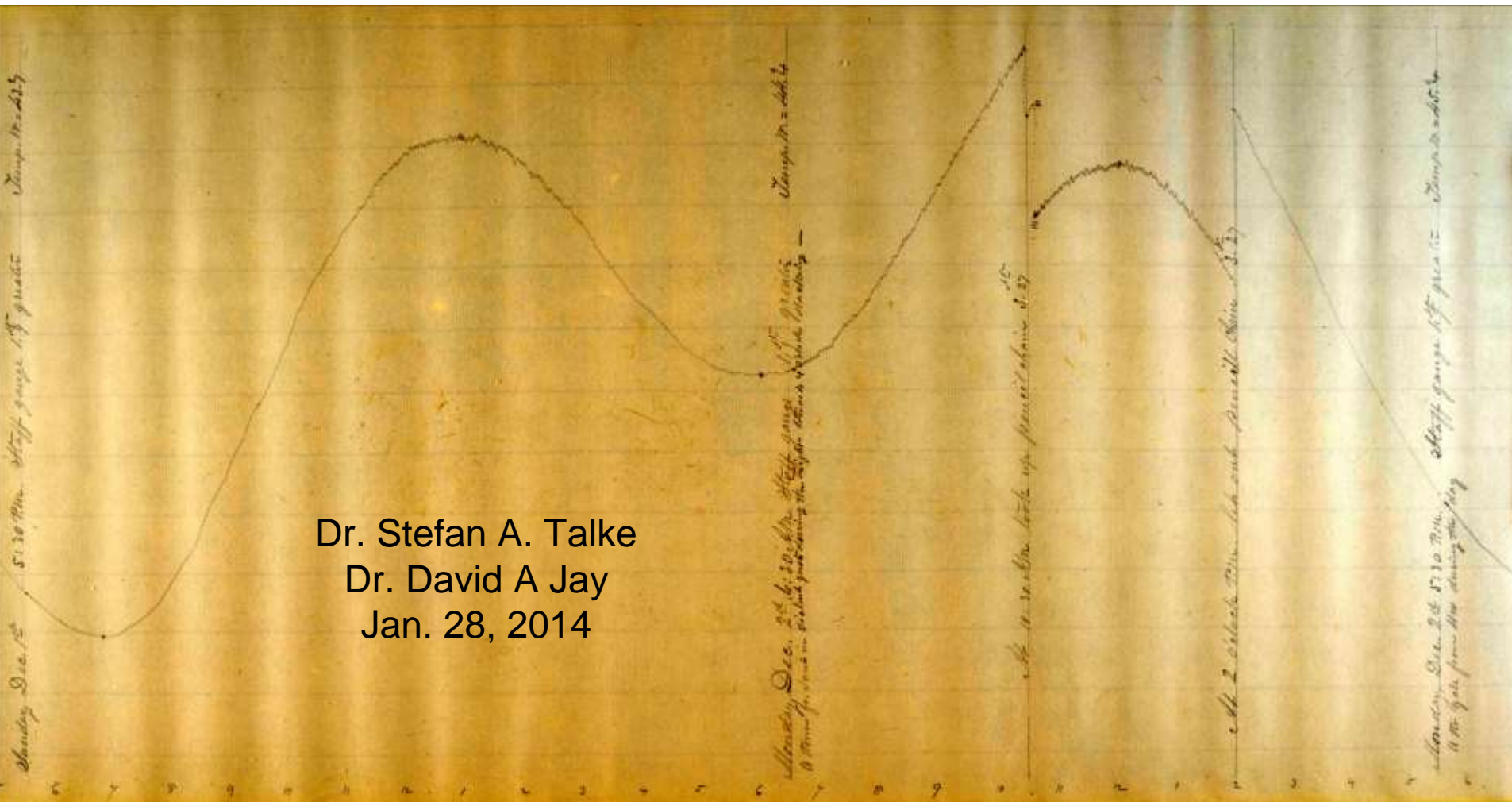


Water levels and extremes in the Columbia River Estuary since 1853



Dr. Stefan A. Talke
Dr. David A Jay
Jan. 28, 2014



The Setting: The lower Columbia River Estuary

The question: What changes will climate change and sea-level rise bring?

Of particular concern:

- water levels
- water temperatures
- extreme events

Walluski River, King Tide, Lower Columbia River Estuary



The future may be uncertain; but perhaps some lessons may be learned from the past.

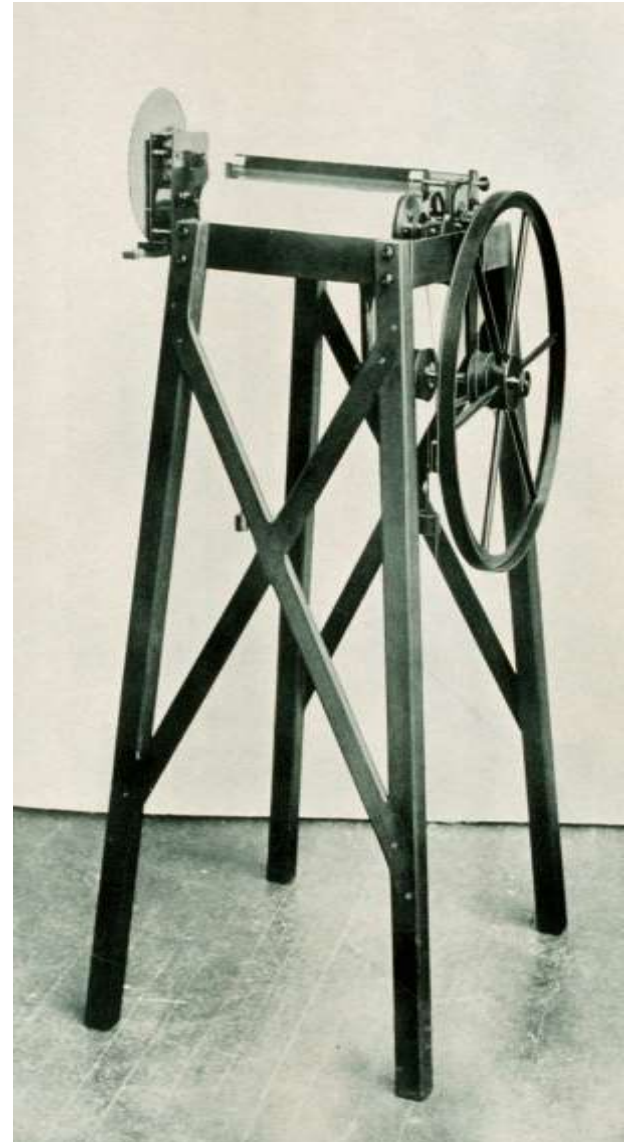
Photo Credits: The Wetlands Conservancy, flown by LightHawk



The US Coastal Survey made measurements in Astoria with an automatic gauge from 1853 to 1876. (see Talke & Jay, 2013 J. Coastal Research)



Astoria 1862 marigrams





Astoria hourly measurements (1870-1876)...

*Tabulation of Tides from the Ash Wharving
at Astoria, Oregon, from 1870 to 1876*

