

Focus Area: Lower Willamette and Columbia

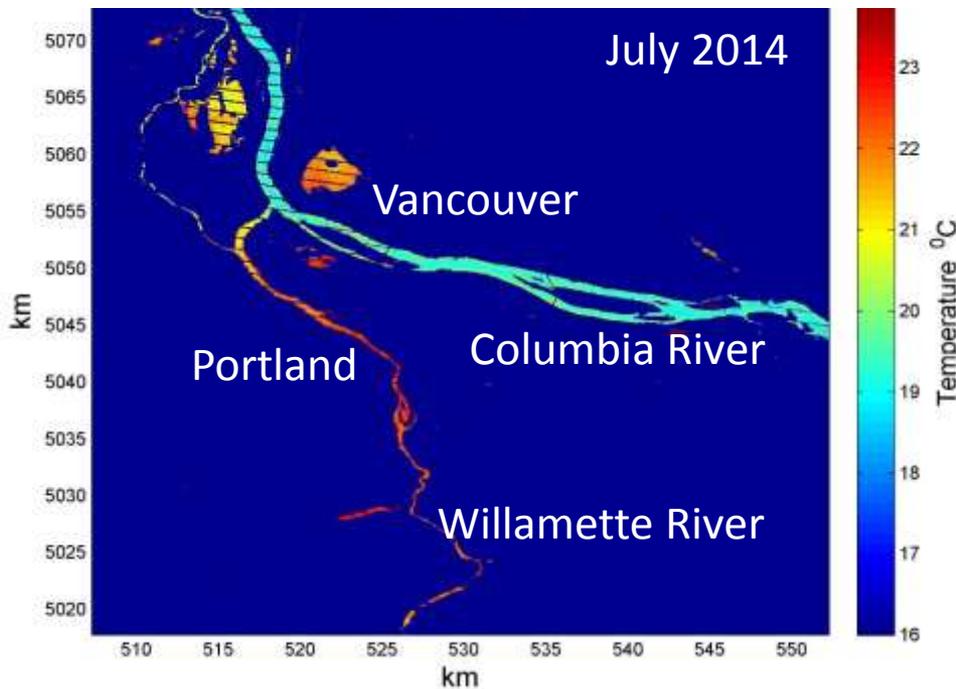
Research Questions:

- 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

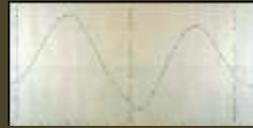
Date	High Water		Low Water		Remarks
	Time	Height	Time	Height	
	76 m	ut Dec	76 m	ut Dec	
1 st P.M.	8 45	13 55			Put sheet in motion at 8:30 A.M.
P.M.			8 23	1 95	
2 nd A.M.	2 15	11 20			Staff 1.9 higher Temp. 11 - 33°
A.M.			7 41	5 50	
P.M.	1 28	12 65			
P.M.			9 5	2 55	
3 rd A.M.	3 4	11 15			Astoria: 1853-1876
A.M.			8 37	5 30	
P.M.	2 21	11 90			NOAA & US National Archives
P.M.			9 36	2 65	

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.

Most of these old records have been forgotten.



Lower Willamette Records

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

DATE	SITES OBSERVATION	TEMPERATURE OF WATER				WIND	STATE	REMARKS
		Surf	1 ft	2 ft	Bottom			
July 1		64.0	64.0	64.0	64.0			
July 2		64.0	64.0	64.0	64.0			
July 3		64.0	64.0	64.0	64.0			
July 4		64.0	64.0	64.0	64.0			
July 5		64.0	64.0	64.0	64.0			
July 6		64.0	64.0	64.0	64.0			
July 7		64.0	64.0	64.0	64.0			
July 8		64.0	64.0	64.0	64.0			
July 9		64.0	64.0	64.0	64.0			
July 10		64.0	64.0	64.0	64.0			
July 11		64.0	64.0	64.0	64.0			
July 12		64.0	64.0	64.0	64.0			

Portland, 1882

US Signal Service Records, 1881-1890

Other Agencies with data:
 USGS, NOAA, CMOP, OR DEQ, EPA
 Superfund, City of Portland, OR F&W

→ Big concatenation effort

Form No. 1066-Mec7 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*, 1942
 Time of observation *7:30 A.M.* Flood stage *8* Warning stage

DATE	RIVER		PRECIPITATION				STATE OF WEATHER	REMARKS, SPECIAL OBSERVATIONS, CRUST STAGES, ETC.
	SEAS	CHANGES	TIME OF BEGINNING	TIME OF ENDING	AMOUNT	SNOWFALL IN INCHES		
July 1	12.1	-0.7						64.0
July 2	11.3	-0.8						64.0
July 3	11.0	-0.3						69.0
July 4	10.8	-0.2						71.0
July 5	10.5	-0.3						74.0
July 6	10.7	+0.2						75.0
July 7	10.5	-0.2						74.0
July 8	10.3	-0.2						74.0
July 9	10.2	-0.1						74.0
July 10	10.2	0.0			0.37			74.0
July 11	10.0	-0.2			0.02			72.0
July 12	10.0	0.0						72.0
July 13	10.3	+0.3						72.0
July 14	10.2	-0.1			0.75			72.0
July 15	10.1	-0.1			0.22			71.0
July 16	10.1	0.0			0.10			71.0
July 17	9.8	-0.3						70.0
July 18	9.5	-0.3						69.0
July 19	8.9	-0.6						68.0
July 20	8.7	-0.2						69.0
July 21	8.8	+0.1						70.0
July 22	8.9	+0.1						70.0
July 23	8.8	-0.1						70.0
July 24	8.6	-0.2						71.0
July 25	8.8	+0.2						72.0
July 26	8.7	-0.1						72.0
July 27	8.8	+0.1						73.0
July 28	8.8	0.0						74.0
July 29	8.4	-0.4						74.0
July 30	7.7	-0.7						73.0
July 31	7.3	-0.4						73.0
Aug 1	7.8				0.96	0.0		73.0
Aug 2	9.6							73.0

Portland, 1942

5 days with .01 or more
 Elevation of zero 113 ft. N.P.S. 11.9 ft.

