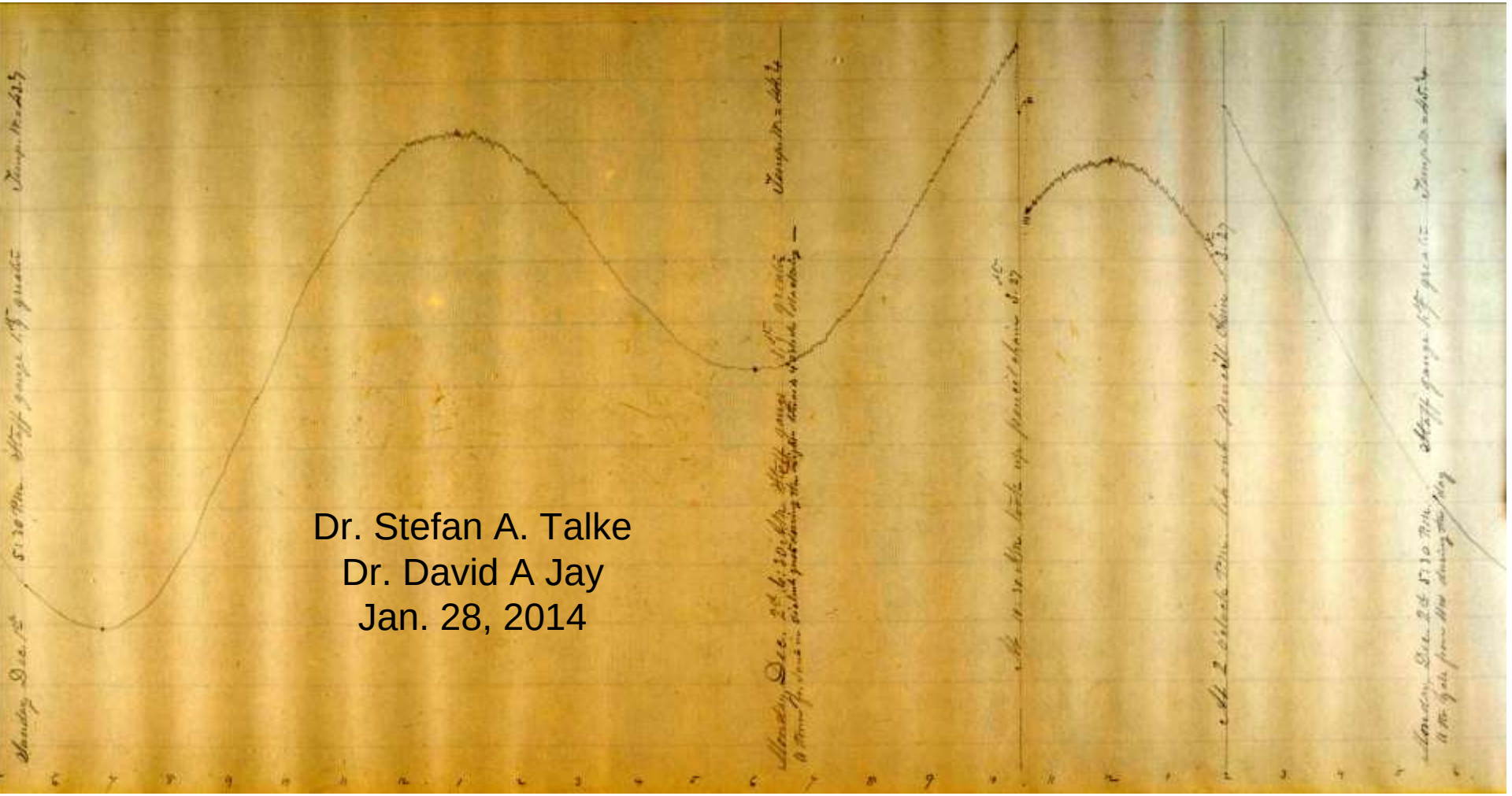
Water levels and extremes in the Columbia River Estuary since 1853



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

Portland State UNIVERSITY

Tide in Astoria, OR, Dec. 2 1861
(from US National Arrchives)

Walluski River, King Tide, Lower Columbia River Estuary

The Setting: The lower Columbia River Estuary

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

Of particular concern:

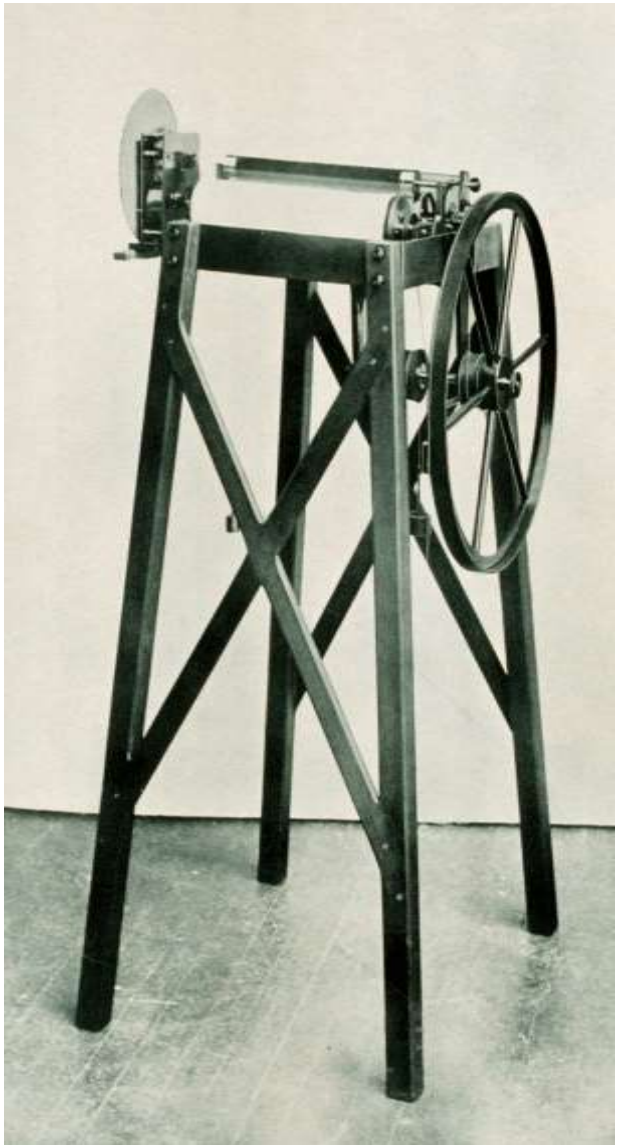
--water levels
--water temperatures
--extreme events

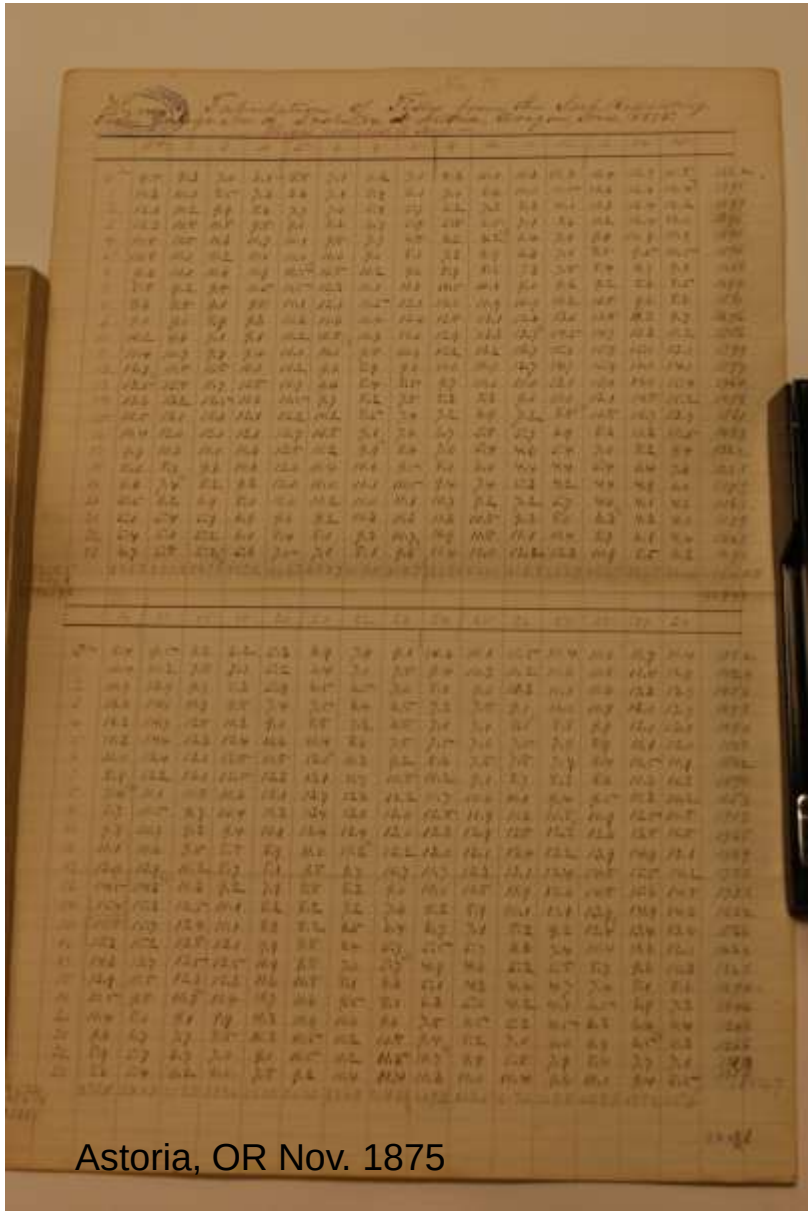
The future may be uncertain; but perhaps some lessons may be learned from the past.