Date	Time	Height	Time	Height	Remarks
1870	1	1.2	2	1.4	
1870	2	1.4	3	1.6	
1870	3	1.6	4	1.8	
1870	4	1.8	5	2.0	
1870	5	2.0	6	2.2	
1870	6	2.2	7	2.4	
1870	7	2.4	8	2.6	
1870	8	2.6	9	2.8	
1870	9	2.8	10	3.0	
1870	10	3.0	11	3.2	
1870	11	3.2	12	3.4	
1870	12	3.4	1	3.6	
1870	1	3.6	2	3.8	
1870	2	3.8	3	4.0	
1870	3	4.0	4	4.2	
1870	4	4.2	5	4.4	
1870	5	4.4	6	4.6	
1870	6	4.6	7	4.8	
1870	7	4.8	8	5.0	
1870	8	5.0	9	5.2	
1870	9	5.2	10	5.4	
1870	10	5.4	11	5.6	
1870	11	5.6	12	5.8	
1870	12	5.8	1	6.0	
1870	1	6.0	2	6.2	
1870	2	6.2	3	6.4	
1870	3	6.4	4	6.6	
1870	4	6.6	5	6.8	
1870	5	6.8	6	7.0	
1870	6	7.0	7	7.2	
1870	7	7.2	8	7.4	
1870	8	7.4	9	7.6	
1870	9	7.6	10	7.8	
1870	10	7.8	11	8.0	
1870	11	8.0	12	8.2	
1870	12	8.2	1	8.4	
1870	1	8.4	2	8.6	
1870	2	8.6	3	8.8	
1870	3	8.8	4	9.0	
1870	4	9.0	5	9.2	
1870	5	9.2	6	9.4	
1870	6	9.4	7	9.6	
1870	7	9.6	8	9.8	
1870	8	9.8	9	10.0	
1870	9	10.0	10	10.2	
1870	10	10.2	11	10.4	
1870	11	10.4	12	10.6	
1870	12	10.6	1	10.8	
1870	1	10.8	2	11.0	
1870	2	11.0	3	11.2	
1870	3	11.2	4	11.4	
1870	4	11.4	5	11.6	
1870	5	11.6	6	11.8	
1870	6	11.8	7	12.0	
1870	7	12.0	8	12.2	
1870	8	12.2	9	12.4	
1870	9	12.4	10	12.6	
1870	10	12.6	11	12.8	
1870	11	12.8	12	13.0	
1870	12	13.0	1	13.2	
1870	1	13.2	2	13.4	
1870	2	13.4	3	13.6	
1870	3	13.6	4	13.8	
1870	4	13.8	5	14.0	
1870	5	14.0	6	14.2	
1870	6	14.2	7	14.4	
1870	7	14.4	8	14.6	
1870	8	14.6	9	14.8	
1870	9	14.8	10	15.0	
1870	10	15.0	11	15.2	
1870	11	15.2	12	15.4	
1870	12	15.4	1	15.6	
1870	1	15.6	2	15.8	
1870	2	15.8	3	16.0	
1870	3	16.0	4	16.2	
1870	4	16.2	5	16.4	
1870	5	16.4	6	16.6	
1870	6	16.6	7	16.8	
1870	7	16.8	8	17.0	
1870	8	17.0	9	17.2	
1870	9	17.2	10	17.4	
1870	10	17.4	11	17.6	
1870	11	17.6	12	17.8	
1870	12	17.8	1	18.0	
1870	1	18.0	2	18.2	
1870	2	18.2	3	18.4	
1870	3	18.4	4	18.6	
1870	4	18.6	5	18.8	
1870	5	18.8	6	19.0	
1870	6	19.0	7	19.2	
1870	7	19.2	8	19.4	
1870	8	19.4	9	19.6	
1870	9	19.6	10	19.8	
1870	10	19.8	11	20.0	
1870	11	20.0	12	20.2	
1870	12	20.2	1	20.4	
1870	1	20.4	2	20.6	
1870	2	20.6	3	20.8	
1870	3	20.8	4	21.0	
1870	4	21.0	5	21.2	
1870	5	21.2	6	21.4	
1870	6	21.4	7	21.6	
1870	7	21.6	8	21.8	
1870	8	21.8	9	22.0	
1870	9	22.0	10	22.2	
1870	10	22.2	11	22.4	
1870	11	22.4	12	22.6	
1870	12	22.6	1	22.8	
1870	1	22.8	2	23.0	
1870	2	23.0	3	23.2	
1870	3	23.2	4	23.4	
1870	4	23.4	5	23.6	
1870	5	23.6	6	23.8	
1870	6	23.8	7	24.0	
1870	7	24.0	8	24.2	
1870	8	24.2	9	24.4	
1870	9	24.4	10	24.6	
1870	10	24.6	11	24.8	
1870	11	24.8	12	25.0	
1870	12	25.0	1	25.2	
1870	1	25.2	2	25.4	
1870	2	25.4	3	25.6	
1870	3	25.6	4	25.8	
1870	4	25.8	5	26.0	
1870	5	26.0	6	26.2	
1870	6	26.2	7	26.4	
1870	7	26.4	8	26.6	
1870	8	26.6	9	26.8	
1870	9	26.8	10	27.0	
1870	10	27.0	11	27.2	
1870	11	27.2	12	27.4	
1870	12	27.4	1	27.6	
1870	1	27.6	2	27.8	
1870	2	27.8	3	28.0	
1870	3	28.0	4	28.2	
1870	4	28.2	5	28.4	
1870	5	28.4	6	28.6	
1870	6	28.6	7	28.8	
1870	7	28.8	8	29.0	
1870	8	29.0	9	29.2	
1870	9	29.2	10	29.4	
1870	10	29.4	11	29.6	
1870	11	29.6	12	29.8	
1870	12	29.8	1	30.0	
1870	1	30.0	2	30.2	
1870	2	30.2	3	30.4	
1870	3	30.4	4	30.6	
1870	4	30.6	5	30.8	
1870	5	30.8	6	31.0	
1870	6	31.0	7	31.2	
1870	7	31.2	8	31.4	
1870	8	31.4	9	31.6	
1870	9	31.6	10	31.8	
1870	10	31.8	11	32.0	
1870	11	32.0	12	32.2	
1870	12	32.2	1	32.4	
1870	1	32.4	2	32.6	
1870	2	32.6	3	32.8	
1870	3	32.8	4	33.0	
1870	4	33.0	5	33.2	
1870	5	33.2	6	33.4	
1870	6	33.4	7	33.6	
1870	7	33.6	8	33.8	
1870	8	33.8	9	34.0	
1870	9	34.0	10	34.2	
1870	10	34.2	11	34.4	
1870	11	34.4	12	34.6	
1870	12	34.6	1	34.8	
1870	1	34.8	2	35.0	
1870	2	35.0	3	35.2	
1870	3	35.2	4	35.4	
1870	4	35.4	5	35.6	
1870	5	35.6	6	35.8	
1870	6	35.8	7	36.0	
1870	7	36.0	8	36.2	
1870	8	36.2	9	36.4	
1870	9	36.4	10	36.6	
1870	10	36.6	11	36.8	
1870	11	36.8	12	37.0	
1870	12	37.0	1	37.2	
1870	1	37.2	2	37.4	
1870	2	37.4	3	37.6	
1870	3	37.6	4	37.8	
1870	4	37.8	5	38.0	
1870	5	38.0	6	38.2	
1870	6	38.2	7	38.4	
1870	7	38.4	8	38.6	
1870	8	38.6	9	38.8	
1870	9	38.8	10	39.0	
1870	10	39.0	11	39.2	
1870	11	39.2	12	39.4	
1870	12	39.4	1	39.6	
1870	1	39.6	2	39.8	
1870	2	39.8	3	40.0	
1870	3	40.0	4	40.2	
1870	4	40.2	5	40.4	
1870	5	40.4	6	40.6	
1870	6	40.6	7	40.8	
1870	7	40.8	8	41.0	
1870	8	41.0	9	41.2	
1870	9	41.2	10	41.4	
1870	10	41.4	11	41.6	
1870	11	41.6	12	41.8	
1870	12	41.8	1	42.0	
1870	1	42.0	2	42.2	
1870	2	42.2	3	42.4	
1870	3	42.4	4	42.6	
1870	4	42.6	5	42.8	
1870	5	42.8	6	43.0	
1870	6	43.0	7	43.2	
1870	7	43.2	8	43.4	
1870	8	43.4	9	43.6	
1870	9	43.6	10	43.8	
1870	10	43.8	11	44.0	
1870	11	44.0	12	44.2	
1870	12	44.2	1	44.4	
1870	1	44.4	2	44.6	
1870	2	44.6	3	44.8	
1870	3	44.8	4	45.0	
1870	4	45.0	5	45.2	
1870	5	45.2	6	45.4	
1870	6	45.4	7	45.6	
1870	7	45.6	8	45.8	
1870	8	45.8	9	46.0	
1870	9	46.0	10	46.2	
1870	10	46.2	11	46.4	
1870	11	46.4	12	46.6	
1870	12	46.6	1	46.8	
1870	1	46.8	2	47.0	
1870	2	47.0	3	47.2	
1870	3	47.2	4	47.4	
1870	4	47.4	5	47.6	
1870	5	47.6	6	47.8	
1870	6	47.8	7	48.0	
1870	7	48.0	8	48.2	
1870	8	48.2	9	48.4	
1870	9	48.4	10	48.6	
1870	10	48.6	11	48.8	
1870	11	48.8	12	49.0	
1870	12	49.0	1	49.2	
1870	1	49.2	2	49.4	
1870	2	49.4	3	49.6	
1870	3	49.6	4		



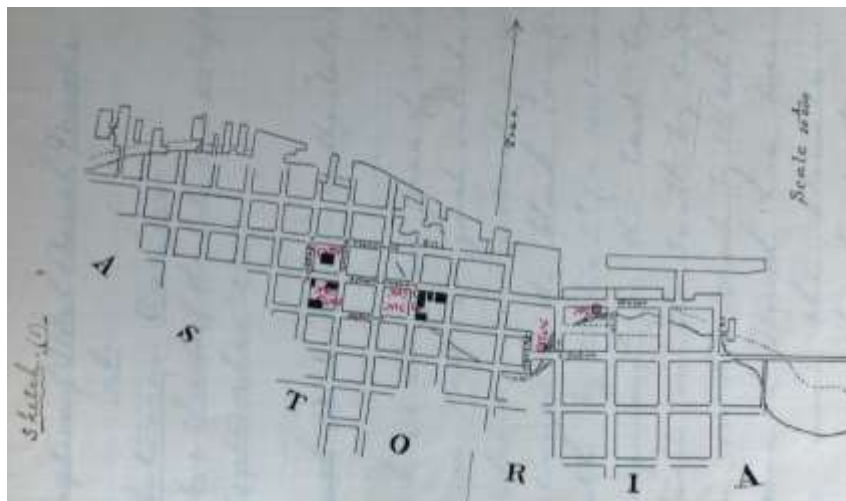
Meteorological Register										Astoria, Oregon, January, 1864.	
Bar	Therm	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	Remarks
Bar	Therm	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	W. Wind	Remarks
1.00	30.20	35.8	30.20	38.6	0.8	38.6	0.8	38.6	0.8	38.6	mod. fog
10.12	22.42	27	41.30	50.8	do	41.30	50.8	do	41.30	50.8	mod. fog with drizzling rain
12.06	20.47	24	42.0	52.0	do	42.0	52.0	do	42.0	52.0	drizzly with v. dense fog
2	6.30	05	44.0	50.12	44.0	50.12	44.0	50.12	44.0	50.12	by dense fog
12	04	44.3	07	43.7	05	43.2	do	43.2	do	43.2	mod. fog - (morning fog)
6.24	97	47.3	29.99	42.3	01	42.2	do	42.2	do	42.2	by dense fog

Meteorological register, Jan. 1864

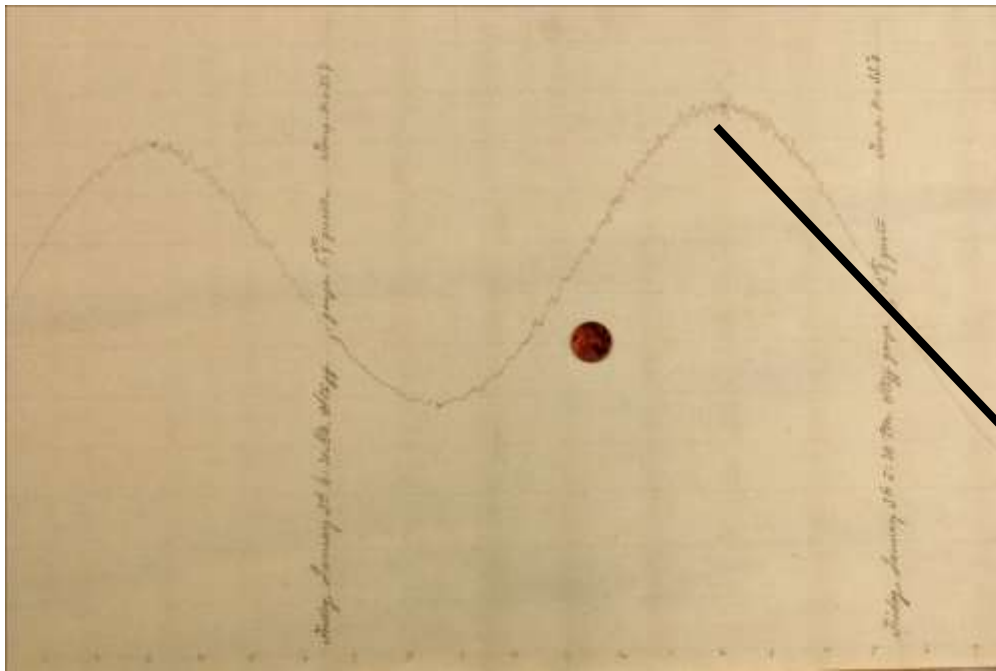
Data are being digitized and quality assured