Weather Bureau Records, 1941-1961

River Stage measurements

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	191	78	48	29	26	32
2	23	182	14	58	124	178	130	78	46	34	25	32
3	17	227	22	58	134	172	129	78	46	31	22	29
4	17	267	28	58	139	168	127	74	42	24	17	25
5	17	287	46	61	149	167	126	78	39	20	17	14
6	15	291	62	69	162	161	126	67	32	12	04	13
7	15	279	76	77	170	157	126	56	25	11	02	-0.1
8	11	253	90	78	177	154	123	57	26	08	0.4	-15
9	28	217	97	83	182	150	121	54	26	11	09	-11
10	27	174	94	83	190	146	121	53	30	14	12	-07
11	25	132	87	79	193	142	119	52	32	10	13	-03
12	25	104	81	79	199	140	117	52	31	15	13	24
13	32	86	73	71	202	148	114	53	31	08	16	24
14	25	74	74	67	204	146	113	54	23	22	17	31
15	32	69	67	68	206	148	111	55	24	22	21	32
16	28	69	58	59	207	145	108	55	32	27	20	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	77	67	207	145	102	52	31	25	16	32
20	28	57	61	72	205	139	102	52	32	28	08	28
21	25	53	51	75	208	141	96	50	23	19	04	21
22	27	51	78	75	207	137	92	52	21	15	03	24
23	28	49	79	76	207	137	94	44	16	11	08	22
24	42	52	81	74	202	137	86	43	14	11	08	26
25	61	40	81	77	199	136	82	39	18	16	12	14
26	61	30	82	83	197	133	85	40	21	19	17	31
27	63	30	71	87	196	132	78	43	23	21	17	30
28	50	20	71	91	193	131	77	45	24	22	20	30
29	70		67	99	192	131	77	48	31	24	24	30
30	94		63	108	191	131	77	49	32	25	23	35
31	127		57		188	128	78	49		26		30

PORTLAND OR
DEPARTMENT OF AGRICULTURE, WEATHER BUREAU. 6-1894

MONTHLY METEOROLOGICAL RECORD OF RIVER STATIONS

Taken at Portland Oregon, during June, 1894, at 2⁰⁰ P.M.,
75th meridian time, or 11⁰⁰ A.M., local time, on the Willamette River.

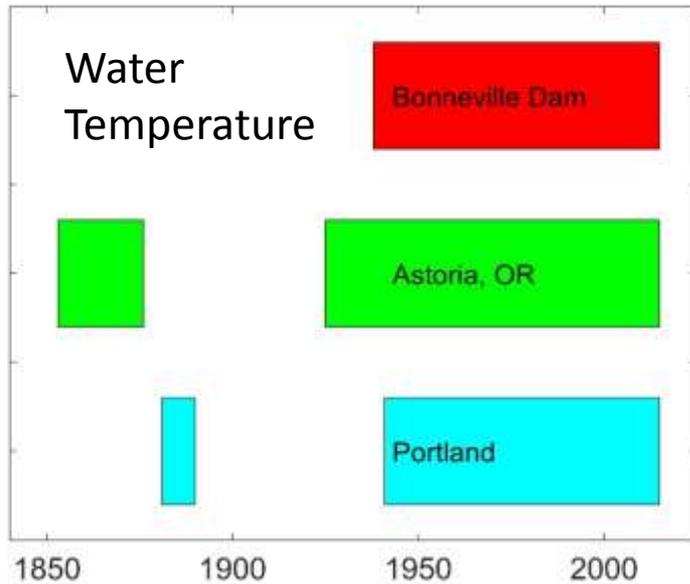
DATE	Reading of River-Gauge.		RIVER.		PRECIPITATION. ϕ			WIND.		Character of Weather at time of Observation.	REMARKS.	
	SURFACE OF WATER.		CHANGE IN 24 HOURS.		DIRGAN.	EXTENDED.	Amount of Rain or Melted Snow.	Depth of Snowfall.	Direction.			Velocity or Force.
	Above.	Below.	Rise.	Fall.								
	Zero or Gauge.		Rise.	Fall.								
Foot and Tenths.		Foot and Tenths.										
1	29.6		0.6						N	2	Clear	Previous high water
2	30.1		0.5				.25		NW	4	Clear	28.2 July June 24 1876.
3	30.8		0.7				.85		SE	8	Light rain	
4	31.7		0.9				.03		NW	6	Light rain	Previous high water
5	32.3		0.6						NW	3	Cloudy	Recorded water
6	32.8		0.5						NW	4	Cloudy	28.7 Feb. 1890, from
7	33.0		0.2				.08		SW	4	Light rain	Willamette Freshet.
8	32.7		0.3				.02		S	2	Cloudy	
9	32.4		0.3				.22		SW	17	Off. cloudy	The River was
10	32.2		0.2				.09		S	4	Off. cloudy	stationary all
11	31.9		0.3				.15		SW	12	Light rain	day of the 7 th
12	31.4		0.5				.02		NW	4	Cloudy	
13	30.7		0.7						NW	4	Off. cloudy	
14	30.1		0.6						NW	6	Cloudy	
15	29.3		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	3	Cloudy	
20	26.7		0.3						NW	1	Cloudy	

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

Left: City of Portland Archives



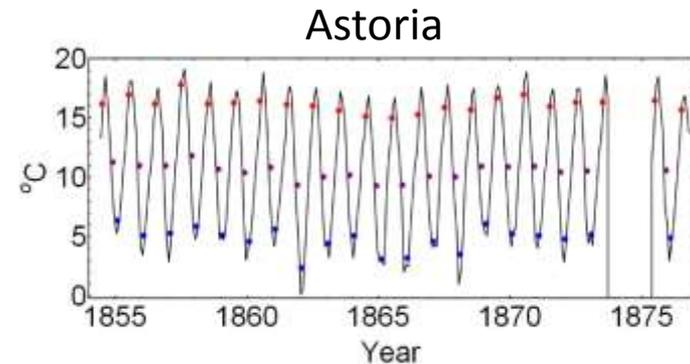
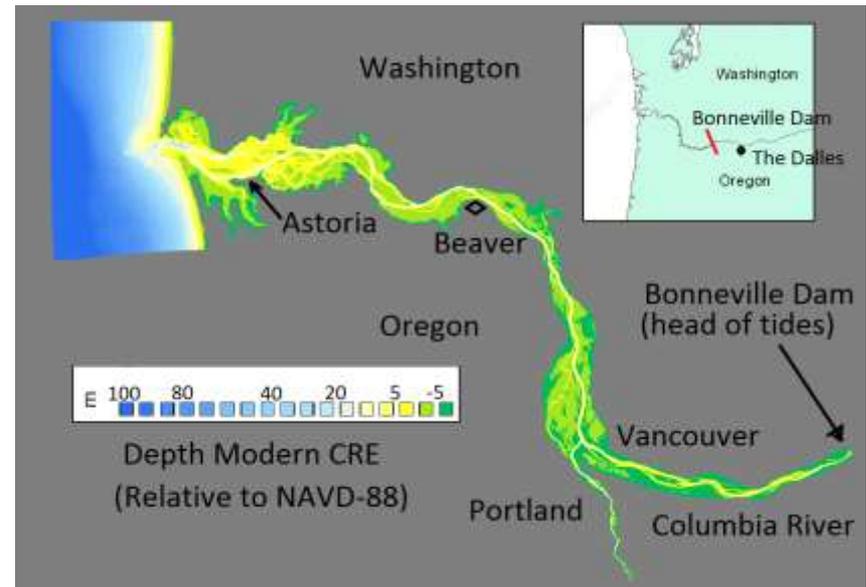
Data Recovery Synopsis



