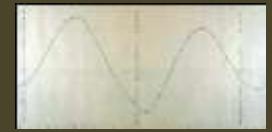


However....

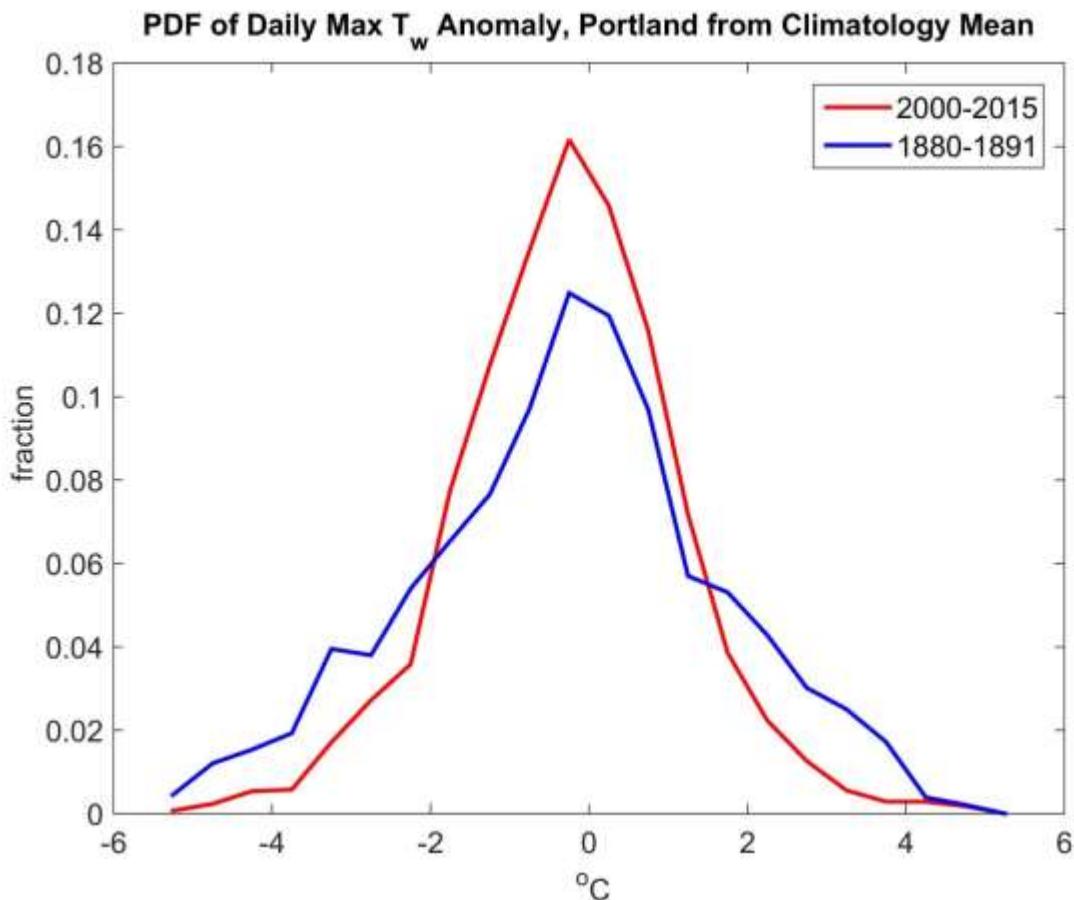


Peak T_w in 1941 and 1889 was nearly the same as 2015!!!

For the Willamette, at least, there have always been some years with high summertime temperatures.



Distribution of T_w anomalies, Portland



Why are the extremes no bigger today?

→ Reservoir management has reduced the deviation from the mean.