>20,000 pictures of documents for Columbia River

> 250k individual data points entered by students



Benchmark map from 1887



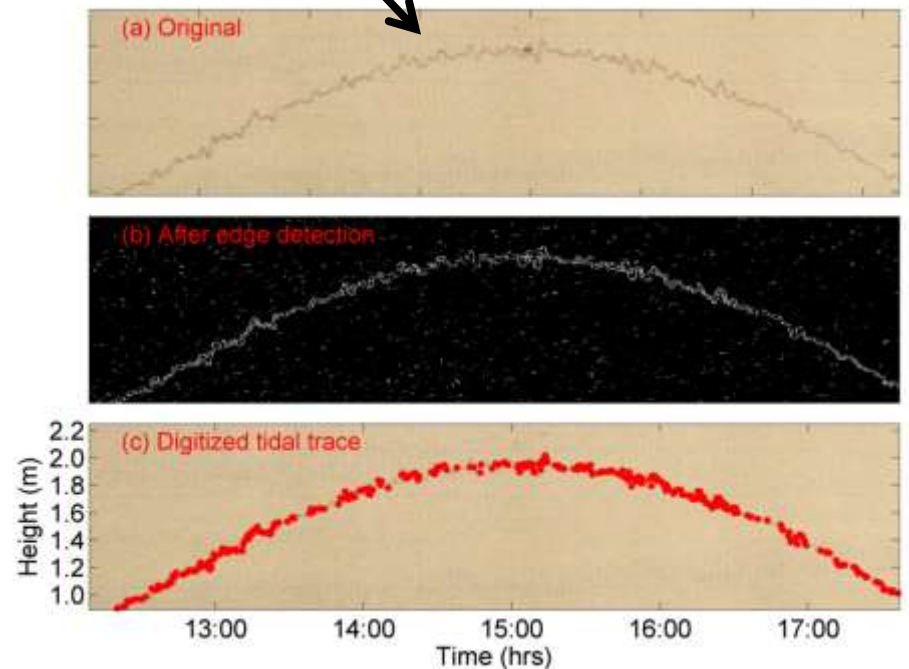
Marigram, Astoria 1862

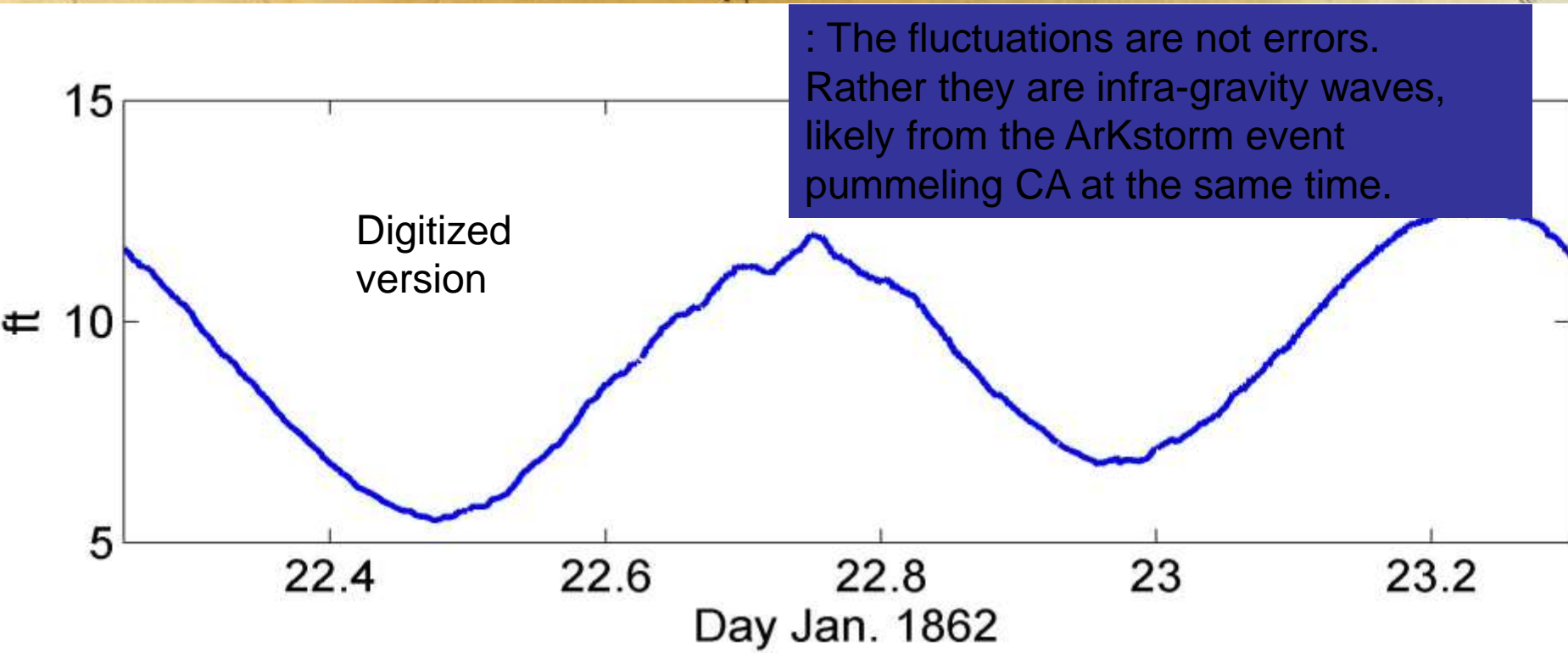
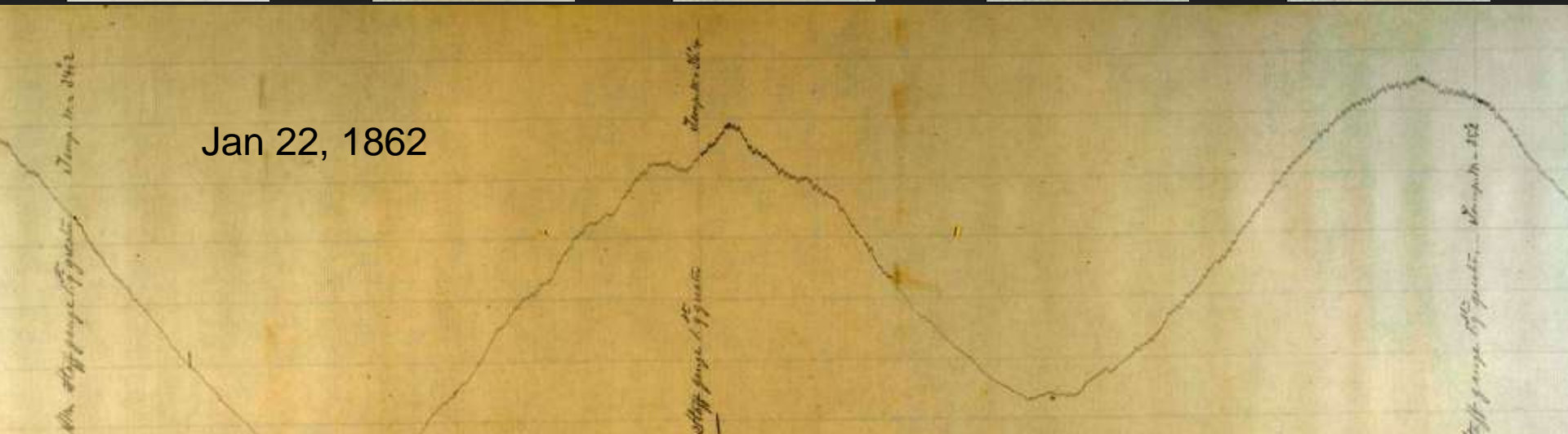
Scaling and rotation done in post-processing, using daily gauge checks for reference

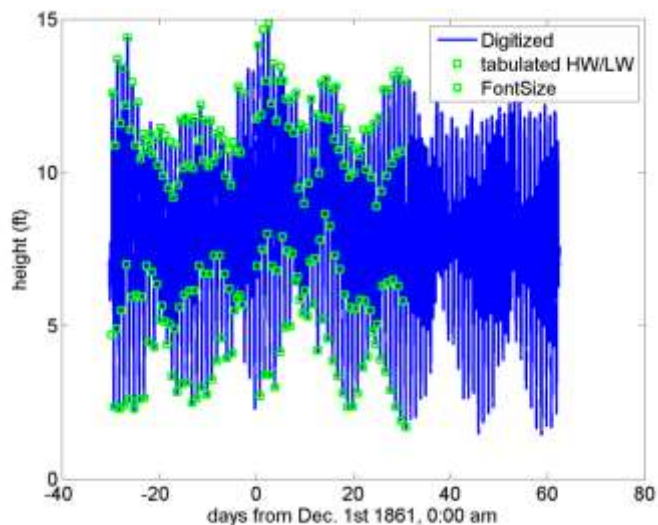
Camera distortion removed via Nikon software; residual distortion is removed during processing.

200 scrolls have been photographed and are being processed into time/height coordinates.

(2 miles of paper, end to end)





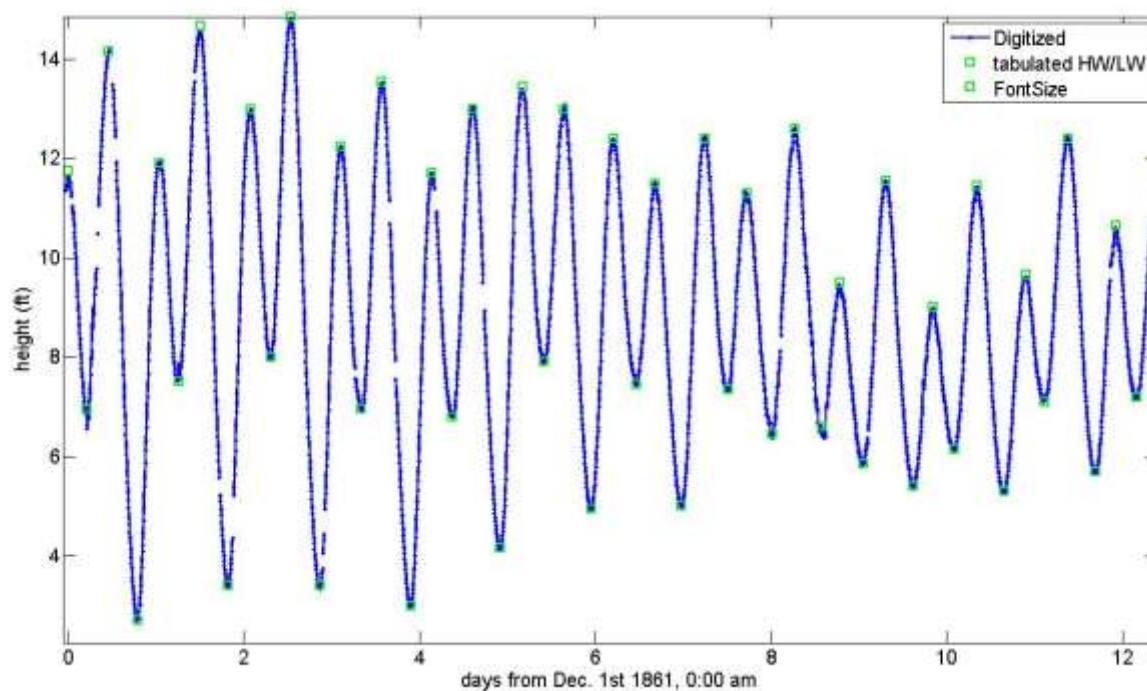


Digitized Astoria data set, winter 1861-1862

Good agreement
between historic
High/Low tabulations
and our estimate

To date, we have
digitized marigrams
from 1860-1869 with
1 minute resolution

QA ongoing...





Astoria superseded benchmark sheet, NOAA

Port 5,415
DEPARTMENT OF COMMERCE
U.S. COAST AND GEODETIC SURVEY

TIDES: SUMMARY - General

Lat. 46 11 Long. 123 50

Station: Astoria, Oregon

OBSERVATION VALUES

No. of	No. of		READING ON STAFF USED										READING ON STAFF OF			REMARKS		
	HT.	L.W.	HT.	L.W.	Mn.	DTQ.	DLQ.	MTL.	Highest.	Lowest.	DM. 1.	DM. 2.	DM. 3.	MTL.	Highest.		Lowest.	
(1) Jan 1, 1874-Dec 31, 1875	2 yrs		0.25	6.70	6.06	0.58	1.39	9.34										<p>Landhamon's constants Highs & Lows Astoria 2nd Reductions</p> <p>Very good 1st Red. By diff from 1st station</p> <p>Camp, Tongue Point</p>
(2) Aug 20, 1875-Aug 22, 1876	1 yr				6.19	0.77	1.32	9.67						9.67				
(3) 1853-1866	12 yrs		0.33	6.73	6.24			7.80										
(4) March 27, 1883	7 mos		0.33	6.79	6.51	0.76	1.13	9.21	15.5	3.4	14.83			9.17				
(5) Oct 1-Dec 29, 1884	3 mos		0.28	6.64	6.56	0.62	1.09	9.02	9.9	-2.8	9.57							
(6) Nov 1873-Oct 1876	3 yrs				6.43	0.65	1.18	9.47						9.47				
(7) Nov 1873-Oct 1876	3 yrs																	
(8)																		
(9)																		
(10) Aug 6-16, 1926	21	20			6.19	0.61	1.16	9.72						9.57				
(11) Sep 11-Oct 18, 1936	57	56			6.09	0.66	1.08	6.93						6.73				
(12) Apr 1936	57	57			6.51	0.66	1.15	6.23						6.73				