Talke/Jay digitized: >50 station years

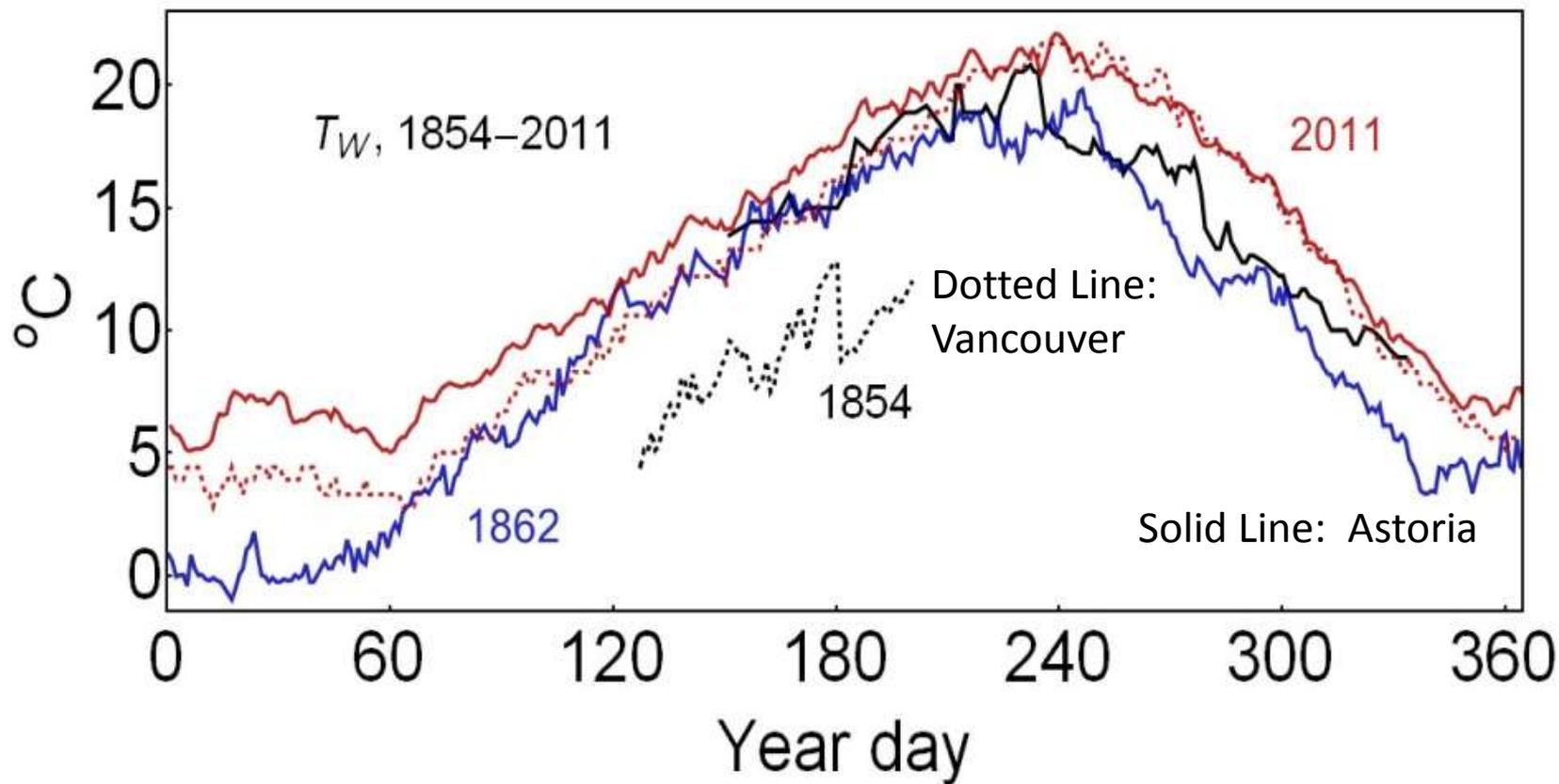
Notes:

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



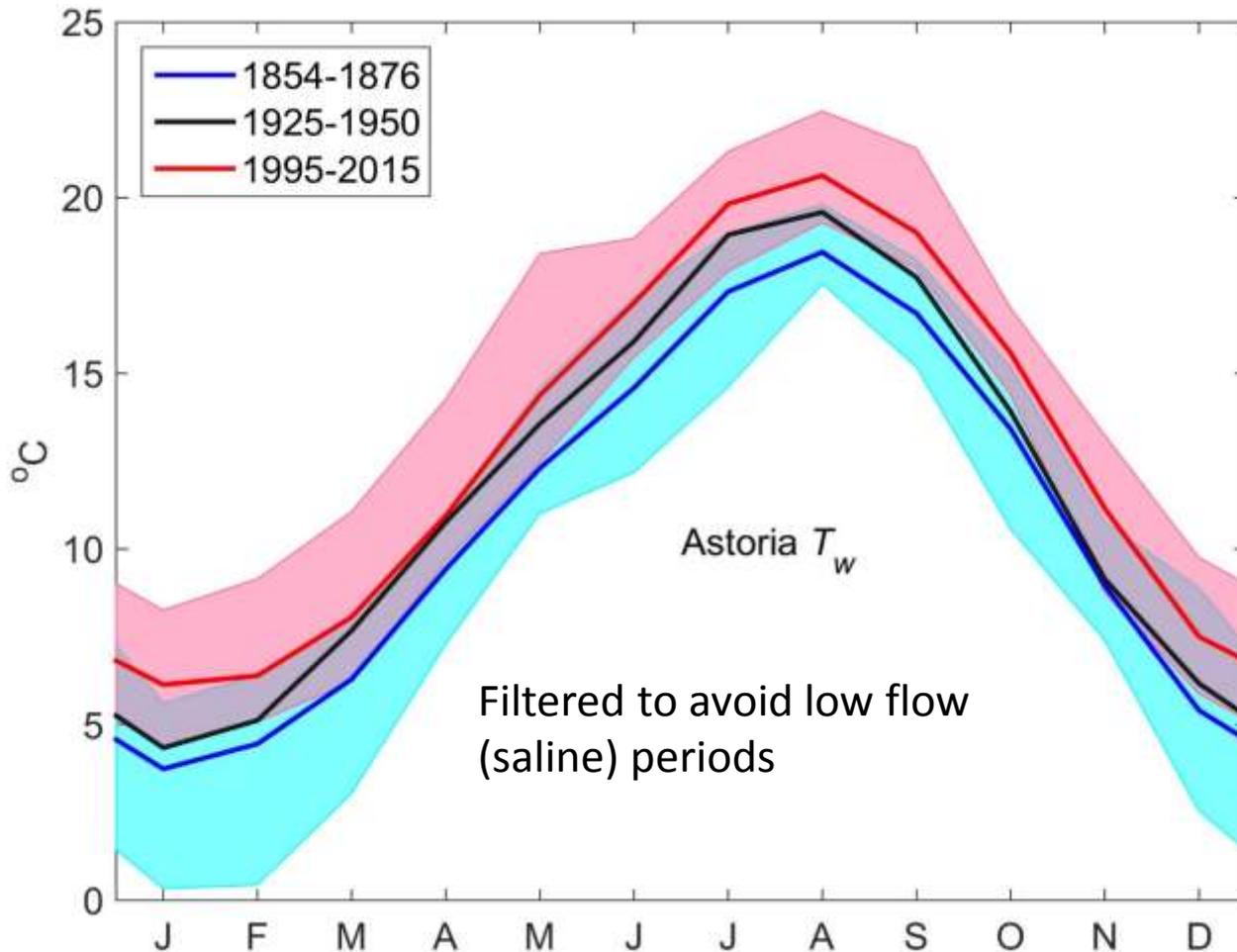


Water Temperature—Columbia Mainstem





Water Temperature Astoria: Climatology



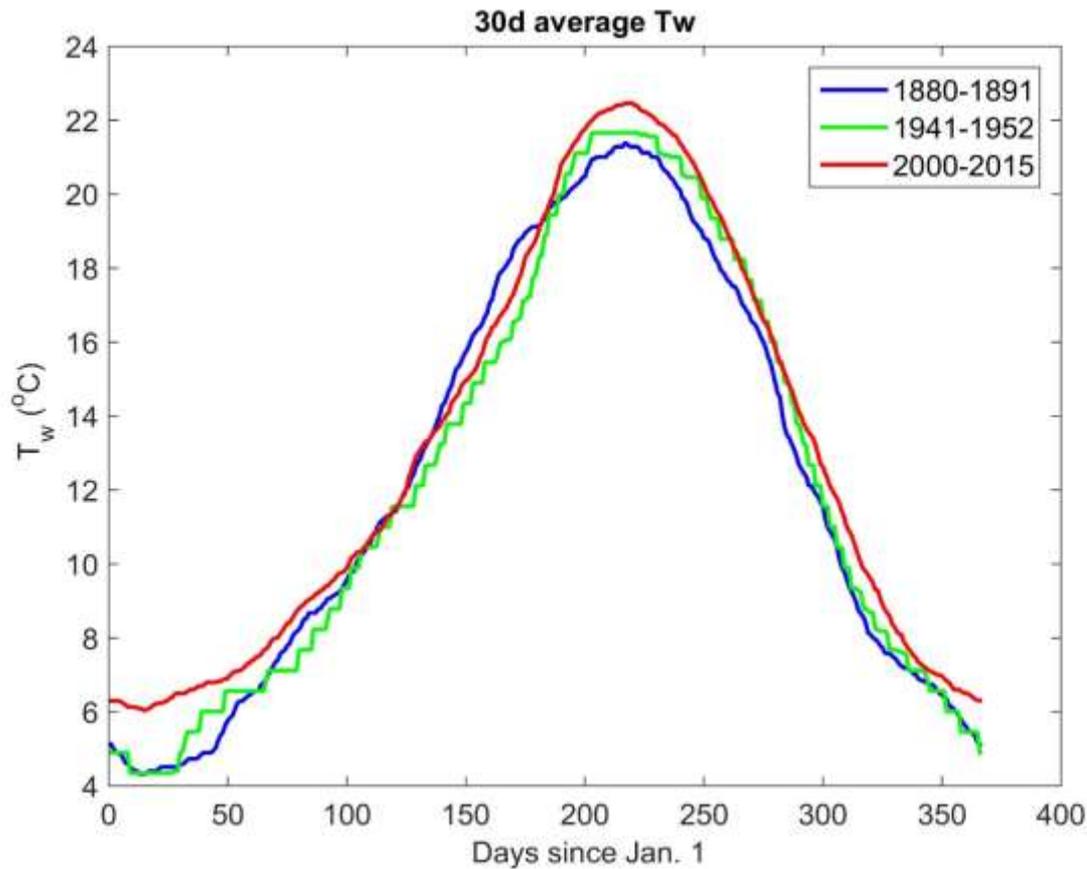
Columbia River Water Temperature ~ 2 °C larger now than in past, on average

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

→ Historical Astoria measurement was a river measurement



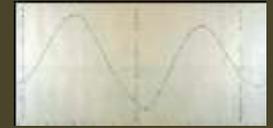
Lower Willamette River (Portland) Climatology



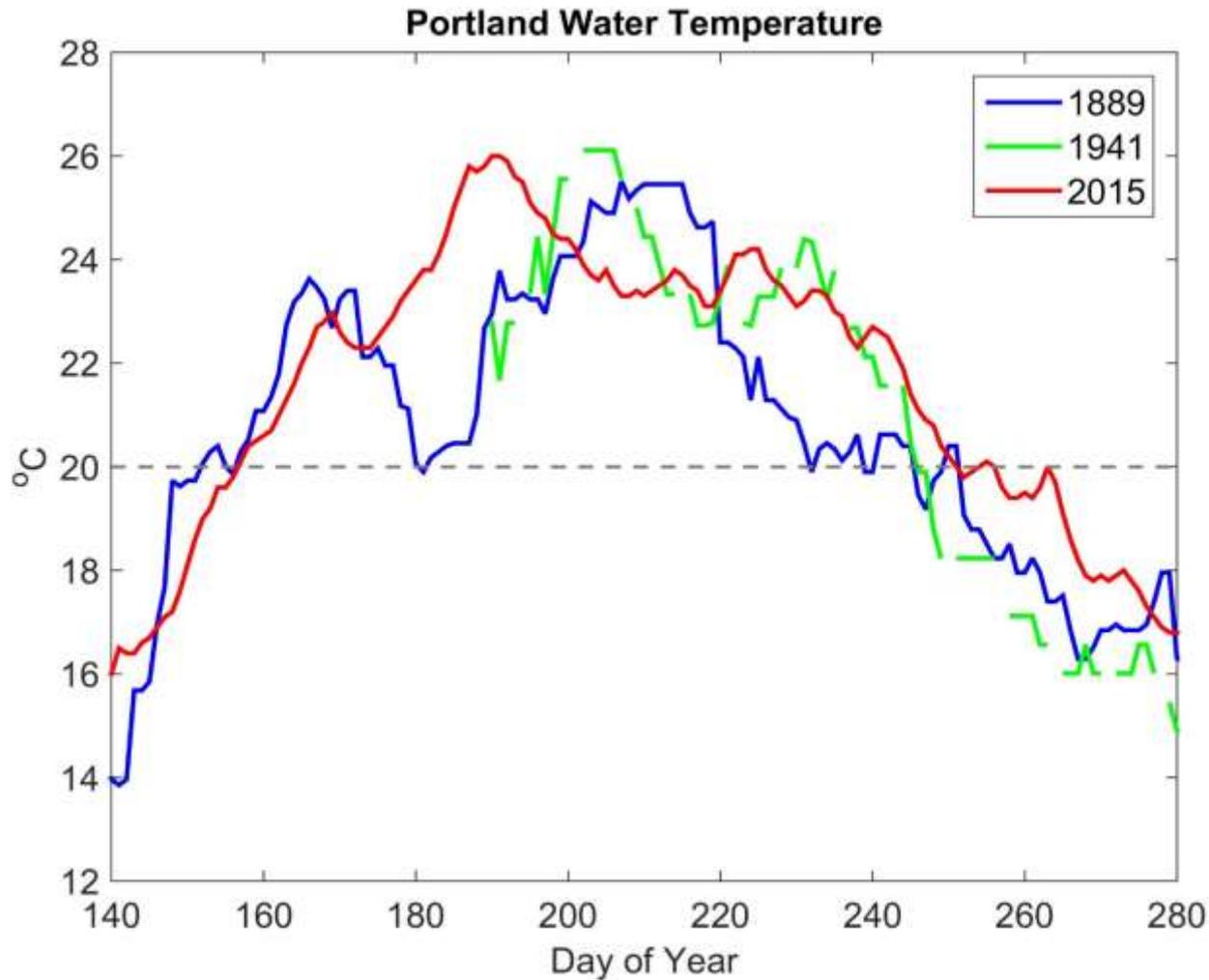
Little Change in climatology between 1880 and 1952