→ Much more common to have a +/- 4 degree excursion from normal in the past than today



Interpretation: Over a day, Temperature changes because of

$$\frac{\partial T_w}{\partial t} = -u \frac{\partial T_w}{\partial x} + \frac{\partial}{\partial x} \left(K \frac{\partial T_w}{\partial x} \right) + \frac{H}{\rho c_p d}$$

1D Advection/Diffusion
(see e.g., Wagner et al. 2011)

Time rate of change

Advection from upstream

Dispersion

Input/Export of heat H
(inverse to depth d)

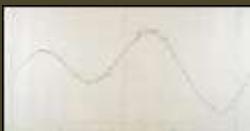


It can be shown (by rubbing your eyes and adding fairy dust):

1. $\frac{\partial T_w}{\partial x}$ and dispersion are usually small

2. $\frac{H}{\rho c_p d} \approx a_1 T_a + b_1 T_w - c_1 Q + \text{small nonlinear terms}$

3. $u \frac{\partial T_w}{\partial x} \approx cQ$ (a,b,c are constants)



Pulling it all together:

$$\text{On day } n: \rightarrow T_w(n) = aT_a(n) + bT_w(n - 1) + cQ_{River}(n)$$



Temperature today



Daily Heat added



Temperature yesterday

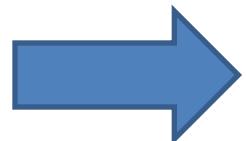


Upstream Input

$$T_w(n - 1) = aT_a(n - 1) + bT_w(n - 2) + cQ_{River}(n - 1)$$

But Also:

$$T_w(n - 2) = aT_a(n - 2) + bT_w(n - 3) + cQ_{River}(n - 2) \text{ etc}$$

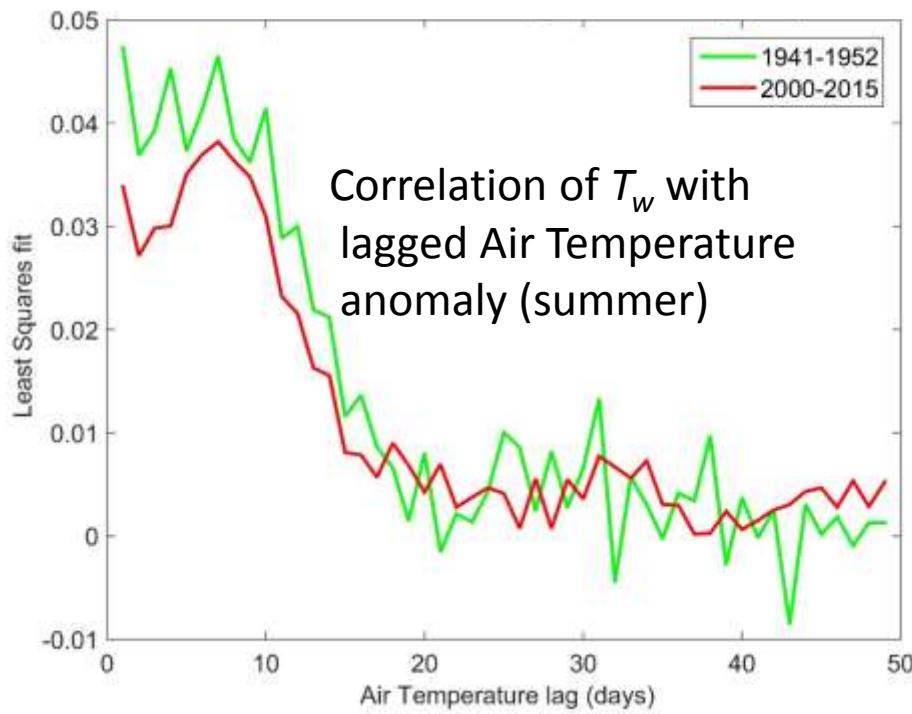


$$T_w(t) = a_0 T_a(t) + a_1 T_a(t - 1) + a_2 T_a(t - 2) + \dots + a_n T_a(t - n) + b_0 Q(t) + b_1 Q(t - 1) + b_2 Q(t - 2) + \dots + b_n Q(t - n)$$