ACCEPTED VALUES

No. of	No. of		READING ON STAFF OF										READING ON STAFF OF			REMARKS
	HT.	L.W.	HT.	L.W.	Mn.	DTQ.	DLQ.	Gr.	Sp.	Highest.	Lowest.	MTL.	L.W.	Date	Name	
Jan 1, 1874-Dec 31, 1875	2 yrs		6.06	0.25	0.15	6.36	0.58	1.37	8.3							
Nov 1873-Oct 1876	3 yrs		9.98	0.56	0.34	6.4	0.6	1.2	7.9							
Port Docks	57	56	5.88	9.82	0.34	0.20	6.1	0.7	1.7	7.9						

READINGS ON TIDE STAFFS

Staff of	1873-6		1874-5		1875-6		1876-7		1877-8		1878-9		REMARKS
	H.	L.	H.	L.	H.	L.	H.	L.	H.	L.	H.	L.	
Highest tide,	16.54		13.37		12.67		9.47		9.31		6.27		<p>* Used in the determination of elevations of B.M. in 1810. M.T.L. is based upon 1 yr of obs. Aug 20, 1875-Aug 22, 1876. Range Transpennsular from 2 goods, 1874-1875. 5.11 ft has been adopted by U.S. Engineers as Astoria L.W. Since this value is supported by the 3 yrs Nov. 1873-Oct. 1876 it should be retained for the present. 7/24/29</p>
Higher high water,													
Mean high water,													
Mean tide level,													
Mean sea level,													
Mean low water,													
Lower low water datum,													
Lowest tide,													

FMSL of F.O. Level not

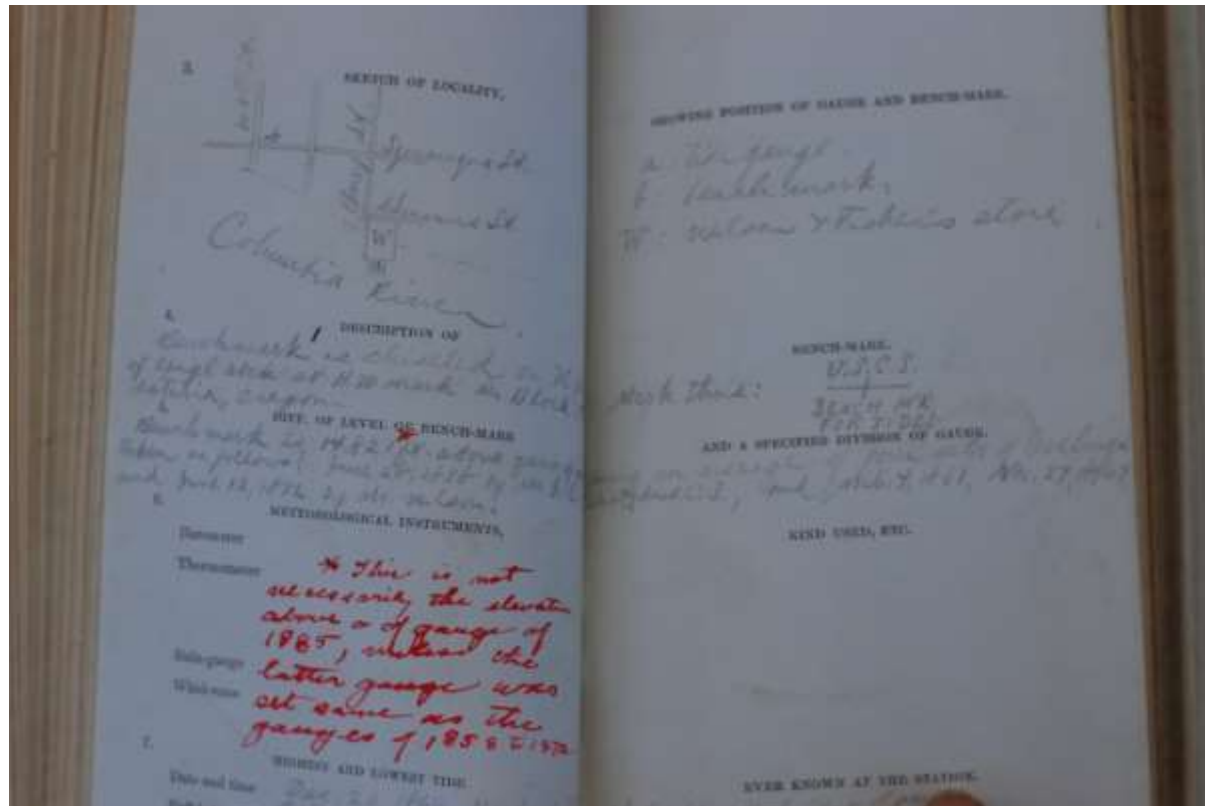
1874-75 = 2.539m

Range 1873-1876 = 2.513m

1875-76 = 2.524



Tide Staff: Comparison to Benchmarks



However, we have found additional information in various notebooks, tabulated data, and the marigrams themselves. These were unknown to the historic tabulators (different government divisions).

Hydrographic survey, 1885

(Note states tide-staff level).



Year	Source	height of BM1 above zero of staff	Plane of Reference (height above zero of tide staff)	Height of BM1 above plane of reference (MLLW)
1853		14.5 ft		
1868	1868 hydrographic survey (USCS)		5.3 ft	
1880	Army Corp report on tide readings at Fort Canby			9.547 ft
1883	Superseded summary sheet (probably from 1936)	14.93 feet		
1884	Superseded summary sheet (probably from 1936)	9.57 feet		
1885	Hydrographic survey (USCG&S)	14.821 (average of 4 surveys from 1858-1872)	5.274ft (average MLLW from 1859- 1867)	9.547 ft
1887	Benchmark survey by Pratt			9.55 ft (BM2 = 9.57 ft)
1889	Letter to USCG&S with information about 1889 tide staff	14.93 feet	5.38 feet (note similarity to 1883/1884)	9.55 ft
1889	Superseded Benchmark sheet (used in 1910)	14.83 ft	5.3 ft	9.53 ft
1910	Superseded Benchmark Sheet	14.83 feet (Staff of 1876)		

Tide Staff results

Quite a lot of information has
been found

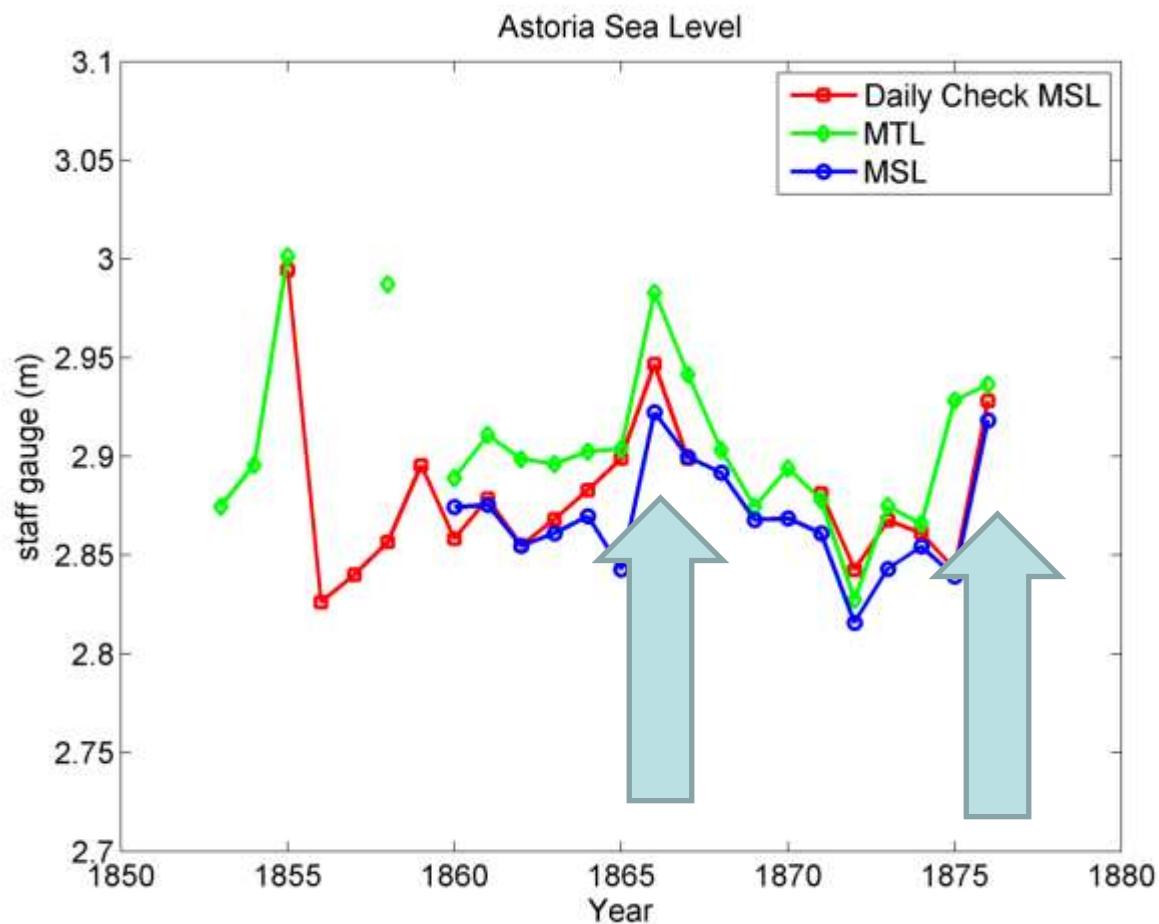
Results of sleuthing:

1856-1876: The tide staff
was 14.82 feet over BM#1.

1853-1855: The tide staff
was 14.5 ft over BM#1



Results: Preliminary Sea-level



Results from 3 different data sets are consistent with each other.

The 'daily check' mean sea-level is from the twice-a-day gauge checks, after removing the predicted tide

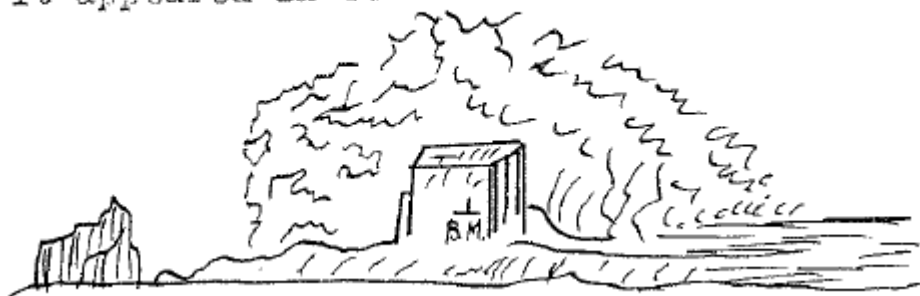
No trend discernable.

1866 and 1876—large flow years.



Sea-Level: Tying to Modern Gauge

Sketch of Astor Rock
as it appeared in 1853.



Original 1853
Astoria
benchmark
on backside

The original benchmark may possibly still
exist...but at least 3 feet of rubble buries it.

Instead, we use Benchmark F31 from the
Courthouse steps.

--In 1920, this benchmark was placed
relative to 1873-1876 sea-level datum.