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....

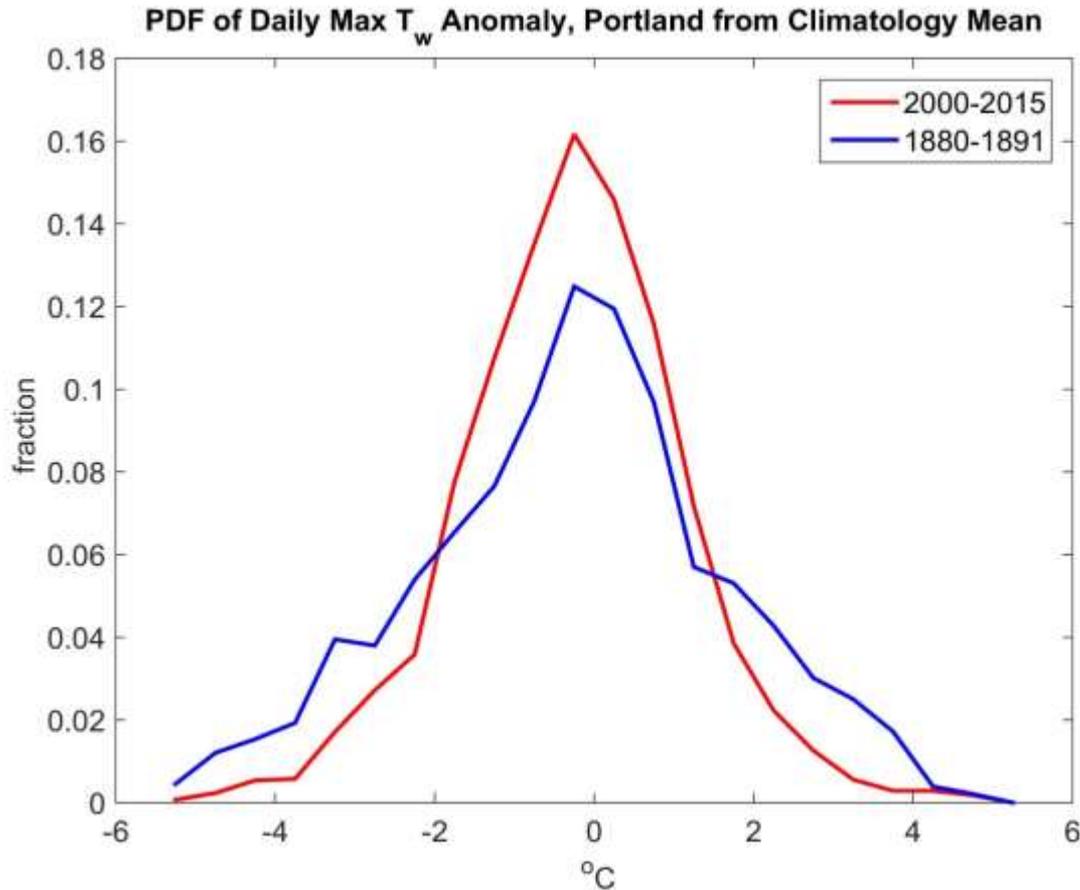


Peak T_w in 1941 and 1889 was nearly the same as 2015!!!

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. $u \frac{\partial T_w}{\partial x} \approx c Q$ (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

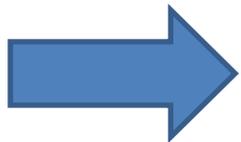
Temperature yesterday

Upstream Input

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

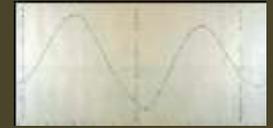
But Also:

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

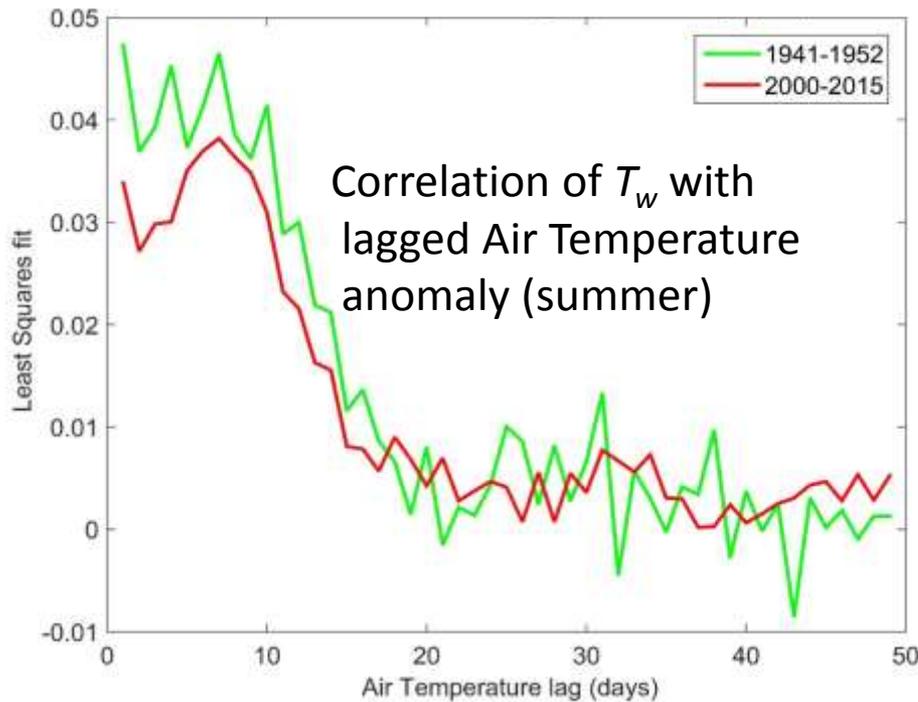


$$T_w(t) = a_0T_a(t) + a_1T_a(t - 1) + a_2T_a(t - 2) + \dots + a_nT_a(t - n) + b_0Q(t) + b_1Q(t - 1) + b_2Q(t - 2) + \dots + b_nQ(t - n)$$