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. Coasltal Research)

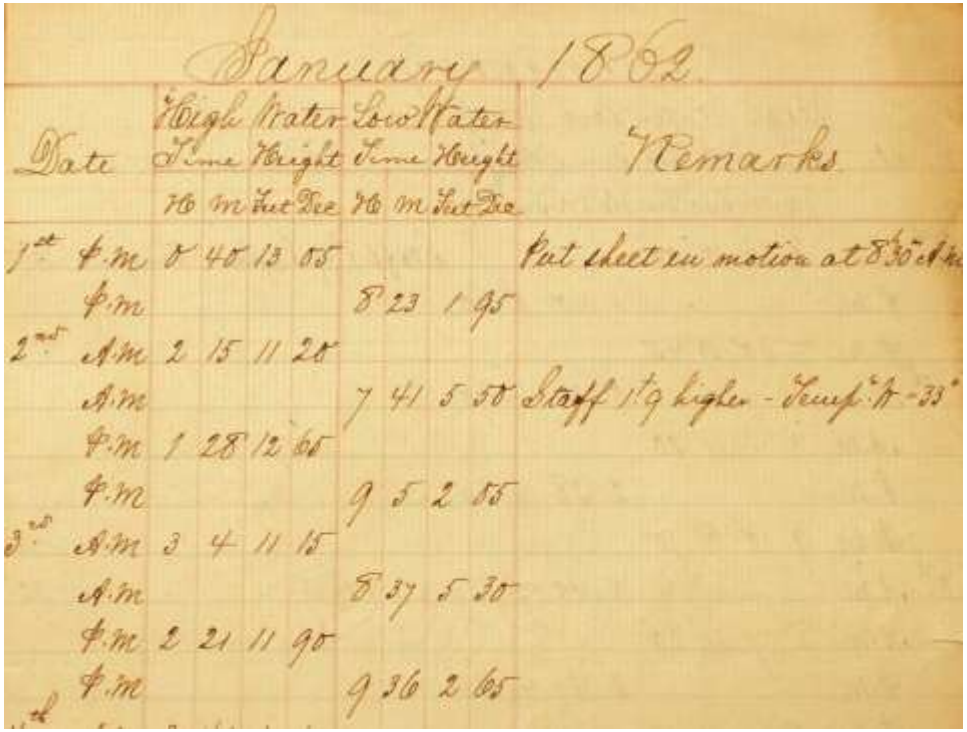
Astoria 1862 marigrams





Astoria, OR Nov. 1875

Astoria hourly measurements (1870-1876)…

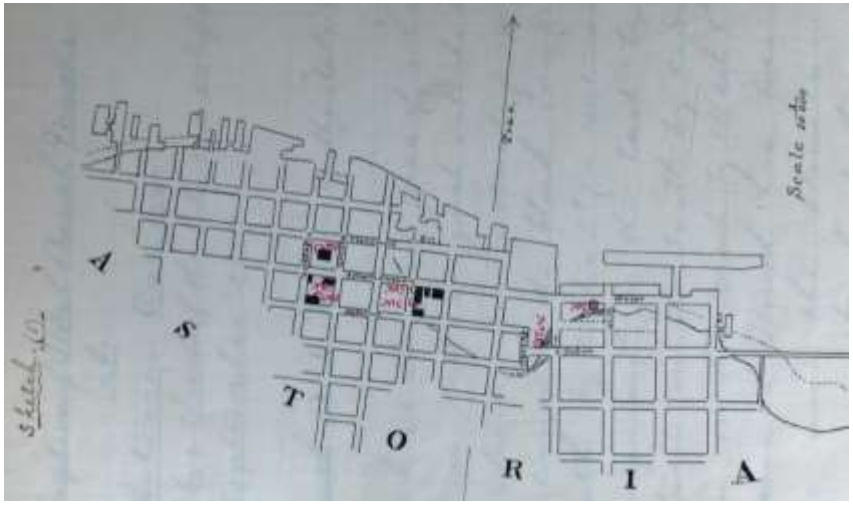


January 1862

Date		High Water Time	High Water Height	Low Water Time	Low Water Height	Remarks
		H M	Feet Dec	H M	Feet Dec	
1st	P.M	0 40	13 05			Put sheet in motion at 8 35 A.M.
	P.M			8 23	1 95	
2nd	A.M	2 15	11 28			
	A.M			7 41	5 50	Staff 1/2 higher - Temp. A -33°
	P.M	1 28	12 65			
	P.M			9 5	2 55	
3rd	A.M	3 4	11 15			
	A.M			8 37	5 30	
	P.M	2 21	11 90			
	P.M			9 36	2 65	

high/low data from Astoria (1853-1876)

Meteorological register, Jan. 1864

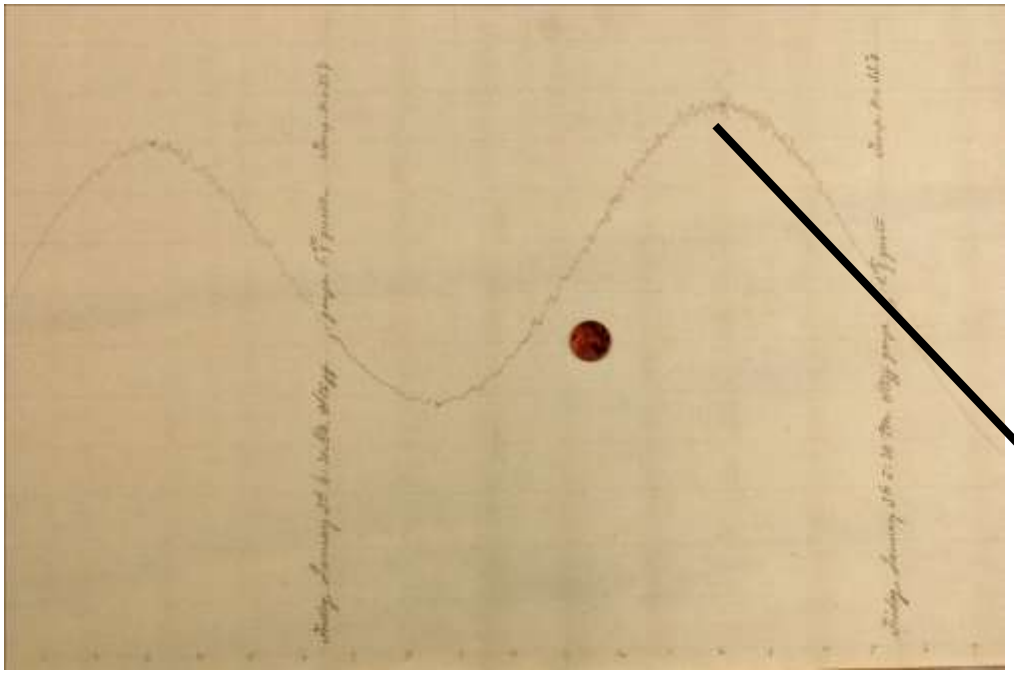


Benchmark map from 1887

Data are being digitized and quality assured

>20,000 pictures of documents for Columbia River

> 250k individual data points entered by students



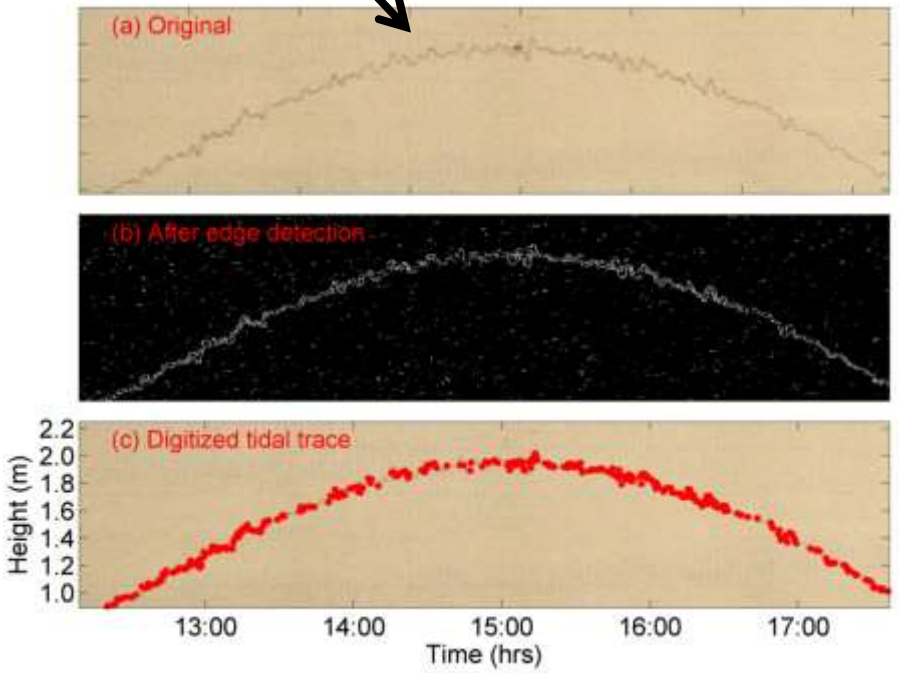
Marigram, Astoria 1862

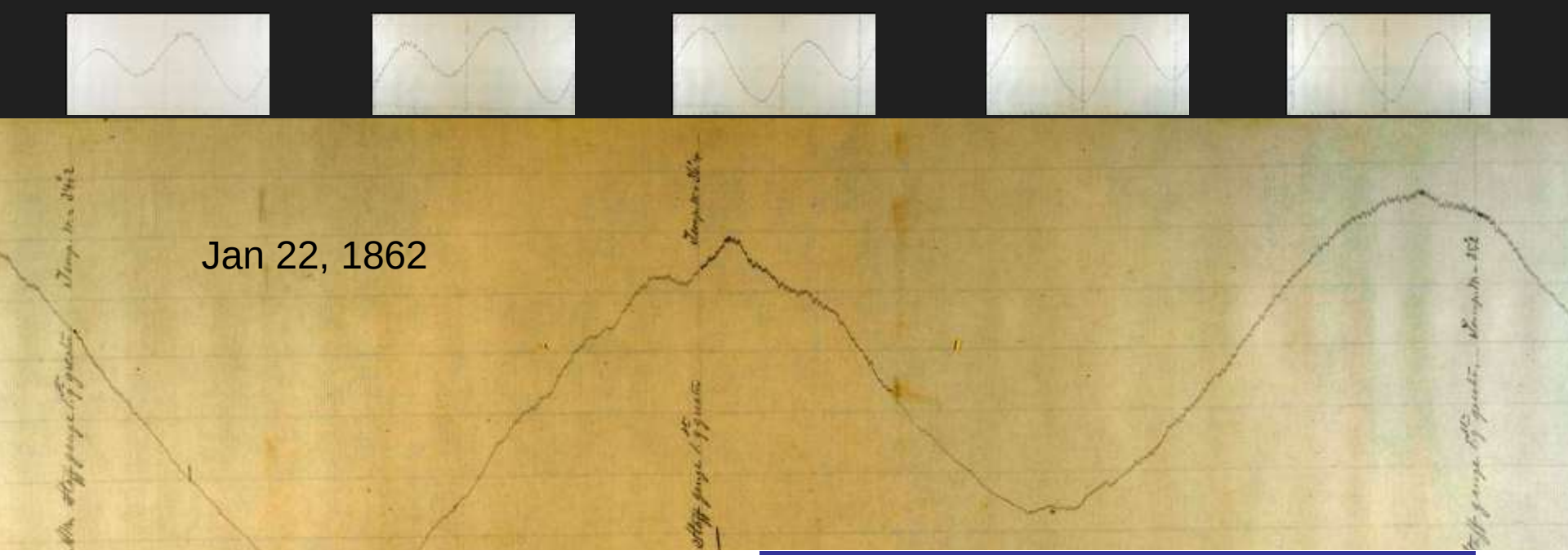
200 scrolls have been photograhed and are being processed into time/height coordinates.