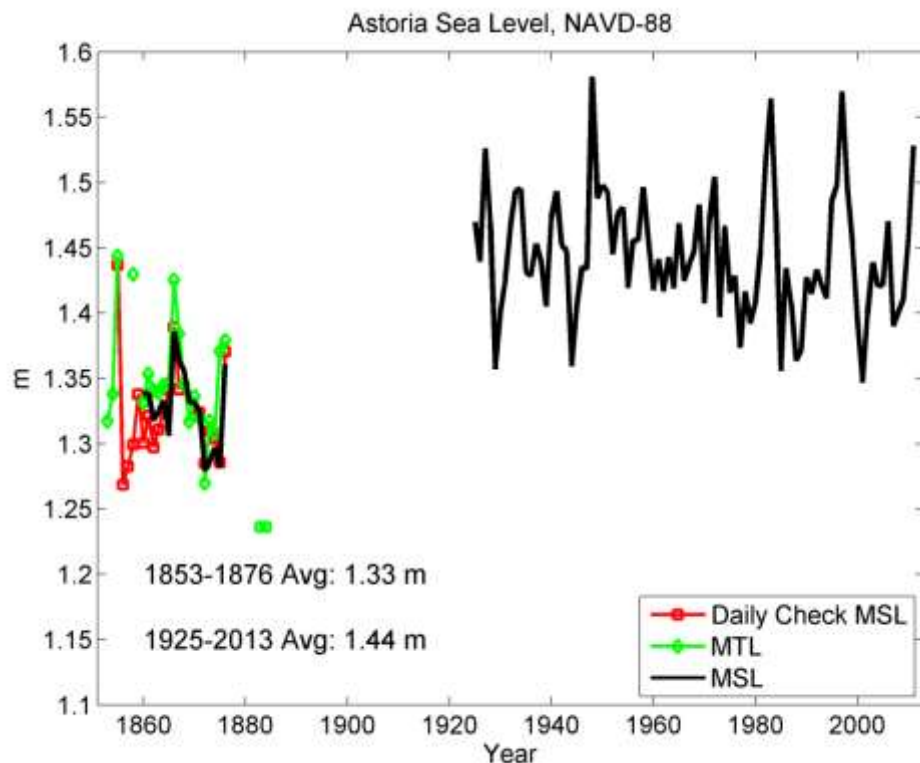
--It is presently defined relative to NAVD-88



Benchmark F31, 1920:
Tied to both old gauge
and modern datums



Sea-Level: Preliminary Results



The historic and modern data are offset by 10 cm,
but no trend discernable.

Perhaps benchmark is unstable?

→ More benchmarks need to be found.



Original 1853
Astoria
benchmark
on backside

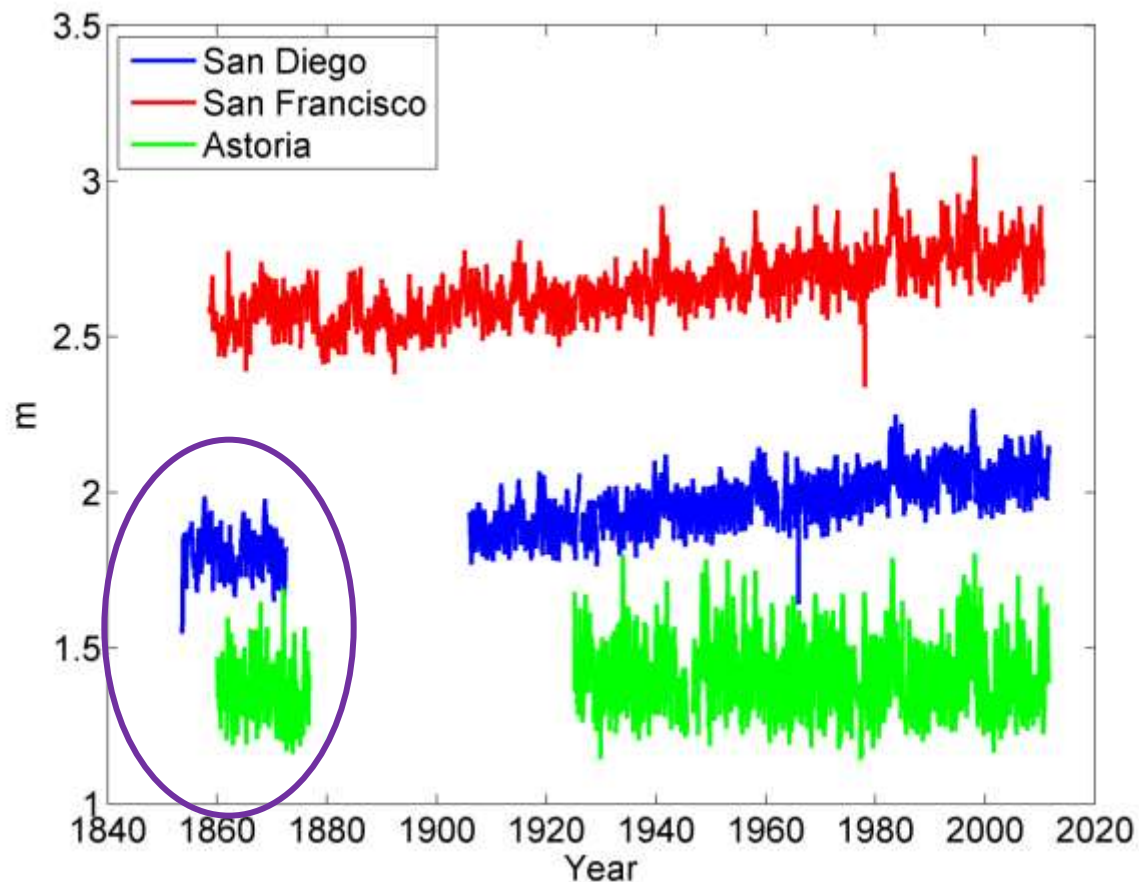
15th &
Commerical



Benchmark F31, 1920:
Tied to both old gauge
and modern datums



Sea-Level: Preliminary Results



Data recovered by Talke & Jay



Original 1853
Astoria
benchmark
on backside



Benchmark F31—it seems to have
subsided 0.2 feet relative to other
benchmarks



Sea-Level: Next Steps

Benchmark	1926 GIVEN MSL (ft)	NGVD 29	NAVD 88 (ft)	Diff NAVD88 – 1905-6 datum surveyed 1926, 1929	Diff NAVD88 NGVD29
S 31 (A 3): Fort Stevens BM [adj 2002]	19.23	20.2	23.8	4.57	3.6
A31 (Hammond)	11.129	12.13	15.74	4.611	3.61
R31 (Fort Stevens)	13.573	14.6	18.20	4.627	3.6
F31(Astoria) warning	18.766	19.84	22.91	4.204	3.3
H31 (45°/Cedar Astoria) [Between town and Tongue Point] warning	19.58	20.6	24.03	4.45	3.43
P 1 (Astoria Youngs Bay)	11.919	12.96	16.48	4.56	3.52
J 31 Reset (adjusted) (Knappa)	11.627	12.54	15.98 (15.9 ft posted)	4.35	3.44
L 31 (Aldrich Point)	12.169	12.97	16.32	4.15	3.35
P31 (Svenson)	8.921	9.77	13.17	4.249	3.4
Tidal 1 Tongue Point 1925 warning	15.44	16.48	20.13	4.69	3.65
Tidal 3 (last found 1952)	14.36	15.3			
Tidal 4	7.59				
943 9040 TIDAL 7 Tongue Pt vert. movement probable 1939 warning		31.21	34.62		3.41
Tidal 8 Tongue 1940 warning		14.47	17.72		3.25
C 421 1.5mi SW Astoria		6.76	10.4		3.64
E 472 200°/commercial Astoria 1941 warning		18.82	22.15		3.33
F 472 1941 300° Franklin East Astoria warning		26.84	29.28		3.44
T 100 Astoria 10/11° street, 1930 PGE		17.12	20.45		3.33
T 263 Astoria SE corner 7° and Bond, 1941; warning		19.55	23.04		3.49
X 100 Astoria downtown (1931)		18.14	21.58		3.45
Y 100 Astoria downtown (1931)		18.41	21.75		3.32
Z 100 Astoria downtown (1931)		19.34	22.81		3.47
W 100 Astoria Downtown (1931)		20.05	23.5		3.45
V 100 Astoria (Downtown)		18.53	22.05		3.52
W 193 Port Docks 1926		14.2	17.72		3.52
P 287 (Astoria) from 1940 (still exists)		18.46	22.87		3.41
Tidal 11 Tongue Point Benchmark of record since 1962 (Burgette)			17.43		
Tongue Point Station Datum		5.56	2.02 ft		3.54



Original 1853
Astoria
benchmark
on backside

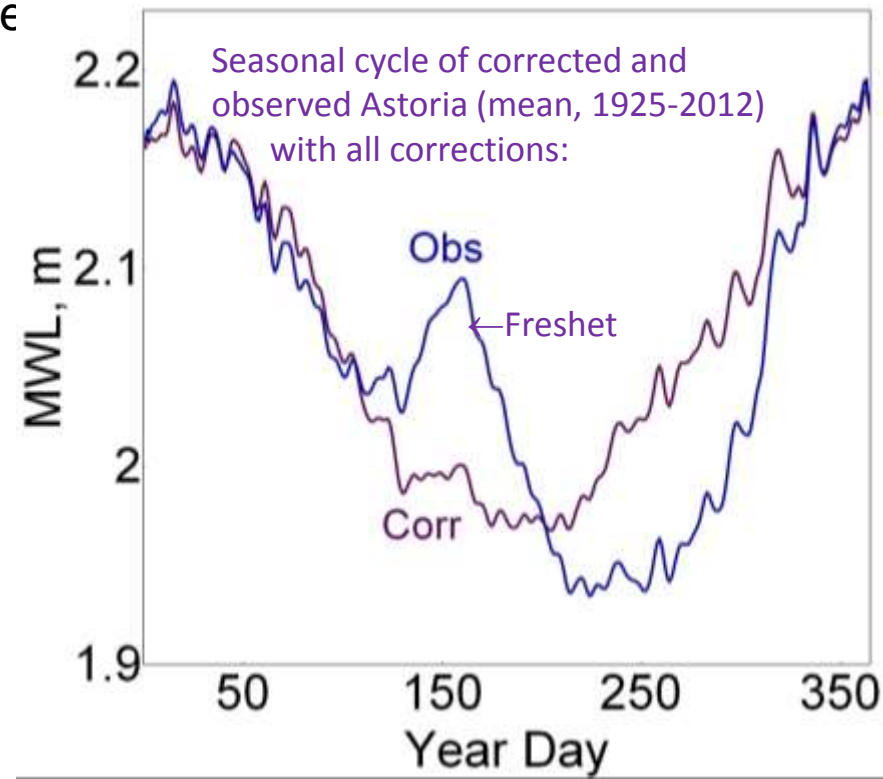
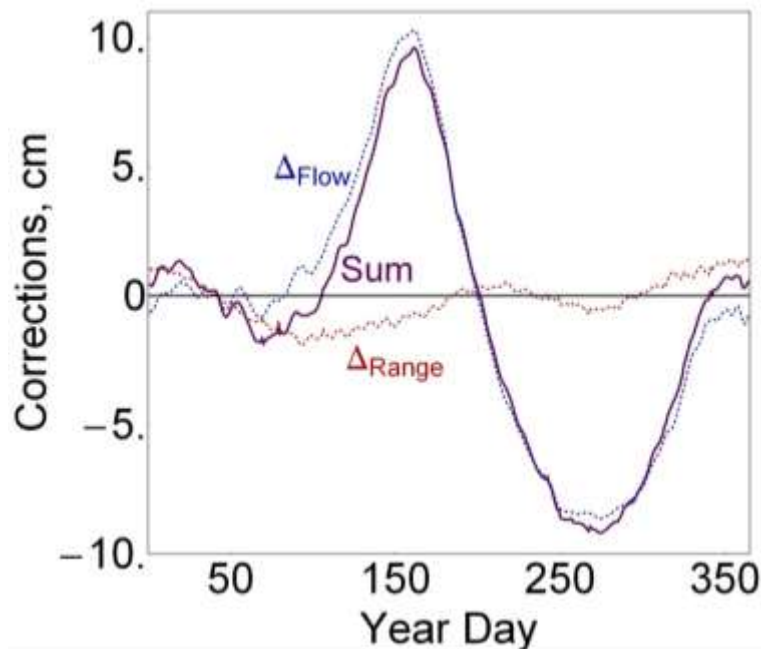
Comparisons of benchmark heights vs. time can help determine the relative stability of F31 (and other benchmarks)