Lagged correlation model



Preliminary Statistical Model results



Little correlation measurable after several weeks

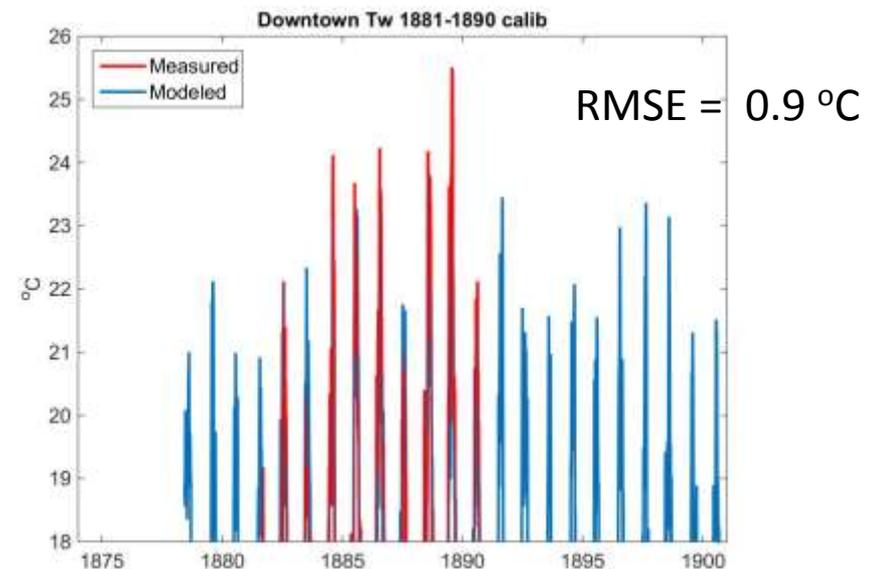
(Weather System effect short lived)

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

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

→ ~ 0.5 degree T_w anomaly

→ Managed system: 0.4 degrees





Effects of Climate Change

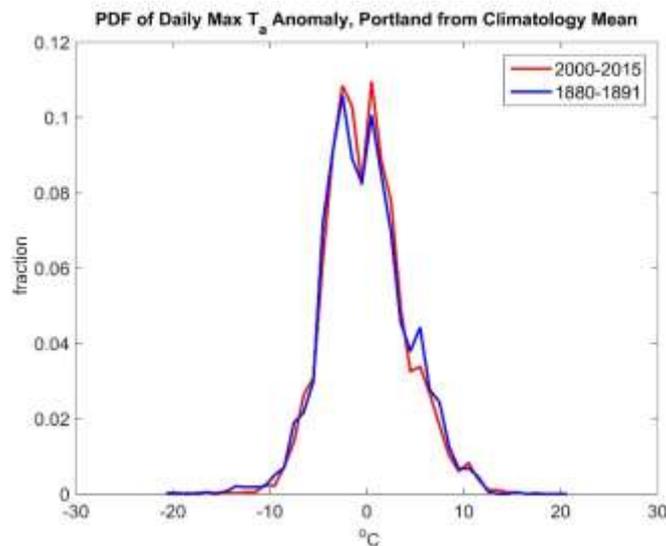
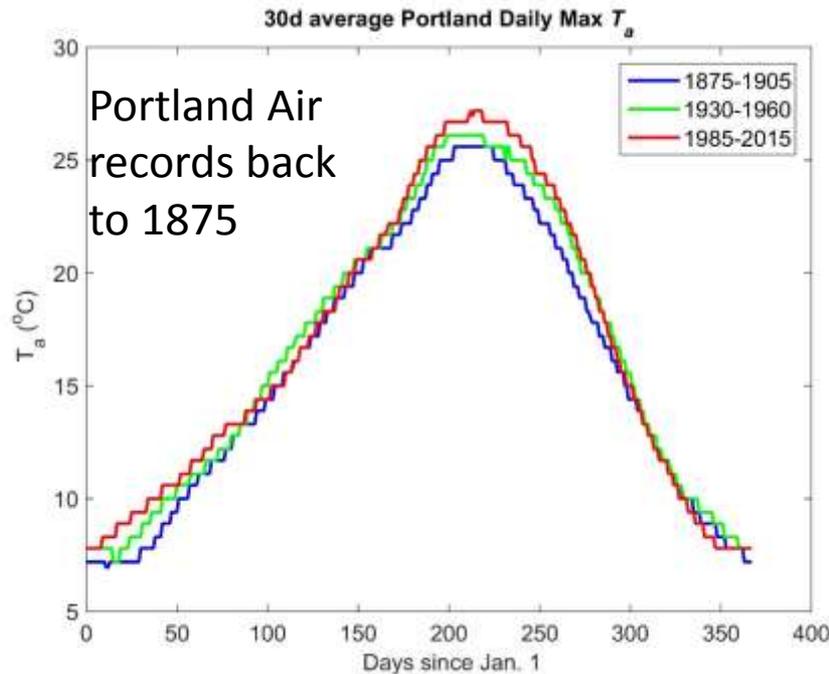
Air ~1-2 degrees warmer in summer

Consistent with about 0.5-1 °C increased water temperature

Distribution of anomalies not much different.

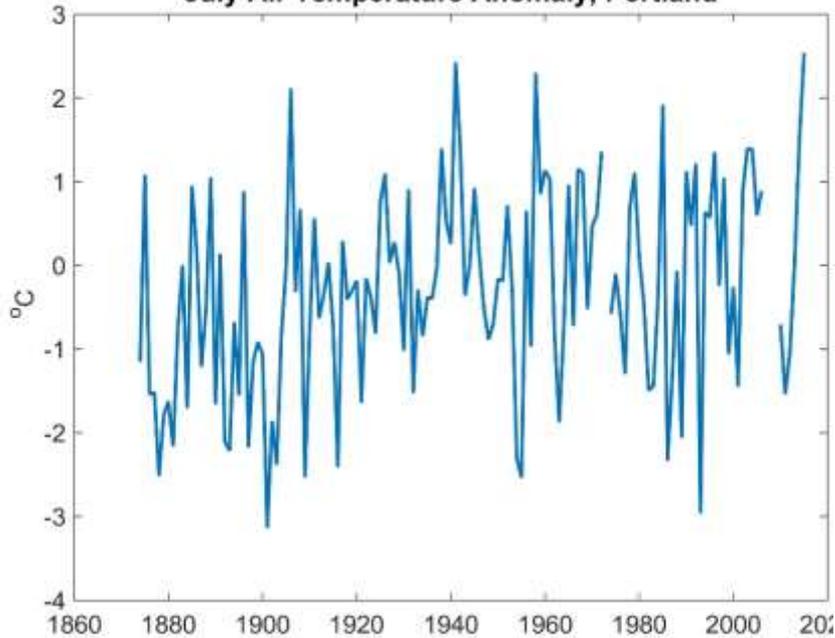
However...