(2 miles of paper, end to end)

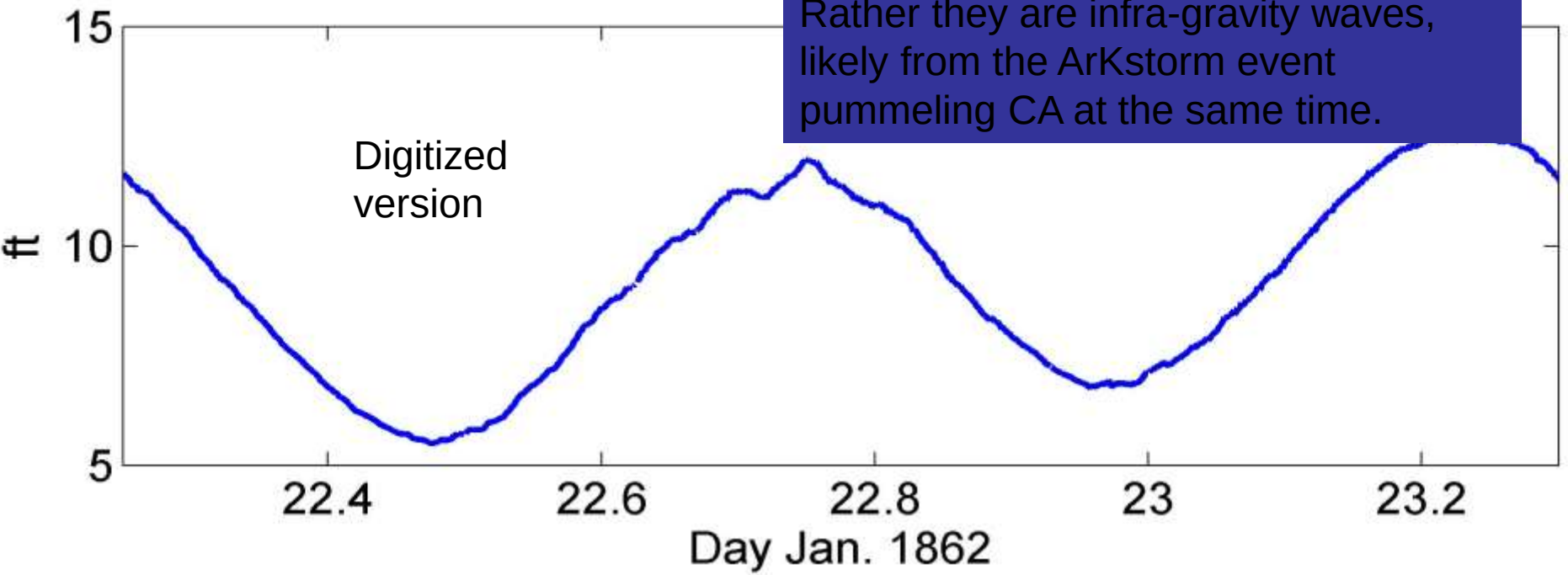
Scaling and rotation done in post-processing, using daily gauge checks for reference

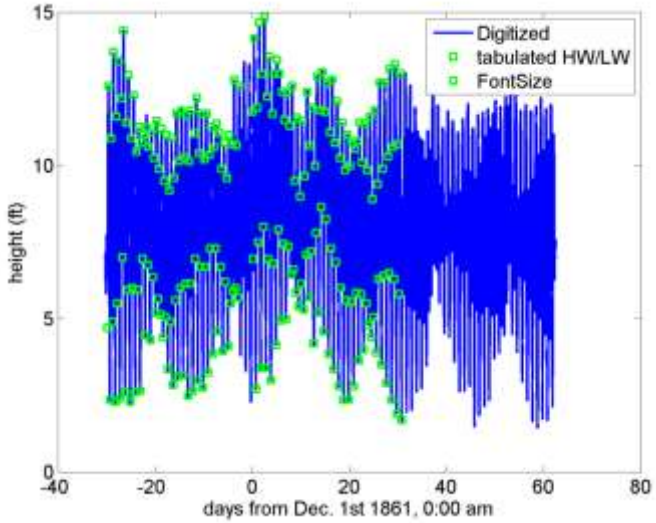
Camera distortion removed via Nikon software; residual distortion is removed during processing.





: The fluctuations are not errors. Rather they are infra-gravity waves, likely from the ArKstorm event pummeling CA at the same time.