Regression Models of Astoria MWL –

- daily MWL can be modeled as:

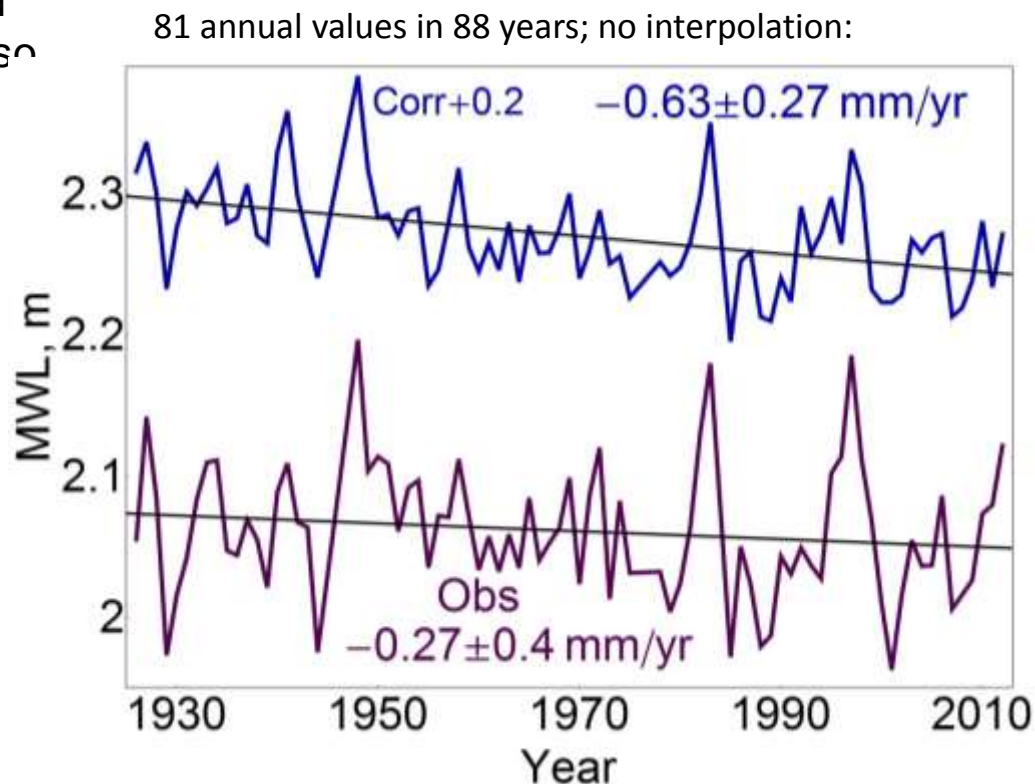
$$\text{MWL} = f[\text{tidal range, river flow, atm pressure, upwelling index}]$$
- This type of model:
 - Captures 75-80% of MTL variance in SF Bay, 90-95% in Astoria (Columbia River)
 - Makes it easier find the 5-20% of the variance that relates to MSL rise
 - Allows correction of MWL times series for long-term changes in river flow and harbor dynamics –changes estimated MSL rise

Entire 1925-2012 daily MWL time series
 Largest corrections to MWL: changing range and flow (mean, 1925-2012):



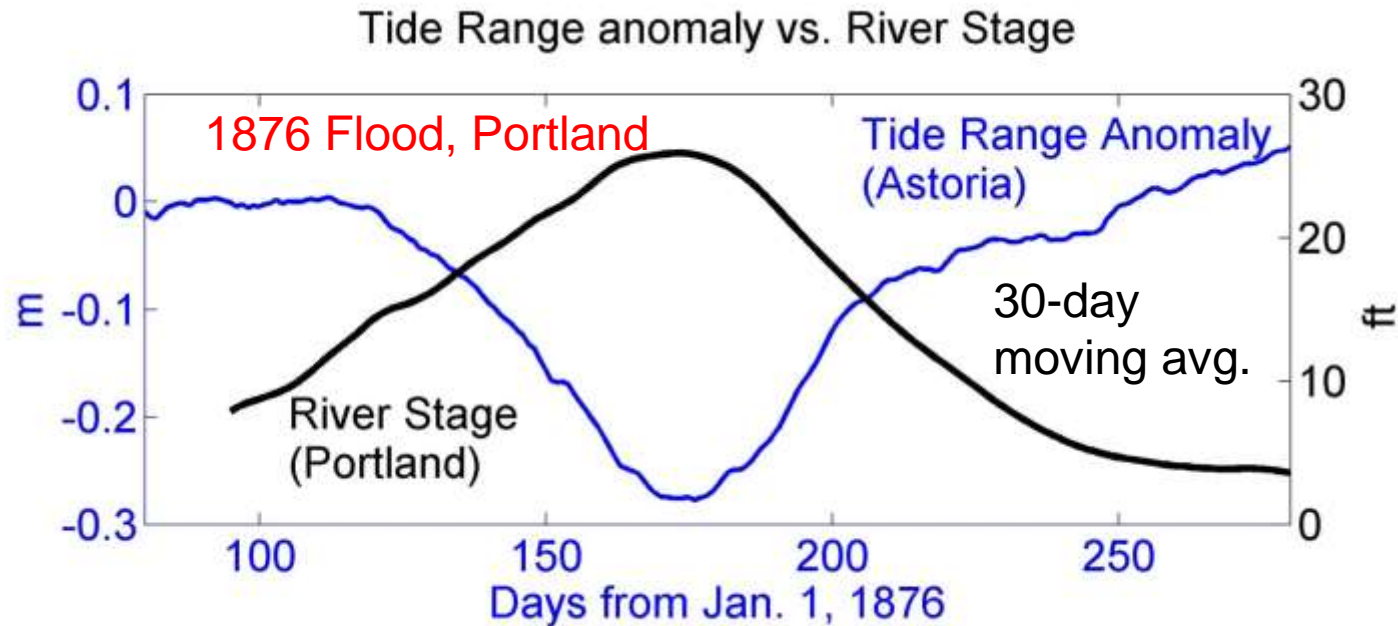
Estimating Astoria MSL Rise –

- Time series of MSL 1925-2012, before and after corrections:
 - Apparent MSL has been “propped up” by increasing tidal range, which increases the slope between the ocean and the gauge at Rkm-30
 - Correcting to long-term average range decreases MSL more than correcting for reduced flow increases it
 - Vertical land motion from GIS is 0.69 ± 1.1 mm/yr
- Conclusions:
 - In relative terms, MSL has fallen since 1925, but this is accounted for entirely by vertical land motion
 - We have a record that can be used for MSL analysis, but – we have also found previously undetected errors (next slide)





Next: Historical River flow and extreme events

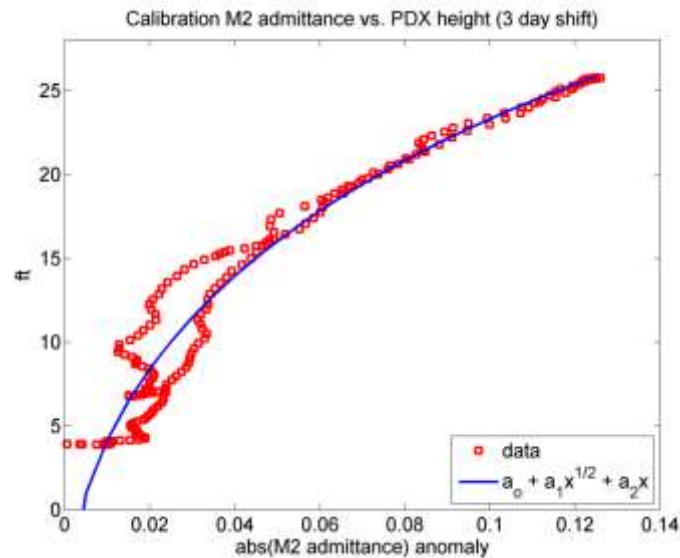


Observation: Tidal range decreases as river flow increases (see Moftakhari et al., 2013 and Jay & Kulkulka, 2003). **Therefore, a tide gauge is also a river flow gauge!**

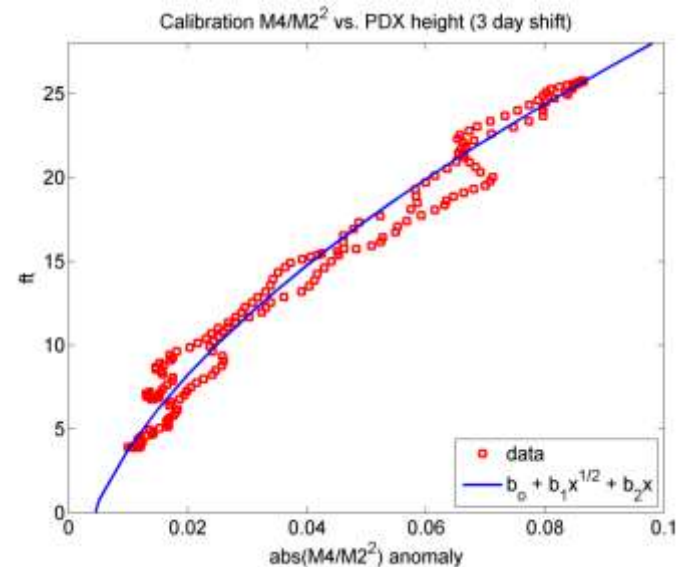
D. Jay will discuss details in a talk later this quarter.



Calibration: --32 day harmonic analysis vs 32 day mean flow
-- Stepped forward by 1 day at a time



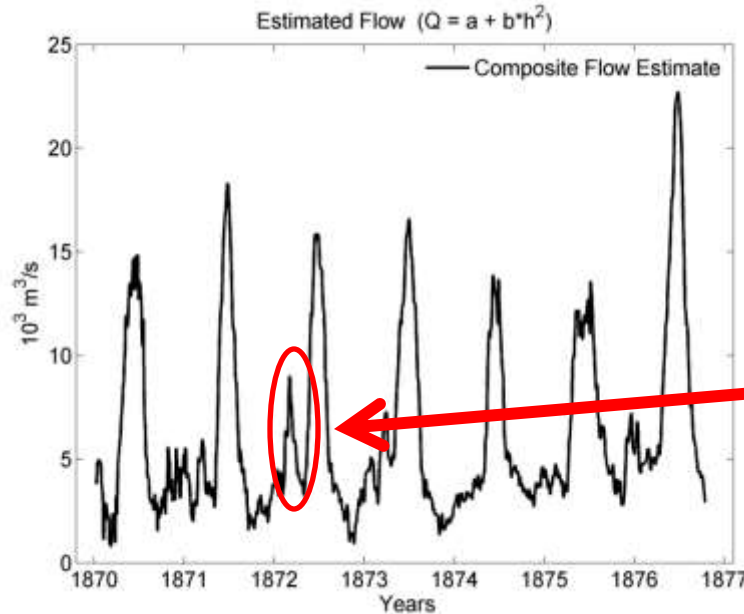
M2 Admittance calibration



M4/M2² calibration

→ Admittance calibration better at high flow; M4/M2² better at low flow

Therefore, we use Admittance for high flow, M4/M2² for low flow



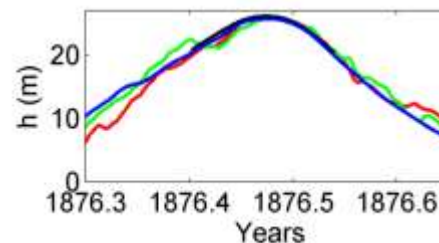
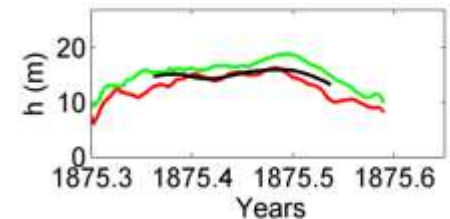
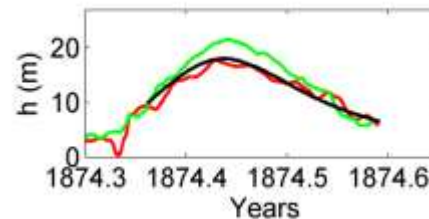
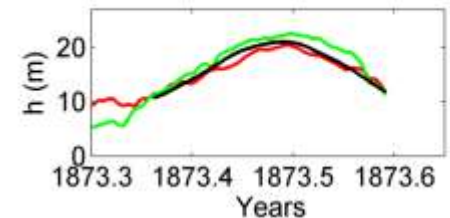
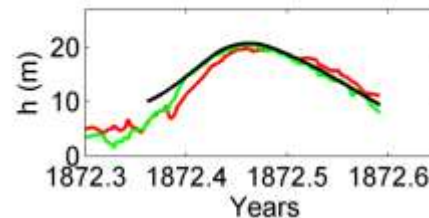
Flow reconstruction shows yearly freshet