Lagged correlation model



Preliminary Statistical Model results

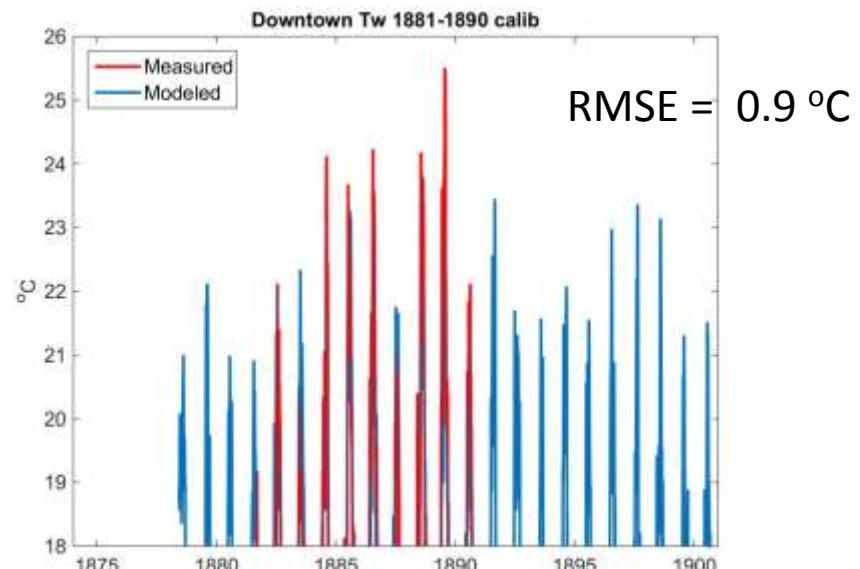


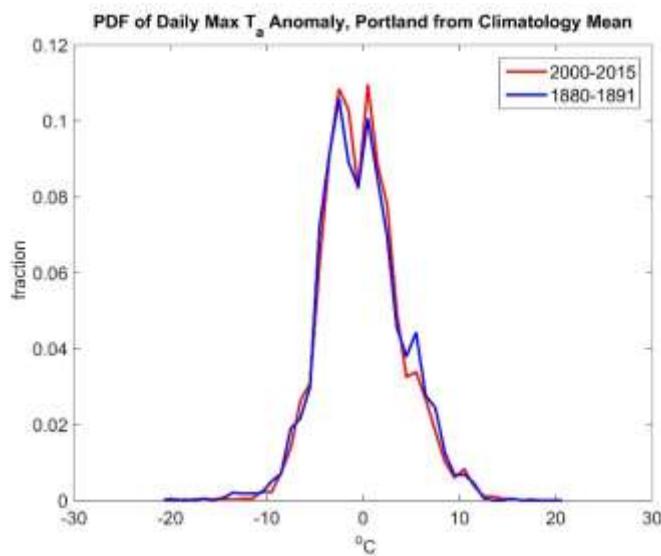
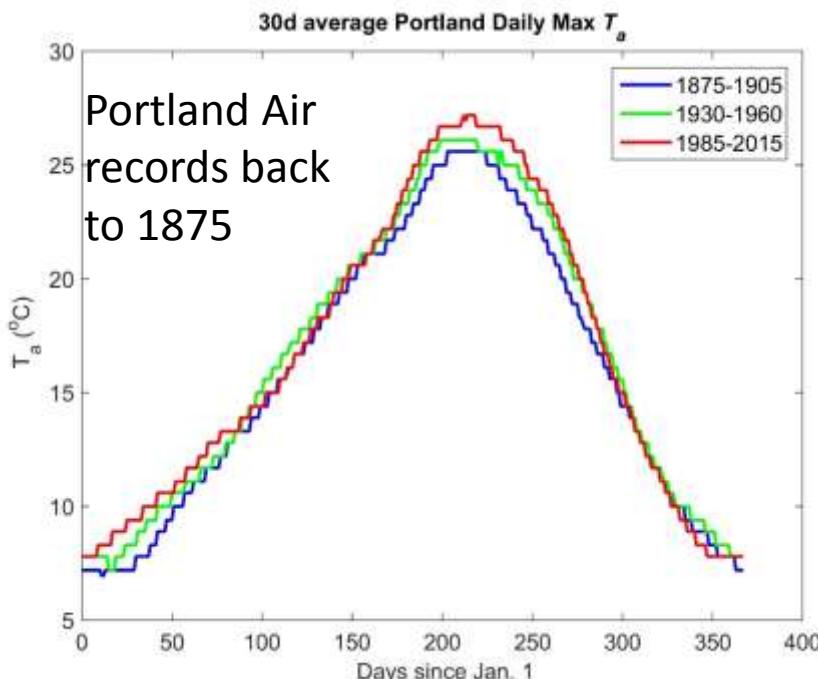
Evidence of system management;
Natural system: 1 degree air anomaly

- ~ 0.5 degree Tw anomaly
- Managed system: 0.4 degrees

Little correlation measurable after several weeks
(Weather System effect short lived)