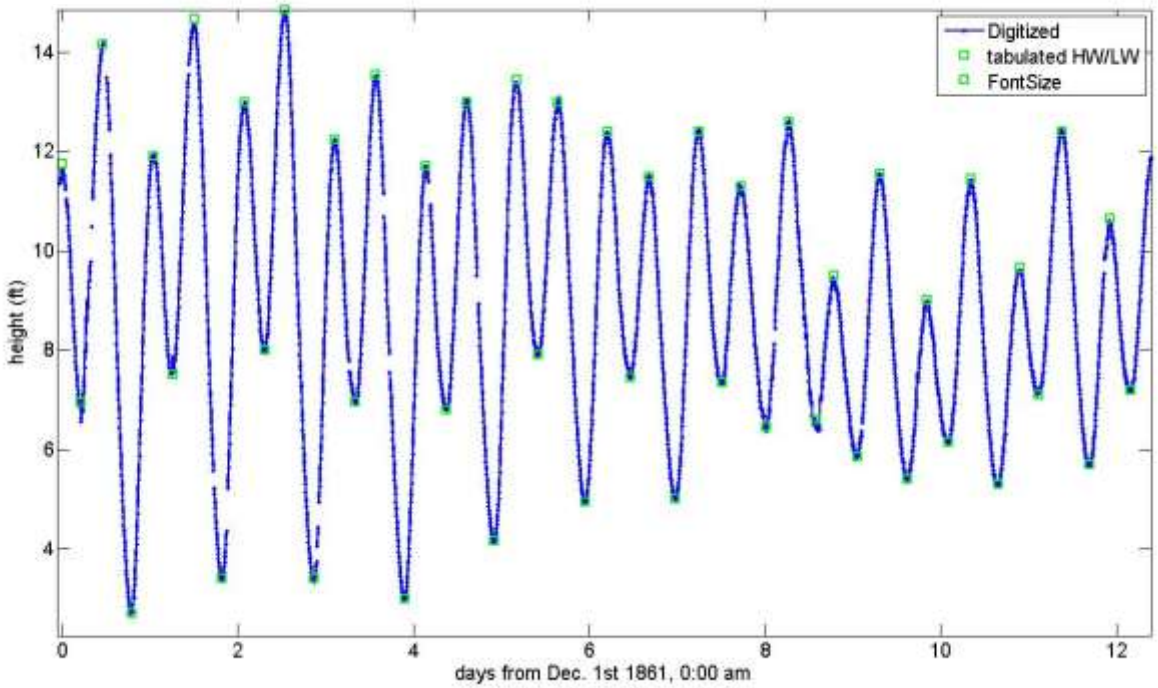


Digitized Astoria data set, winter 1861-1862

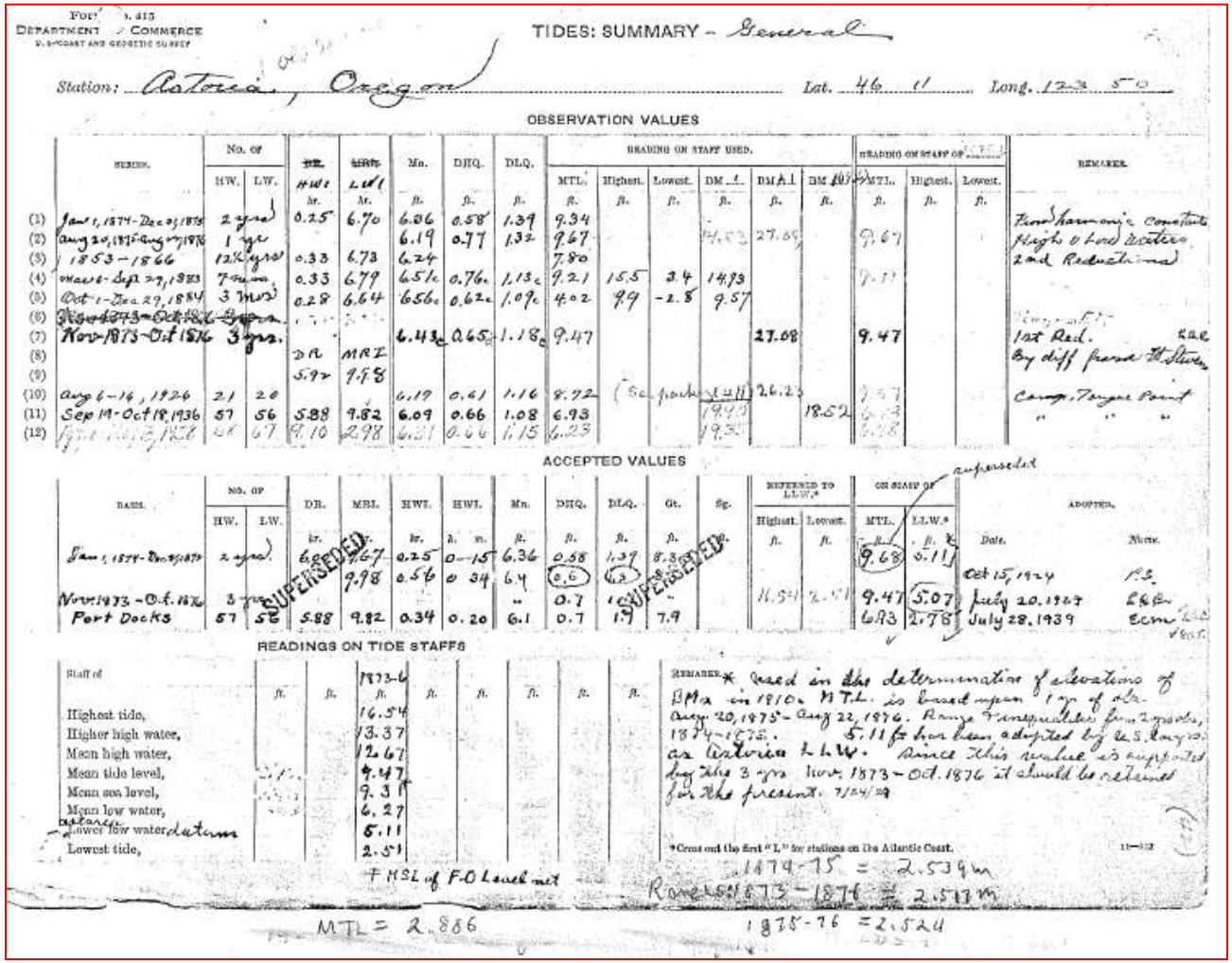
Good agreement between historic High/Low tabulations and our estimate

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

QA ongoing…



Results: Sea-level



DEPARTMENT OF COMMERCE — U. S. COAST AND GEODETIC SURVEY

TIDES: SUMMARY – General

Station: Astoria, Oregon — Lat. 46 11 — Long. 123 5 0

OBSERVATION VALUES

	Series	No. of HW.	No. of LW.	HWI hr.	LWI hr.	Mn. ft.	DHQ. ft.	DLQ. ft.	Reading on staff used: MTL. ft.	Highest. ft.	Lowest. ft.	DM 1 ft.	DM A 1 ft.	DM 2 ft.	Reading on staff of ___: MTL. ft.	Highest. ft.	Lowest. ft.	Remarks
(1)	Jan 1, 1874 - Dec 31, 1875	2 yrs		0.25	6.70	6.36	0.58	1.39	9.34									Tidal harmonic constants, Heights of land waters and Reductions
(2)	Aug 20, 1875 - Aug 22, 1876	1 yr				6.19	0.77	1.32	9.67						9.67			
(3)	1853 – 1866	12½ yrs		0.33	6.73	6.24			7.80									
(4)	March - Sept 27, 1883	7 mos		0.33	6.79	6.51c	0.76c	1.13c	9.21	15.5	3.4	14.93						
(5)	Oct 1 - Dec 29, 1884	3 mos		0.28	6.64	6.56c	0.62c	1.09c	4.02	9.9	-2.8	9.57						
(6)	~~Nov 1873 – Oct 1876~~	~~3 yrs~~																
(7)	Nov 1873 – Oct 1876	3 yrs.				6.43c	0.65c	1.18c	9.47				27.08		9.47			1st Red. By diff from U.S.
(8)				DR	MRI													
(9)				5.92	9.78													
(10)	Aug 6 - 16, 1926	21	20			6.19	0.61	1.16	8.72	(Sc. peaks)		(HH)	26.23					Camp Tongue Point
(11)	Sep 14 - Oct 18, 1936	57	56	5.88	9.82	6.09	0.66	1.08	6.93			19.49		18.52				" " "
(12)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			19.54						

ACCEPTED VALUES

Basis	No. of HW.	No. of LW.	DR. hr.	MRI. hr.	HWI. hr.	HWI. h. m.	Mn. ft.	DHQ. ft.	DLQ. ft.	Gt. ft.	Sg.	Referred to L.L.W.: Highest. ft.	Referred to L.L.W.: Lowest. ft.	On Staff of: MTL. ft.	On Staff of: L.L.W. ft.	Adopted: Date.	Adopted: Note.
Jan 1, 1874 - Dec 31, 1875	2 yrs		6.8	9.67	0.25	0 – 15	6.36	0.58	1.37	8.3				9.68	5.11	Oct 15, 1924	
Nov 1873 - Oct 1876	3 yrs		SUPERSEDED	9.98	0.56	0 34	6.4	(0.6)	(1.3)	SUPERSEDED				9.47	5.07	July 20, 1927	
Port Docks	57	56	5.88	9.82	0.34	0.20	6.1	0.7	1.9	7.9				6.93	2.78	July 28, 1939	

superseded

READINGS ON TIDE STAFFS

Staff of	ft.	ft.	1873-6 ft.	ft.	ft.	ft.	ft.	ft.
Highest tide,			16.54					
Higher high water,			13.37					
Mean high water,			12.67					
Mean tide level,			9.47					
Mean sea level,			9.3					
Mean low water,			6.27					
Lower low water, datum of soundings			5.11					
Lowest tide,			2.51					

REMARKS: * used in the determination of elevations of BMs in 1910. MTL is based upon 1 yr of obs. Aug 20, 1875 – Aug 22, 1876. Range 7 inequalities from 2 yrs, 1874-1875. 5.11 ft has been adopted by U.S. Lake Survey as Astoria L.L.W. Since this value is supported by the 3 yrs obs Nov 1873 – Oct 1876 it should be retained for the present. 7/24/29

*Cross out the first "L" for stations on the Atlantic Coast.

11—932

F.H.S.L. of F.O. Level net

MTL = 2.886

1874-75 = 2.539 m

Rowell 1873 – 1876 = 2.517 m

1875-76 = 2.524

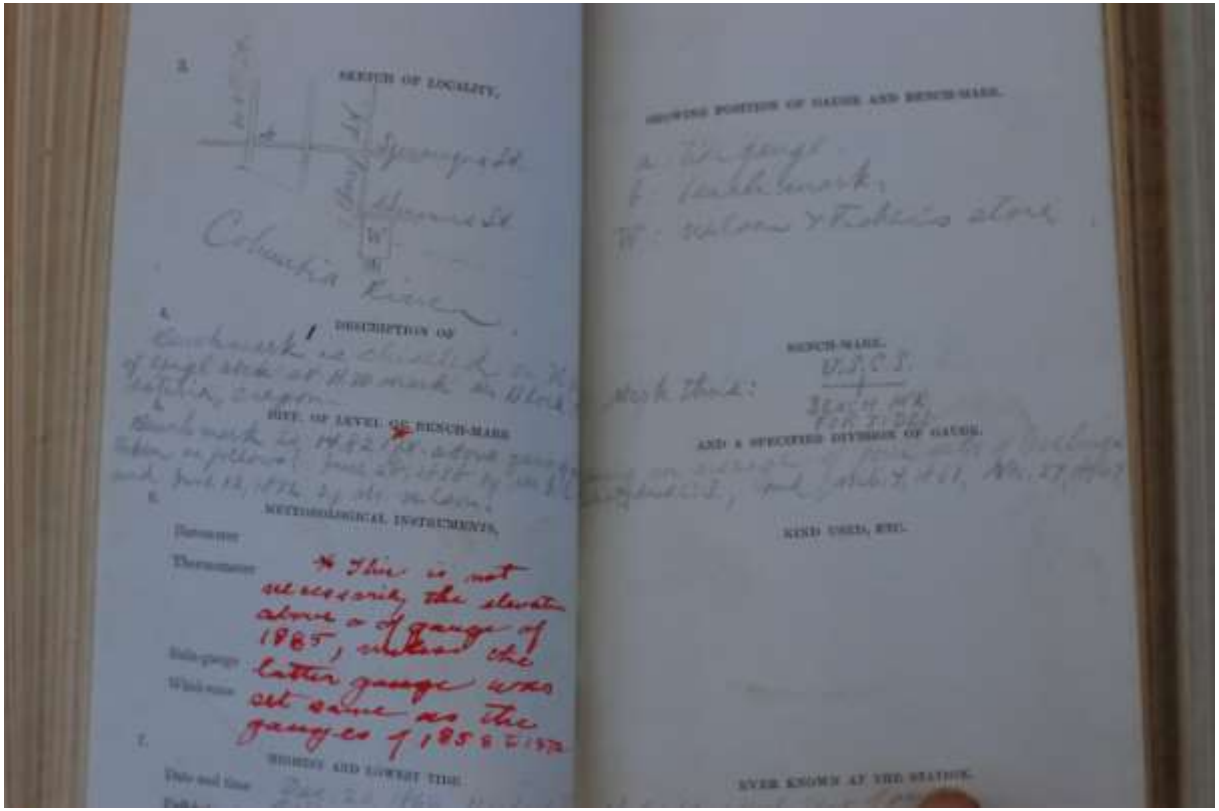
Astoria superseded benchmark sheet, NOAA

An ongoing question has been to determine the height of the measurements relative to land (a benchmark) NOAA's information only back to 1873.

But, the modern gauge is 5 miles away from Astoria, and was never tied to the old series.

US CG&S tried, but failed, to connect the series.