Also evidence of 'almost lost to history' winter floods of $\sim 8k \text{ m}^3/\text{s}$

flow reconstruction matched data from Vancouver, WA

→ Major flow events are being captured.

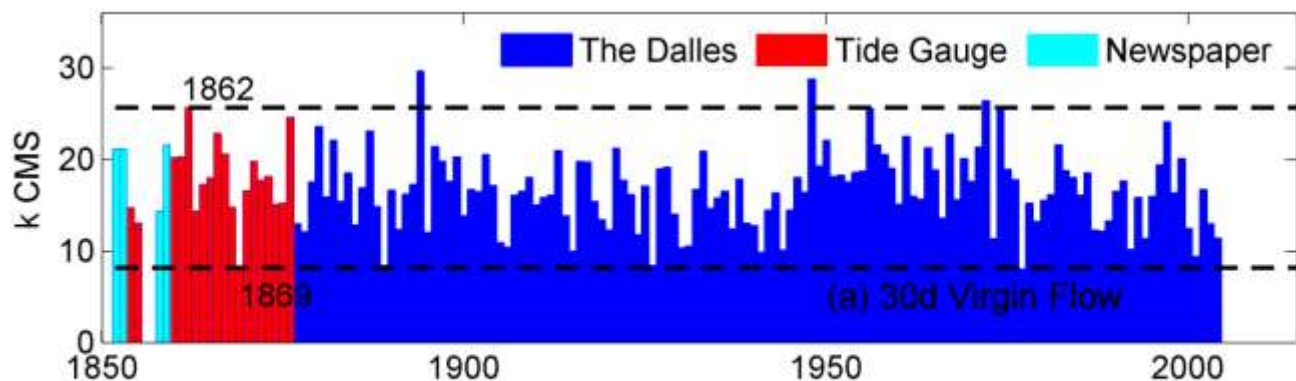
(However, low flow events are more uncertain)



— M2-admit
— M4/M2²
— Vancouver
— PDX

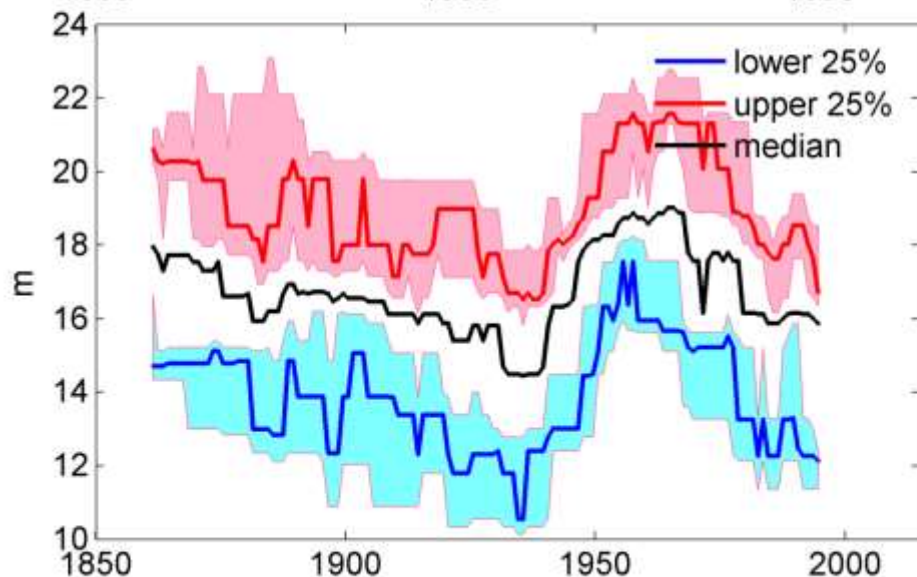


Annual Peak 'Virgin' f'low for the Columbia River 1852-2004



'Virgin' Flow estimates from Naik & Jay, 2005

(Note extreme drought in 1869; large freshets in 1862, 1866, and 1876)



Top 10 Virgin 30d Flows

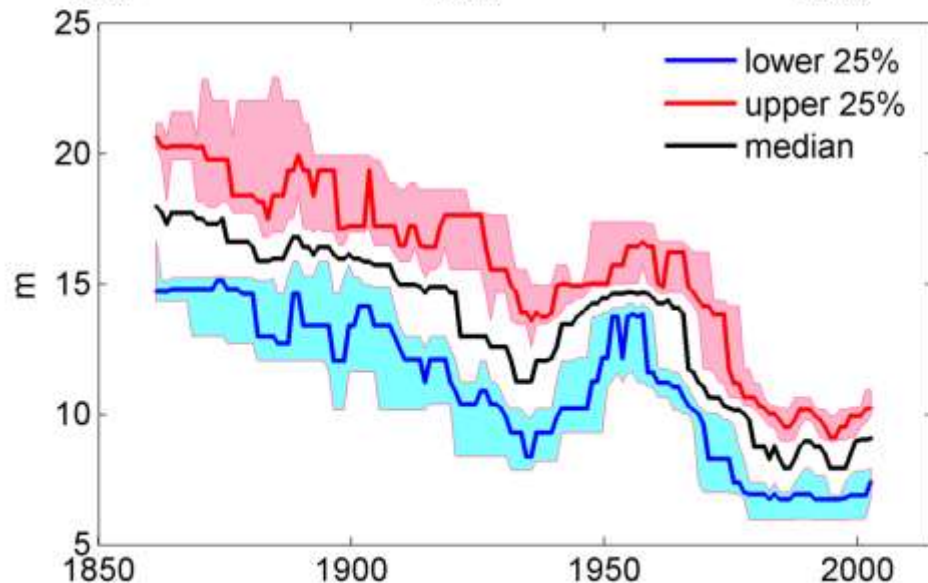
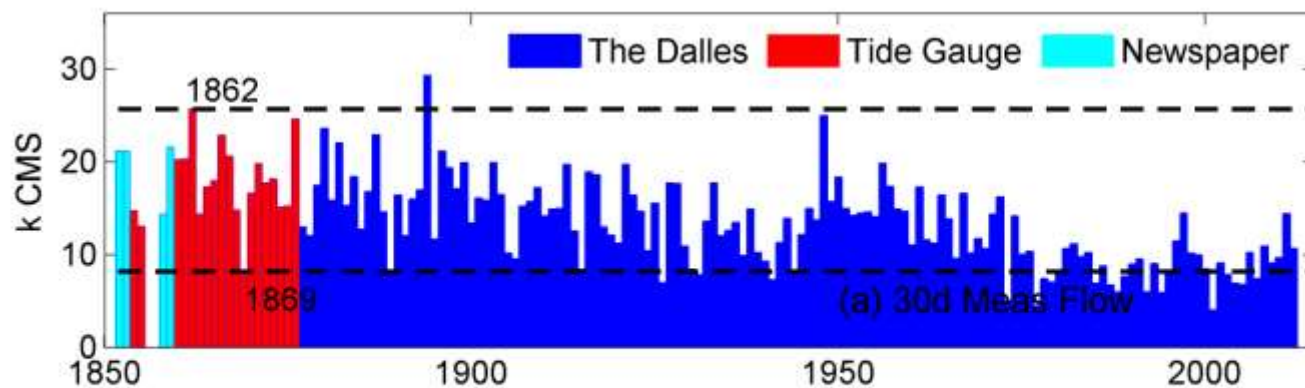
- (1) 1894
- (2) 1948
- (3) 1972
- (4) 1862
- (5) 1956
- (6) 1974
- (7) 1876
- (8) 1997
- (9) 1880
- (10) 1887