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





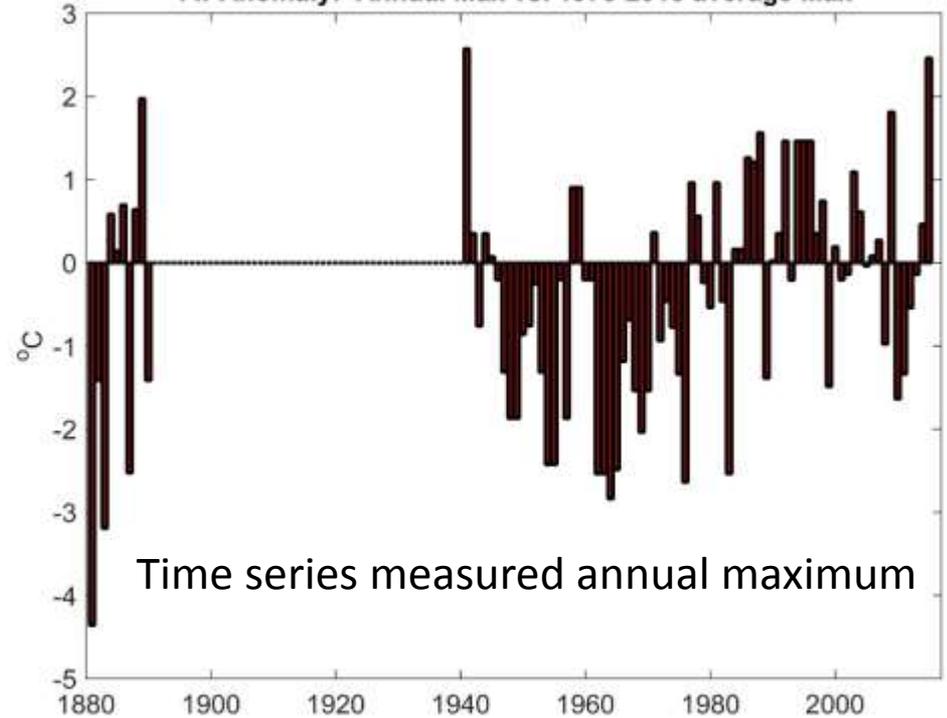
July Air Temperature Anomaly, Portland



Willamette T_w :

Linear function of Air Temperature and (weakly) River Flow

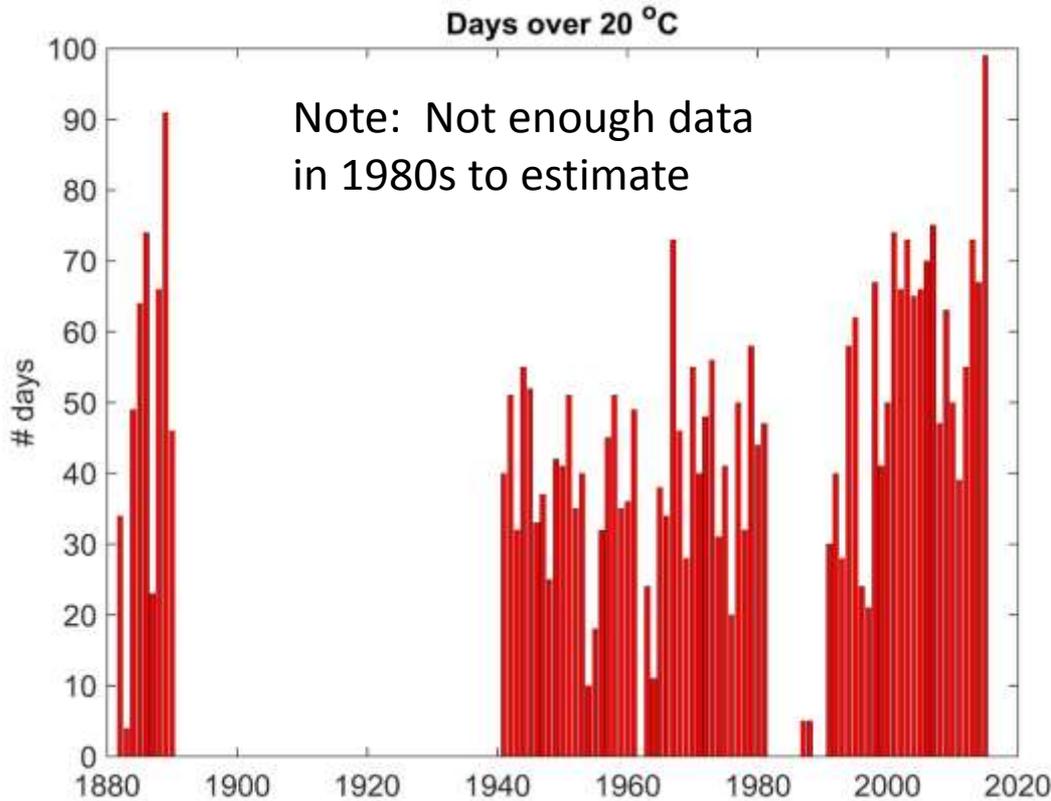
T_w Anomaly: Annual Max vs. 1975-2015 average Max