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

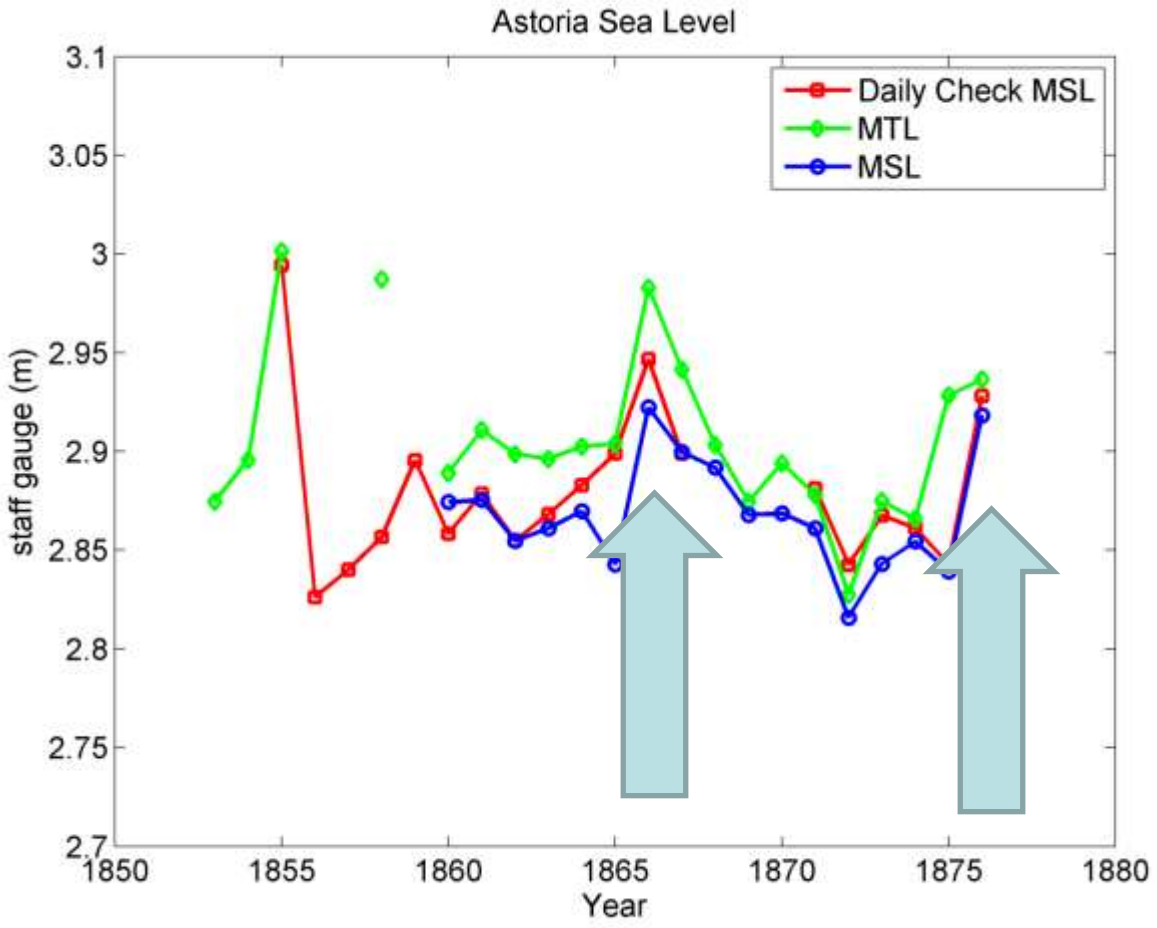
.

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



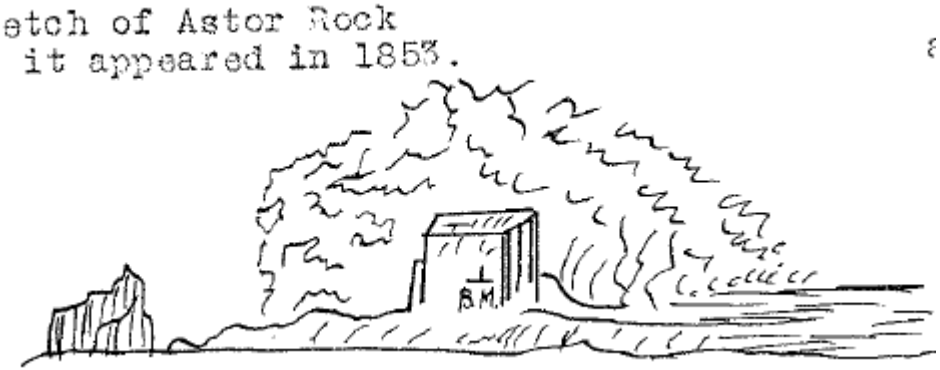
Results from 3 different data sets are consistent with each other.

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



Original 1853 Astoria benchmark on backside

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

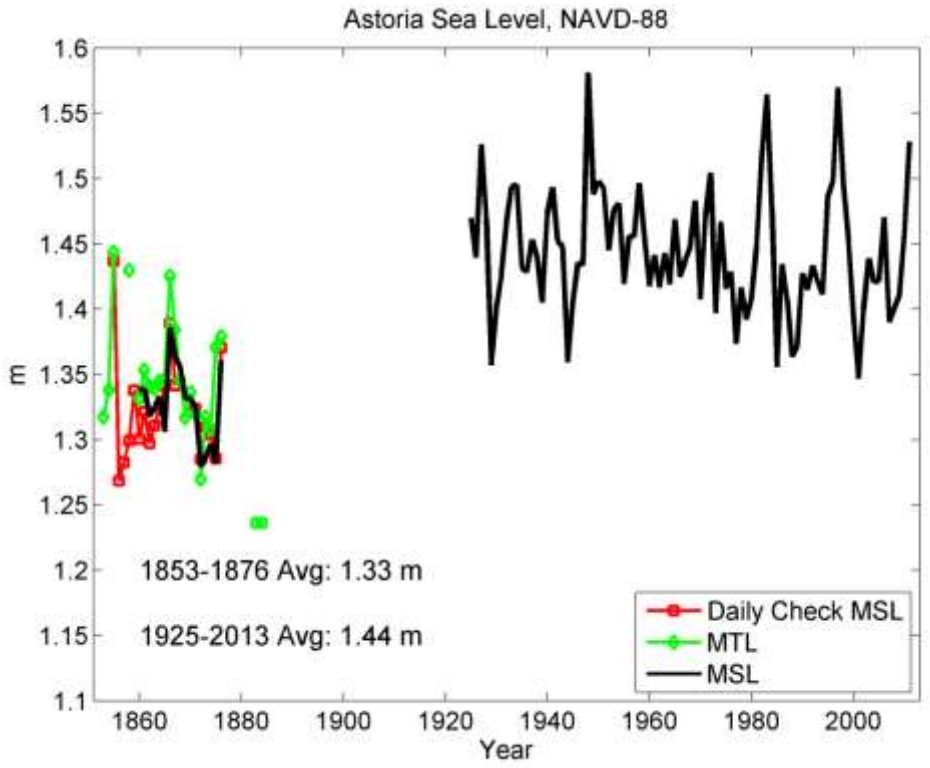
Instead, we use Benchmark F31 from the Courthouse steps.

--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?

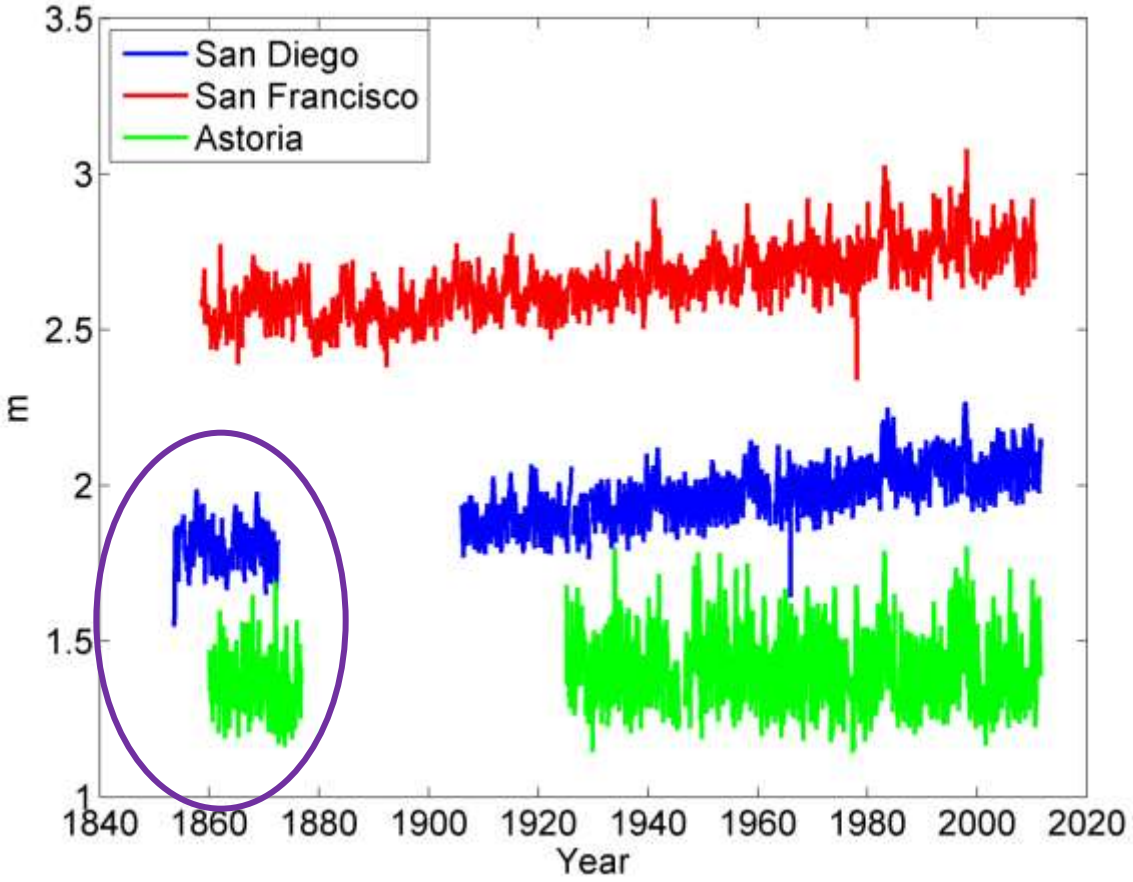
→ More benchmarks need to be found.