A 20 year running average has been applied

Marked Pacific Decadal Oscillation in Flow; No obvious trend



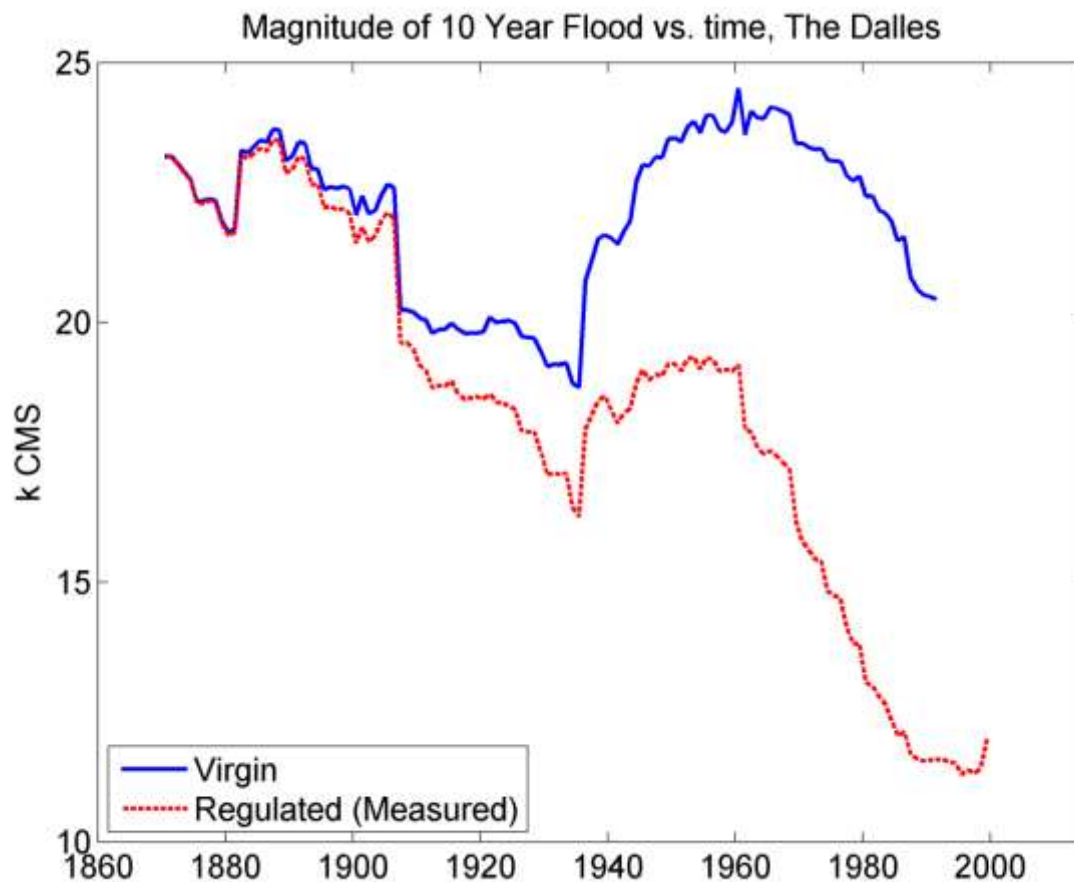
Contrast with actual Measurements



Top 10 Meas 30d Flows

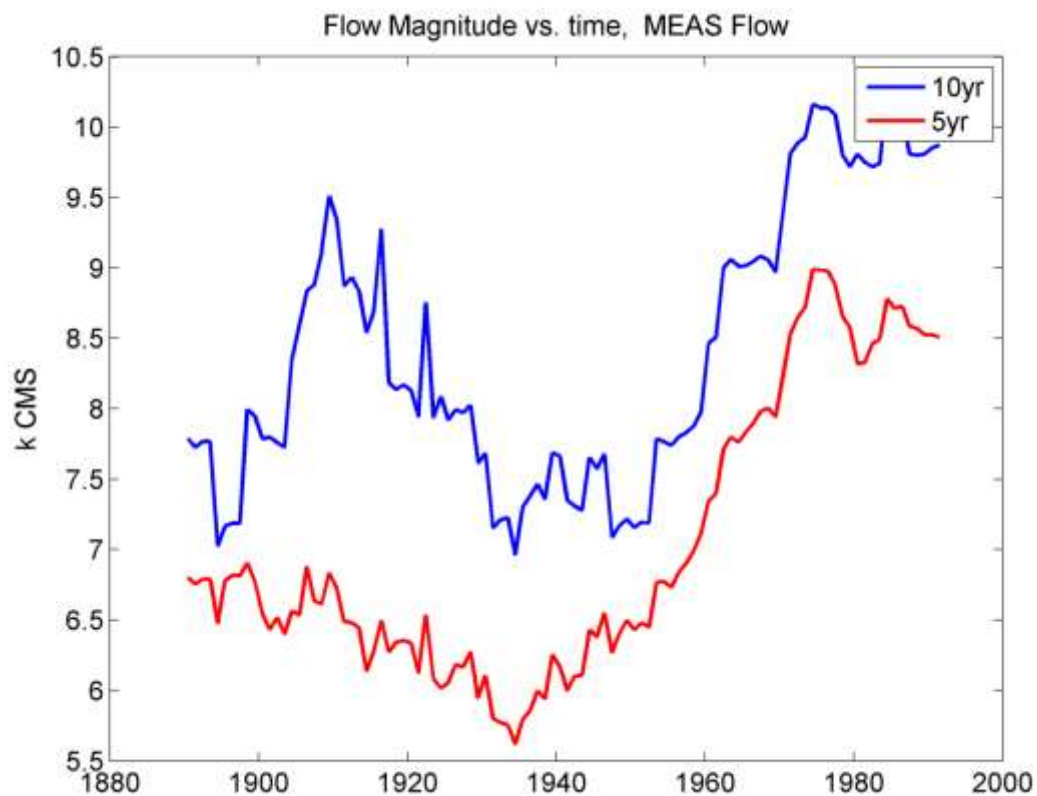
- (1) 1894
- (2) 1862
- (3) 1948
- (4) 1876
- (5) 1880
- (6) 1887
- (7) 1866
- (8) 1882
- (9) 1859
- (10) 1852

The river is now in permanent 'drought', relative to historical norms



10 Year Flood

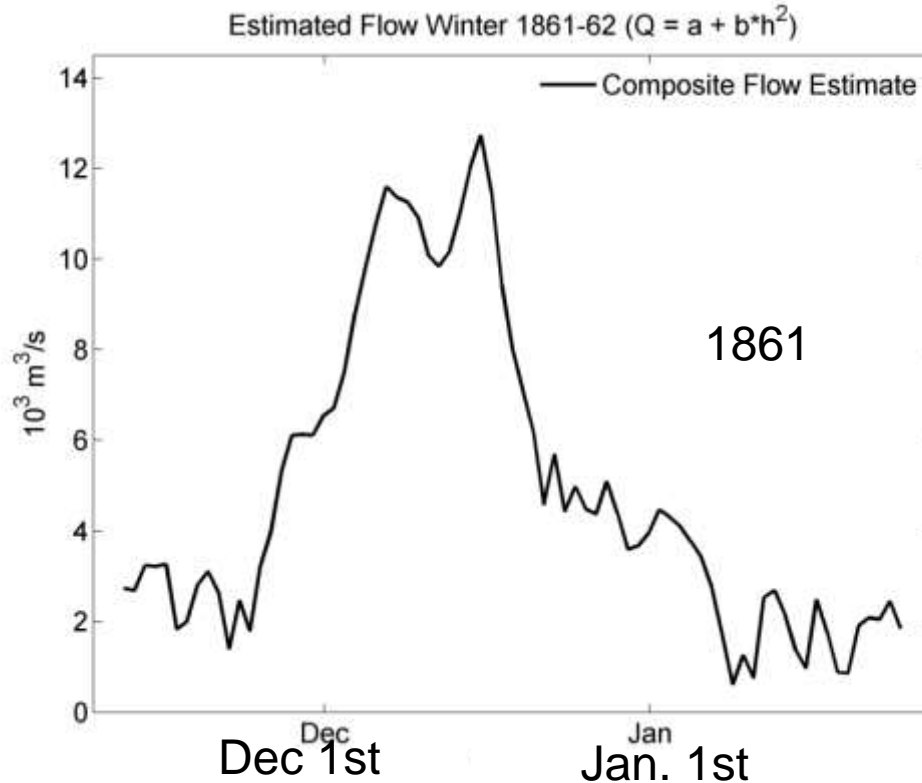
(or rather, the flow with a 10% annual probability of occurring)



Winter flows are increasing



However, largest winter flow still appears to be the 1861 flood, which is 15-20% large (over 30d period) than the 1964 Xmas Day flood

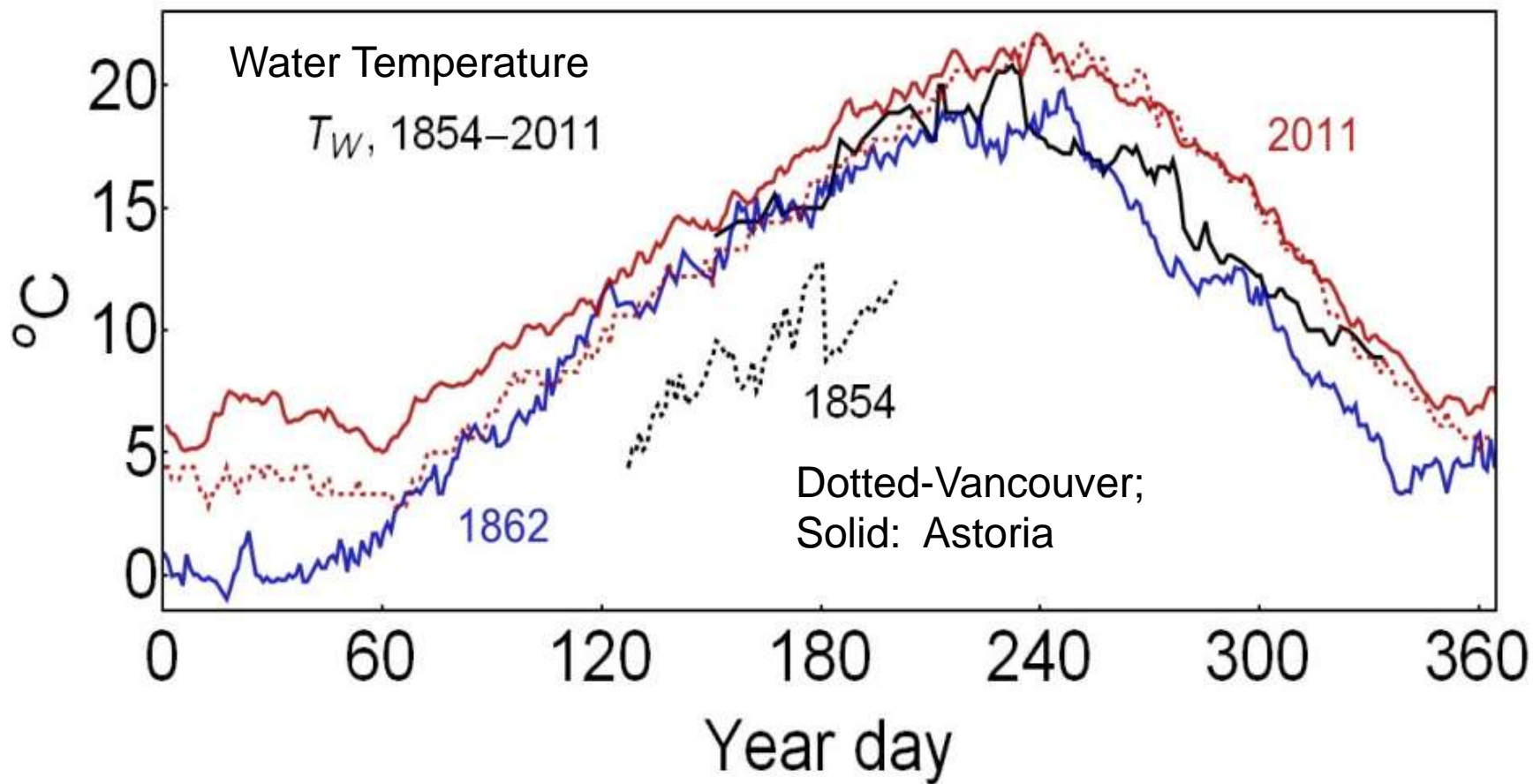


Peak flow $\sim 13\text{k m}^3/\text{s}$

Minimum Flow $< 1\text{ k m}^3/\text{s}$

Double Peak—
Willamette First, then the
Columbia(?)

Note: Still provisional result.
Calibration can still be
improved; 95% ci needs to be
assessed



Water temperature depends on flow rate, air temperature.....



Jan 21. Stand. P. Snuff stood higher - Temp "18-49"

Removed the gauge from the gauge house, which threatened every moment to be washed away by the heavy breakers. - That portion of the wharf, to which the structure was braced was carried off. -

Jan 21. Stand. P. Snuff 21.1 higher - Put the gauge into the house again the hull having gone down somewhat. -

Jan 21. 5.30 P.M. The structure, not being braced, swayed to & fro, stopping the clock & setting it again & again.

Conclusions

--19th century data shows that sea-level rise is not (yet) a large issue

--Changing river flow due to direct anthropogenic intervention is a much bigger effect

--However, it's not only the flow that has changed. See next talk...

Thanks.



Jan 11. about 10. Drift 2 ft. higher - Temp 44°

Removed the gauge from the gauge house, which threatened every moment to be washed away by the heavy breakers. — That portion of the wharf, to which the structure was braced was carried off. —

11 A.M. Sea 19. Drift 2 ft. higher - Put the gauge into the house again the swell having gone down somewhat.

Jan 11

5.30 P.M. The structure, not being braced, swayed to & fro, stopping the clock & setting it again.

“Removed the gauge from the gauge house, which threatened every moment to be washed away by the heavy breakers—that portion of the wharf to which the structure was braced was carried off.”

Tide Observer, San
Francisco, Jan. 1862

Thanks.