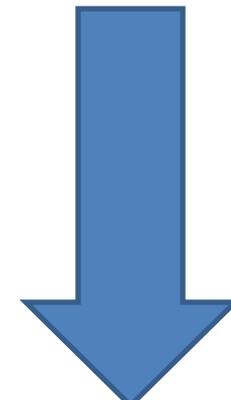
Time series measured annual maximum

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

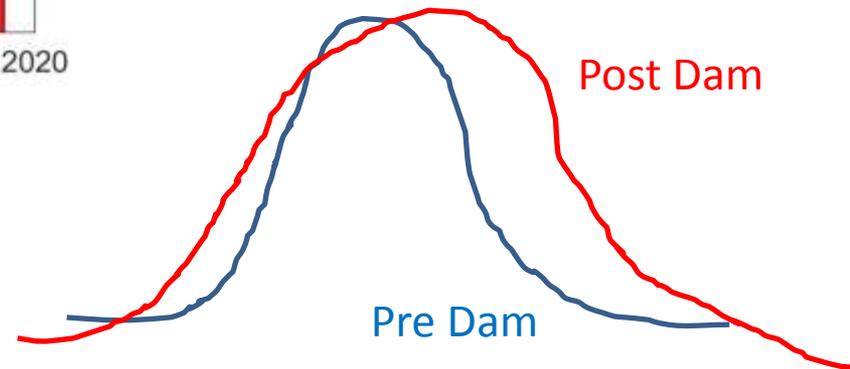
Only a few years match 2015



2015 did set the record number of days above 20 degrees

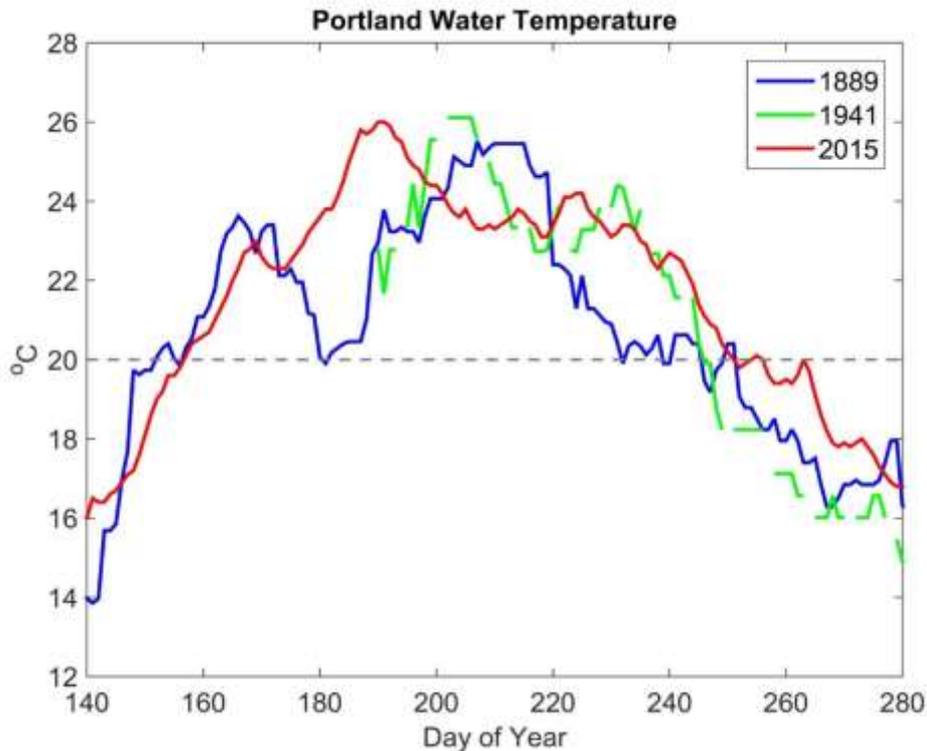


Hypothesis: System more diffusive, less variable, due to selective water releases, especially after ~1990

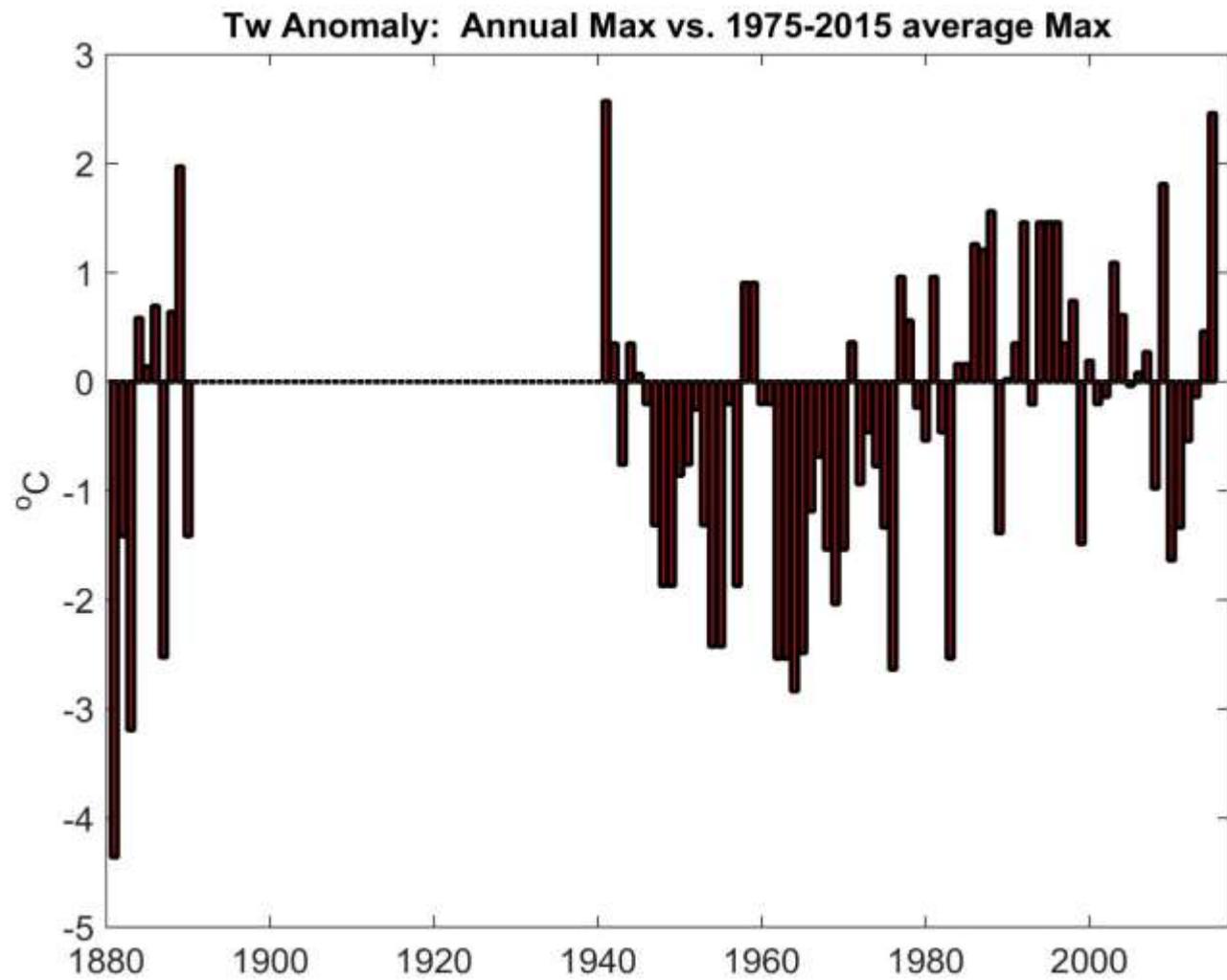




Take home messages today



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



Measured
annual max
anomaly