Original 1853 Astoria benchmark on backside

15th & Commerical

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

Sea-Level: Preliminary Results



Original 1853 Astoria benchmark on backside

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

Data recovered by Talke &Jay

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	19.64	22.97	4.204	3.33
H31 (45th/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 1925warning	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 1939warning		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 20th/commericial Astoria 1941warning		18.82	22.15		3.33
F 472 194130th Franklin East Astoriawarning		25.84	29.28		3.44
T 100 Astoria 10/11th street, 1930 PGE		17.12	20.45		3.33
T 263 Astoria SE corner 7th and Bond; 1941; warning		19.55	23.04		3.49
X100 Astoria downtown (1931)		18.14	21.59		3.45
Y 100 Astoria downtown (1931		18.41	21.73		3.32
Z 100 Astoria downtown (1931)		19.34	22.81		3.47
W 100 Astoria Downtown (1931)		20.09	23.5		3.41
V 100 Astoria (Downtown)		18.58	22.03		3.45
W 193 Port Docks 1926		14.2	17.72		3.52
P 287 (Astoria) from 1940 (still exists)		19.46	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)

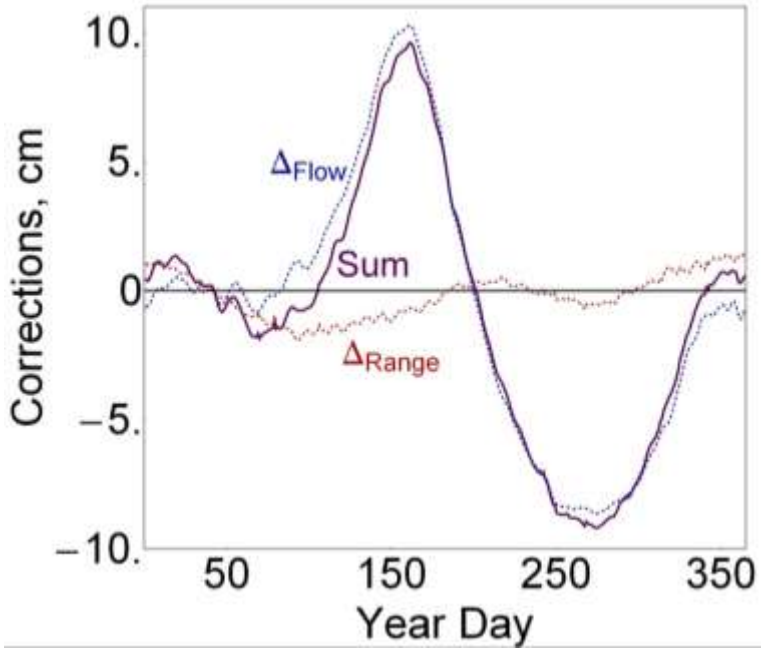
Regression Models of Astoria MWL –

- daily MWL can be modeled as:

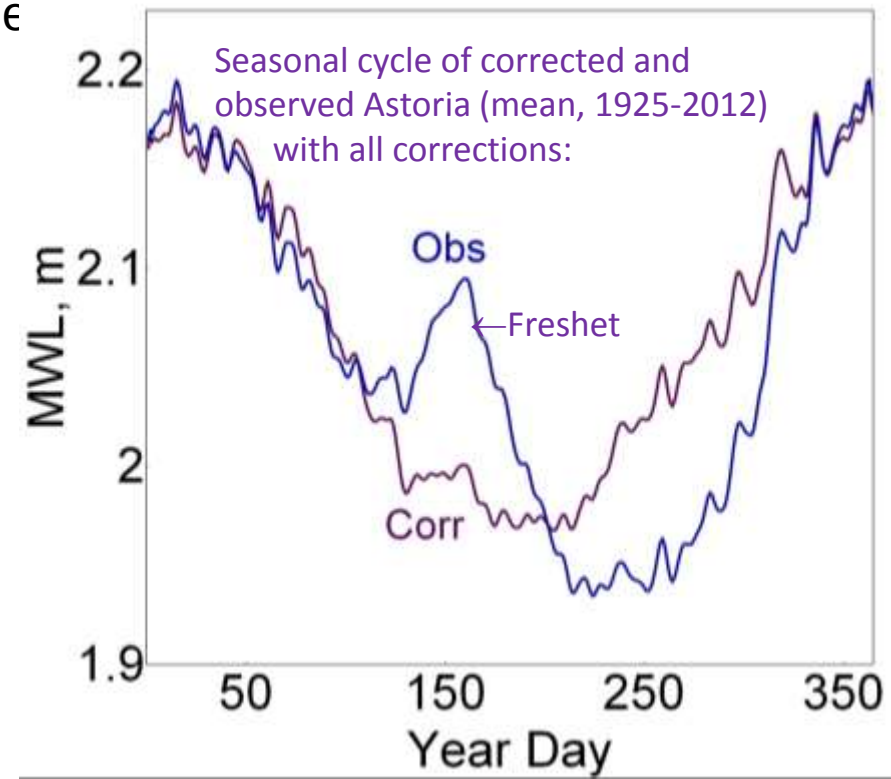
  MWL=f[tidal range, river flow, atm pressure, upwelling index]

- 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 serie range

Largest corrections to MSL: changing range and flow (mean, 1925-2012):



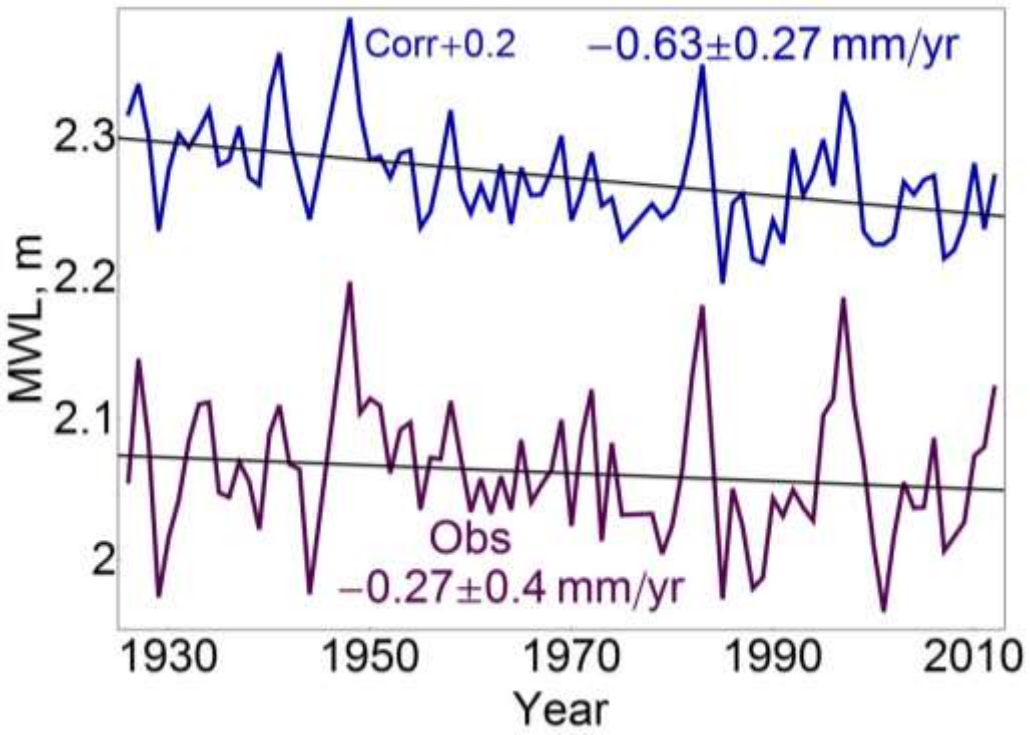
Seasonal cycle of corrected and observed Astoria (mean, 1925-2012) with all corrections:



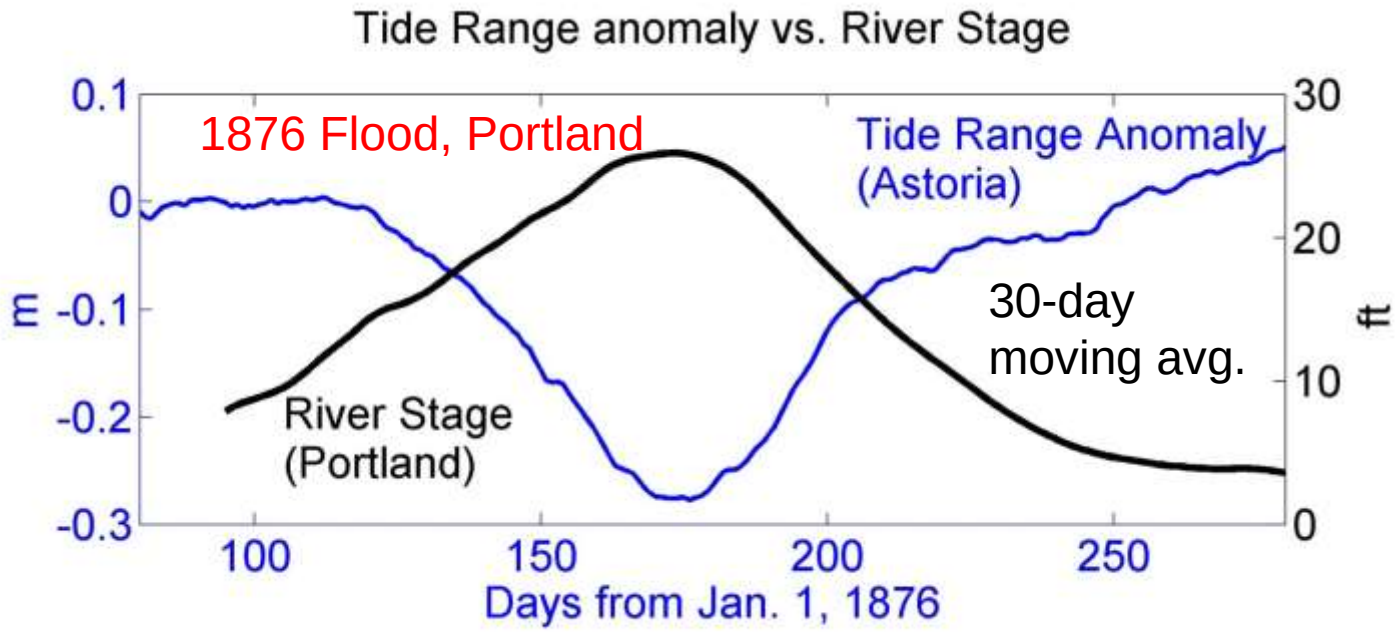
Estimating Astoria MSL Rise –

- 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)