Modern system fluctuates less than in past (Air temperature Anomalies less correlated to Tw)





Effects of Climate Change

Air ~1-2 degrees warmer in summer

Consistent with about 0.5-1 $^{\circ}\text{C}$ increased water temperature

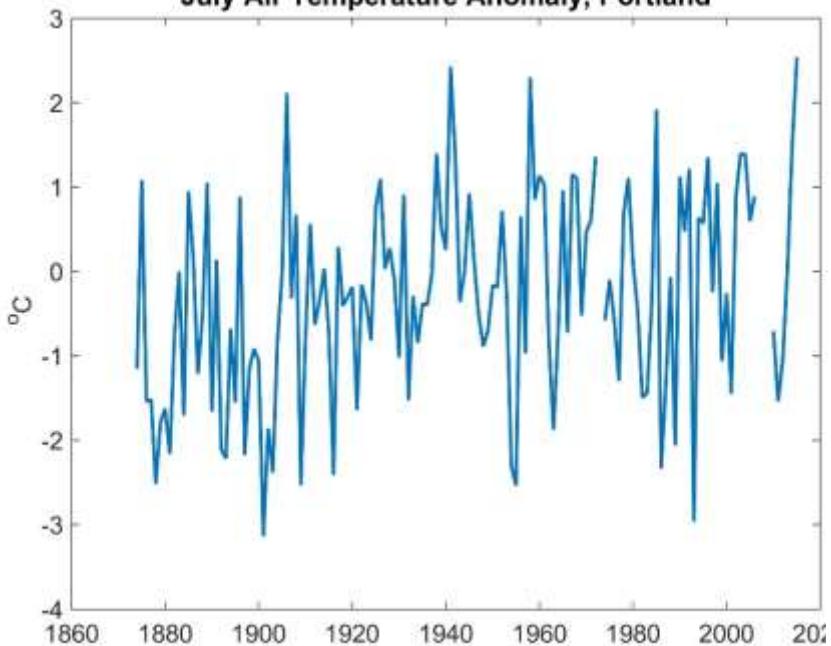
Distribution of anomalies not much different.

However...

1. Not clear how representative Portland is of the entire basin
2. No heat Island correction applied.



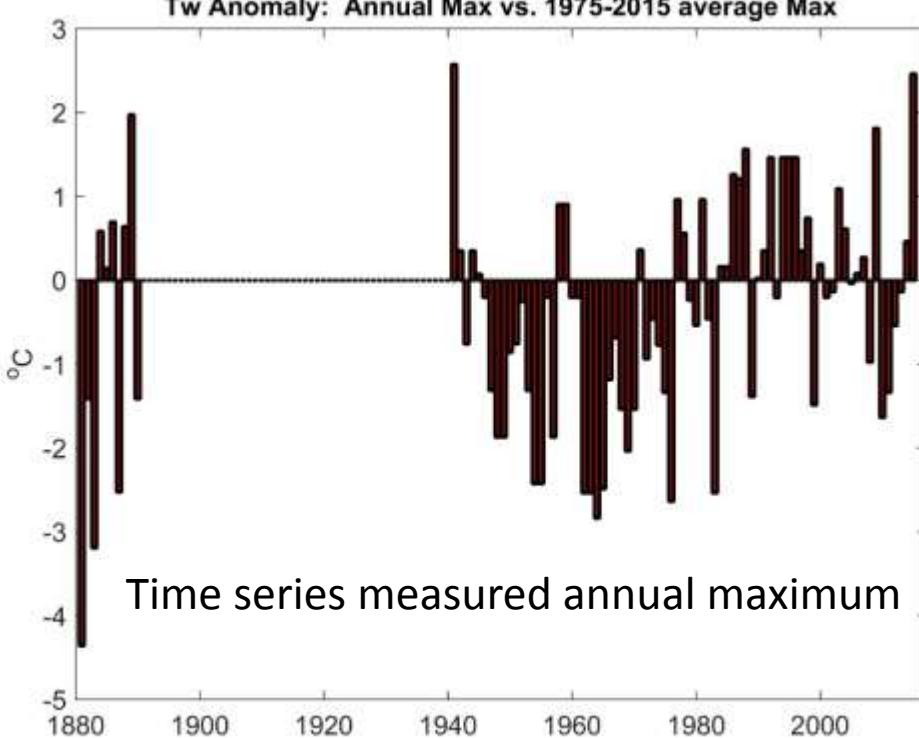
July Air Temperature Anomaly, Portland



Willamette T_w :

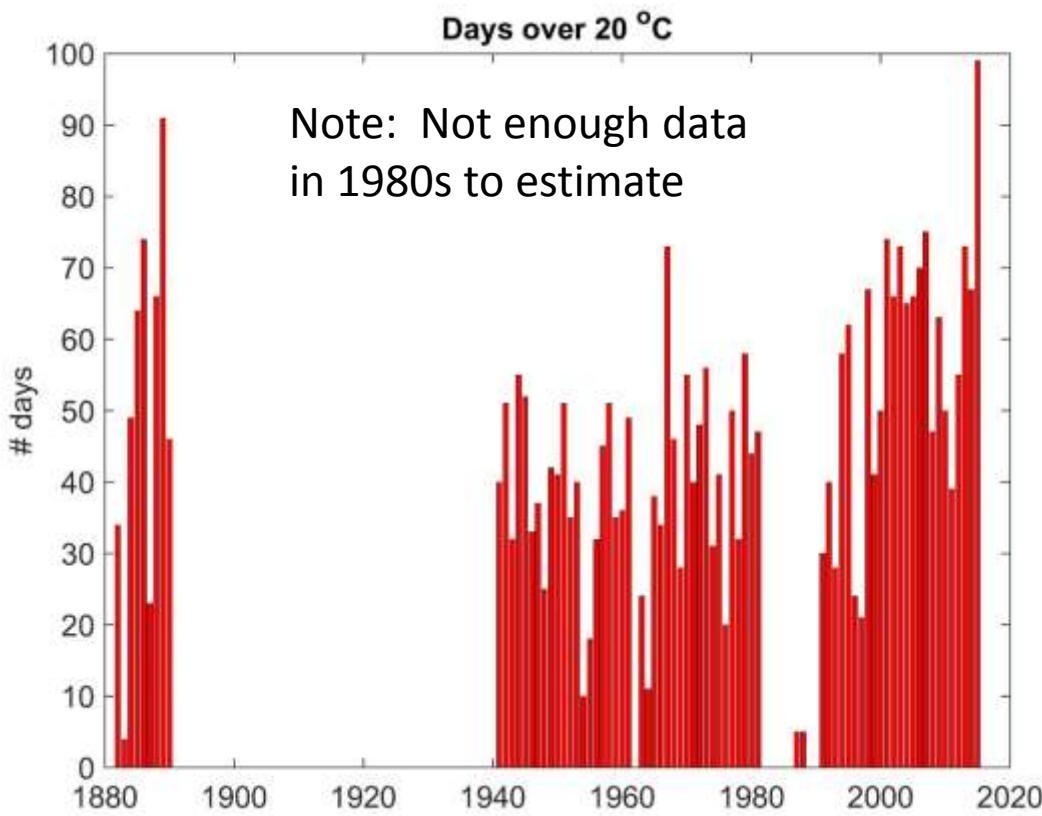
Linear function of Air Temperature and
(weakly) River Flow