81 annual values in 88 years; no interpolation:



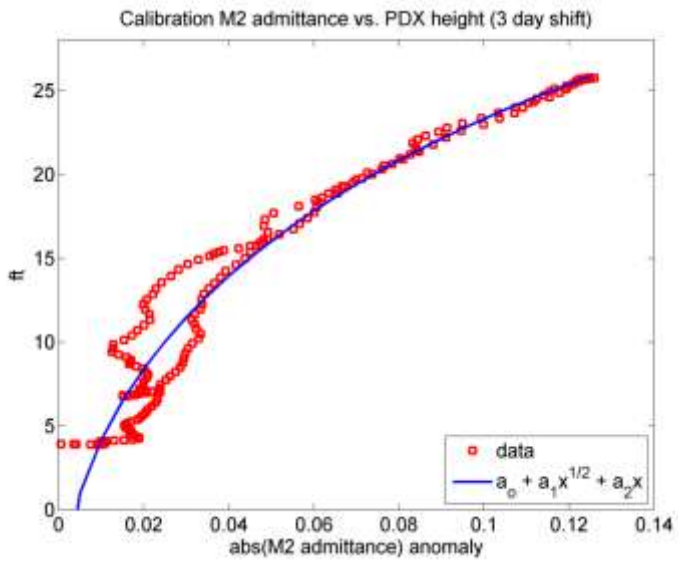
Next: Historical River flow and extreme events



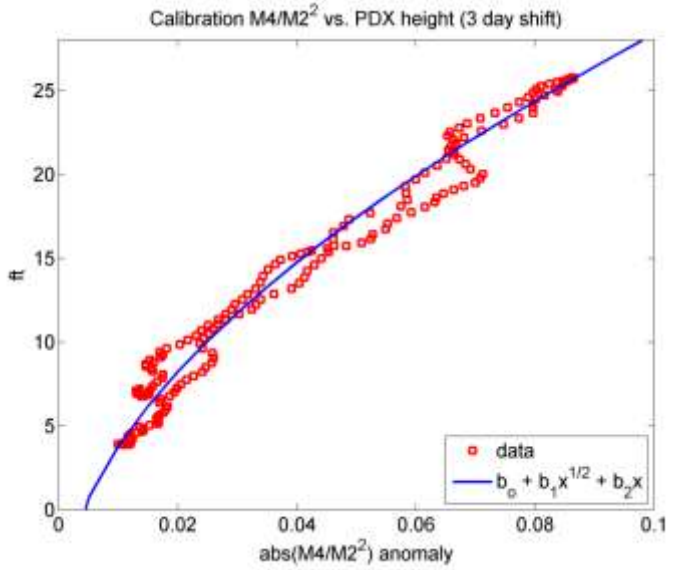
Observation: Tidal range decreases as river flow increases (see Moftakhari et al., 2013 and Jay & Kulkulka, 2003). Therefore, a tide gauge is also a river flow gauge!

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



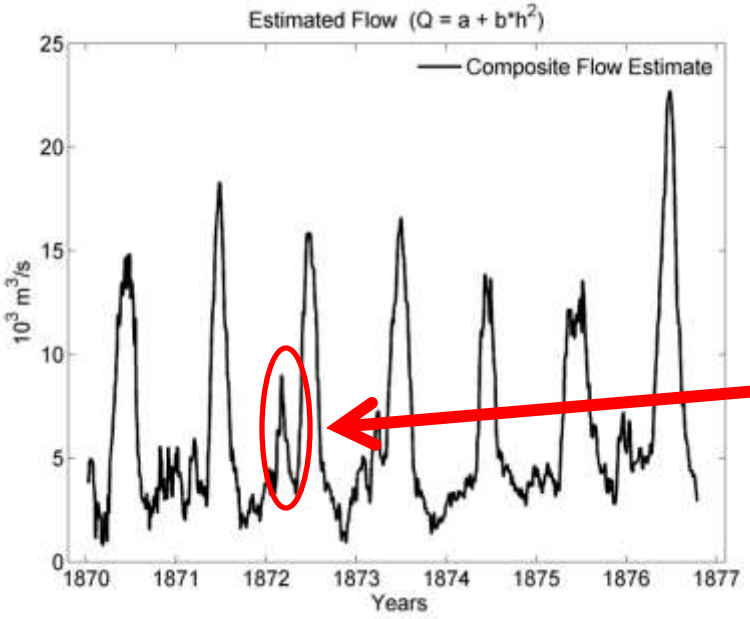
M2 Admittance calibration



M4/M2^2 calibration

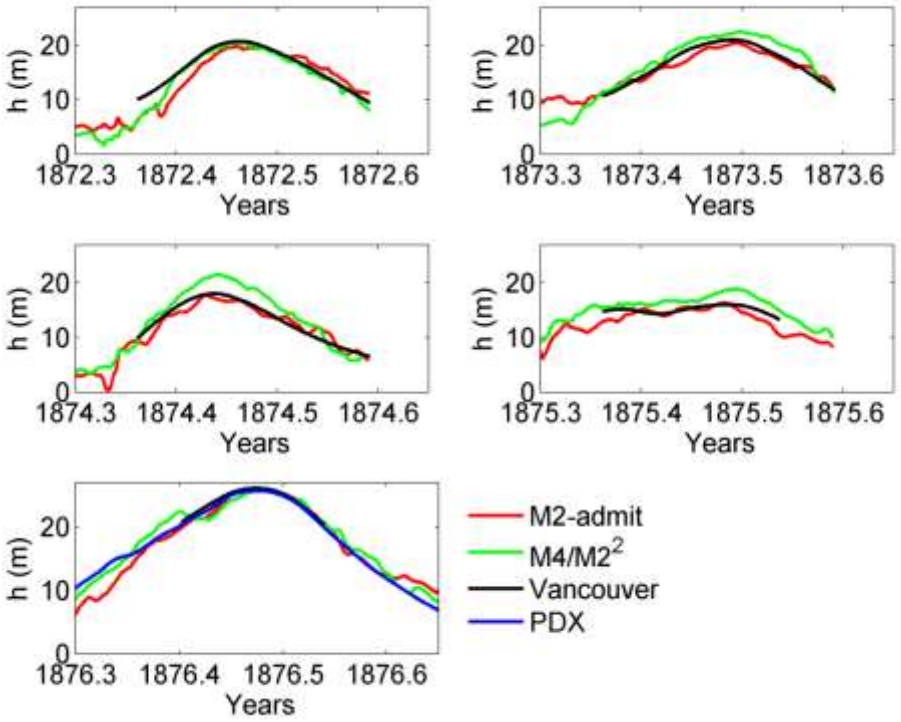
→ Admittance calibration better at high flow; M4/M2^2 better at low flow

Therefore, we use Admittance for high flow, M4/M2^2 for low flow



Flow reconstruction shows yearly freshet

Also evidence of ‘almost lost to history’ winter floods of ~ 8k m^3s

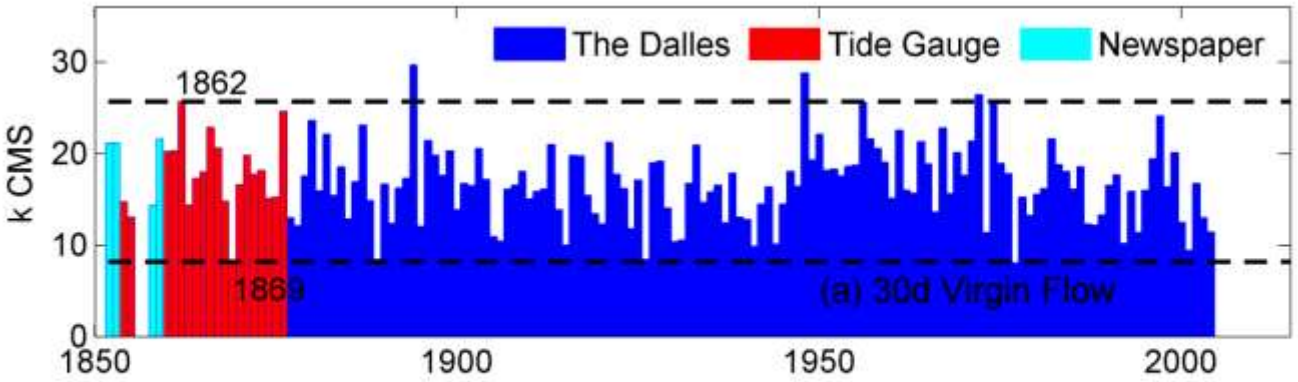


flow reconstruction matched data from Vancouver, WA

→Major flow events are being captured.