T_w Anomaly: Annual Max vs. 1975-2015 average Max

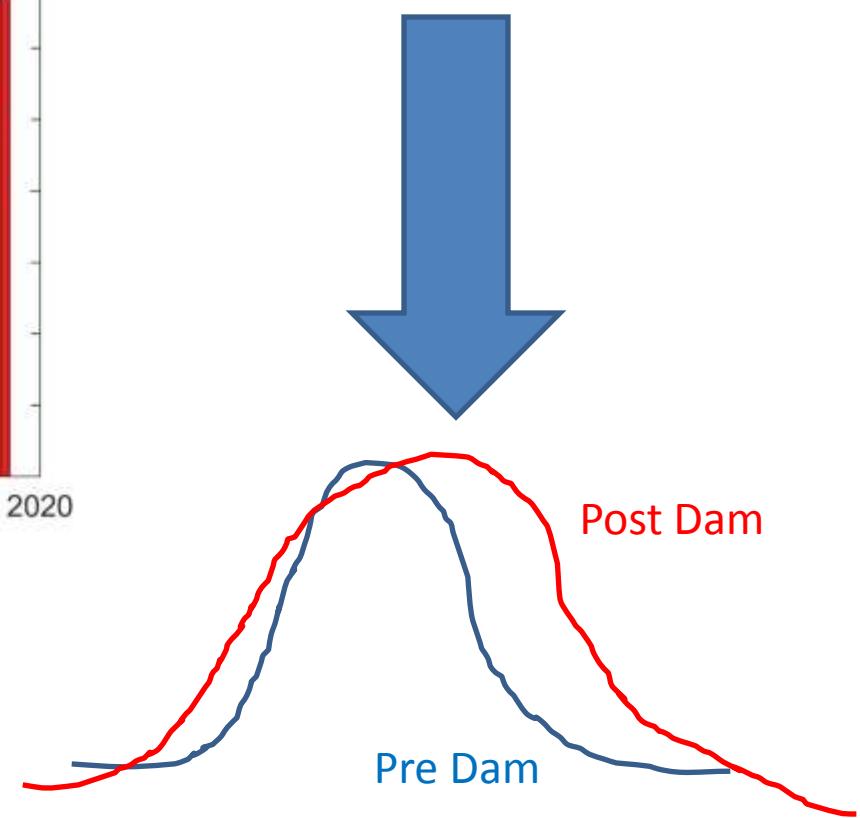


A lot of inter-annual variability
in monthly air temperature anomaly and m
water temperature

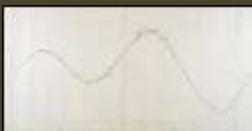
Only a few years match 2015



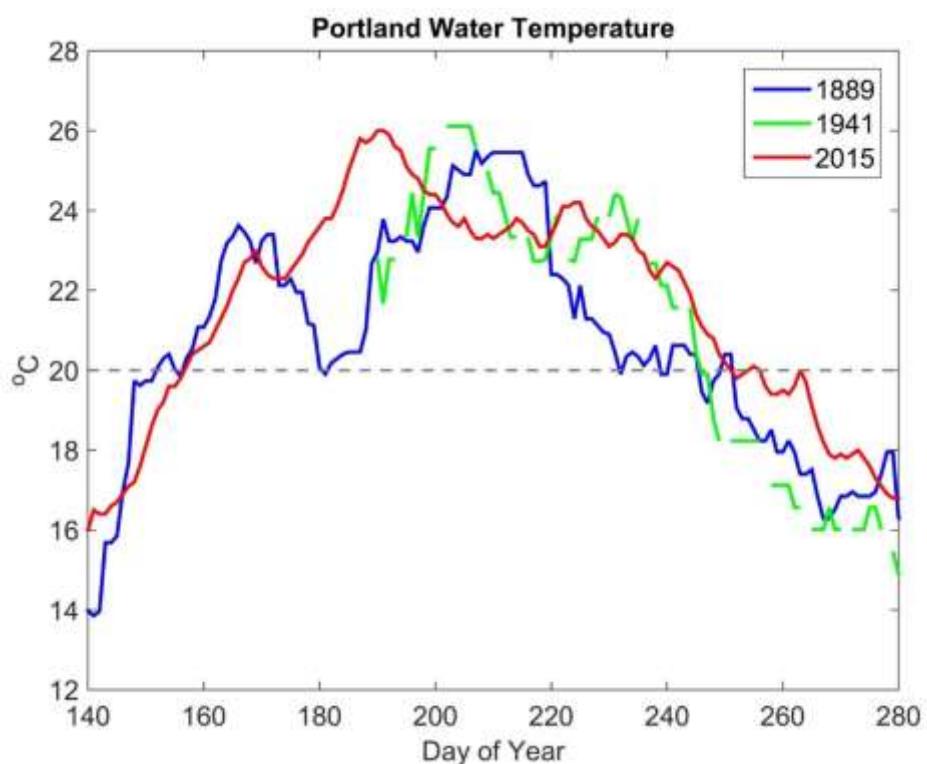
2015 did set the record number of days above 20 degrees



Hypothesis: System more diffusive, less variable, due to selective water releases, especially after ~1990



Take home messages today



1. Large amounts of **data** since ~1850 still **exist** in archives
2. Mean Tw increasing on Willamette, but variability decreasing
3. “Temporal” Refuges decreasing—number of days above 20 degrees increasing
4. Columbia River is 2 degrees warmer than 19th century; Reduced flow larger factor