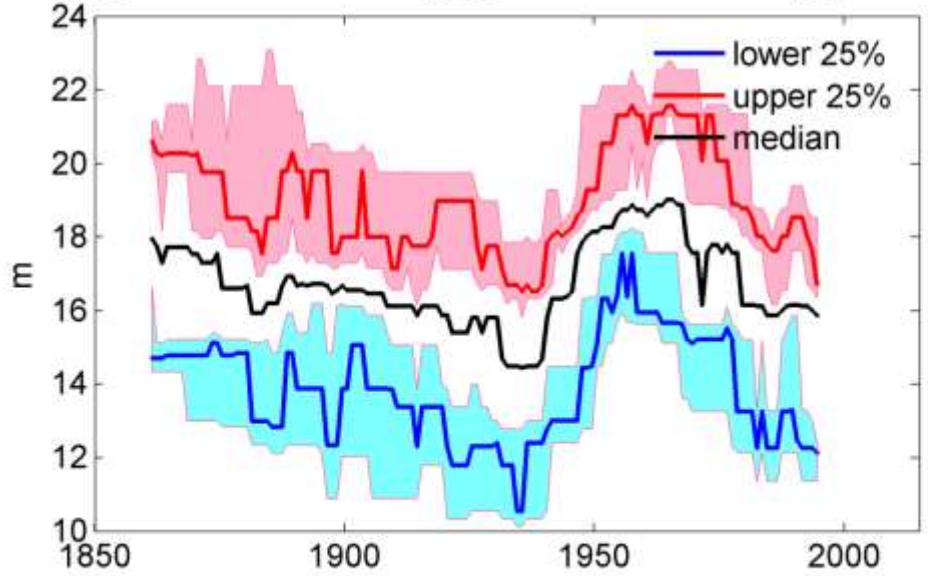
(However, low flow events are more uncertain)

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)



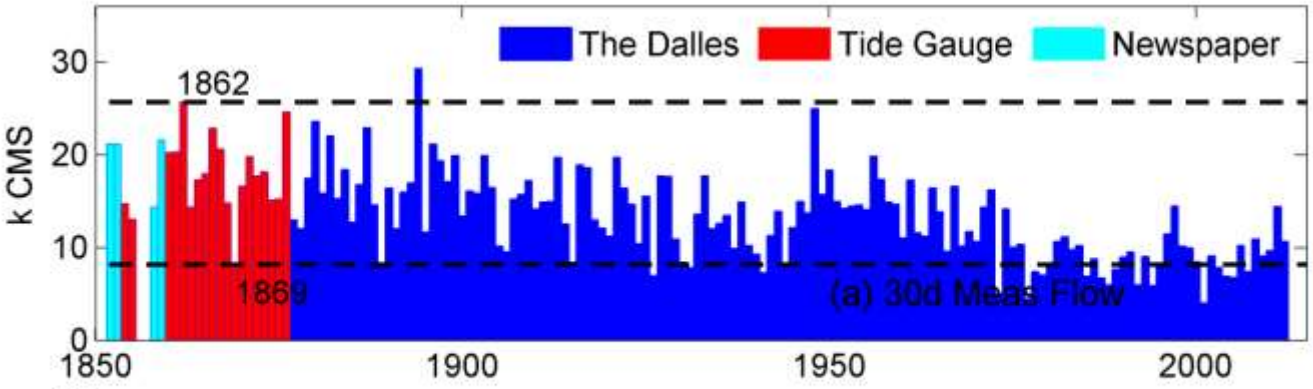
Top 10 Virgin 30d Flows

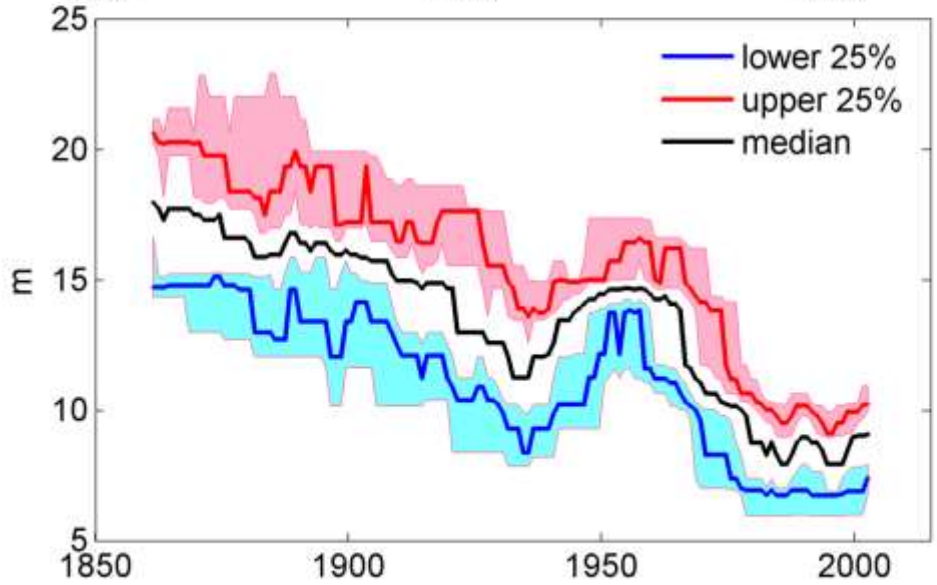
(1) 1894
(2) 1948
(3) 1972
(4) 1862
(5) 1956
(6) 1974
(7) 1876
(8) 1997
(9) 1880
(10) 1887

A 20 year running average has been applied

Marked Pacific Decadal Oscillation in Flow; No obvious trend

Contrast with actual Measurements

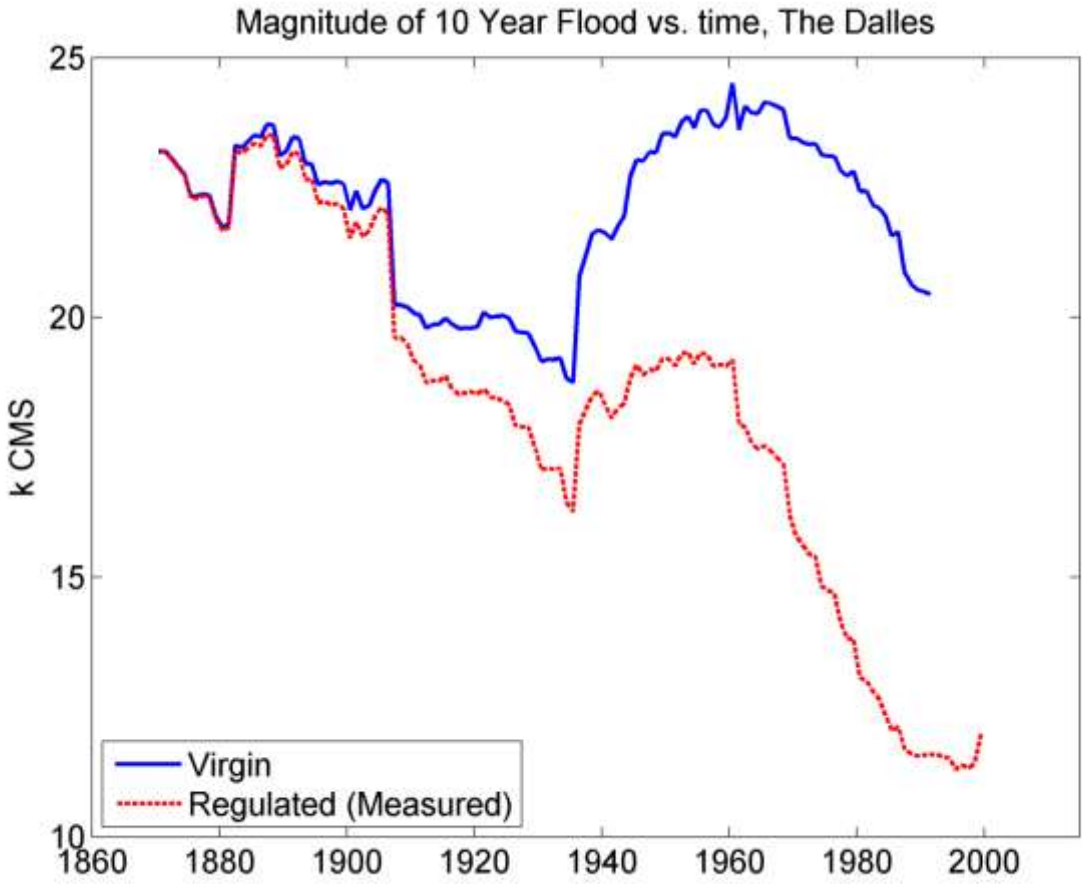




Top 10 Meas 30d Flows

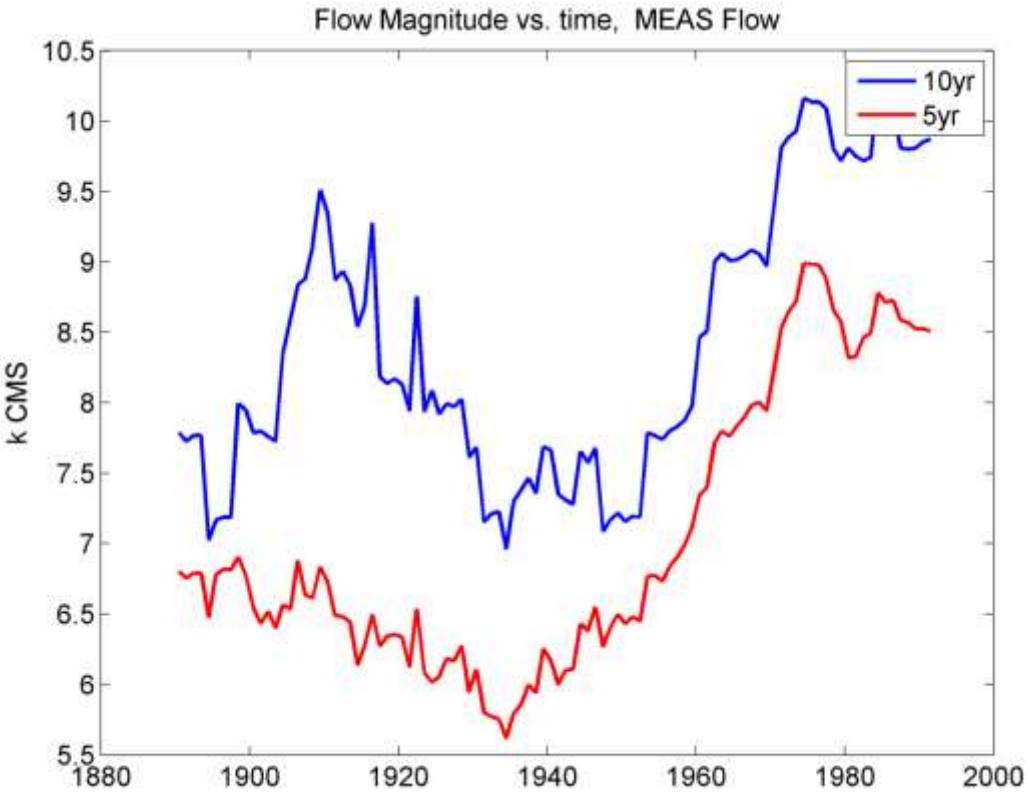
(1) 1894
(2) 1862
(3) 1948
(4) 1876
(5) 1880
(6) 1887
(7) 1866
(8) 1882
(9) 1859
(10) 1852

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



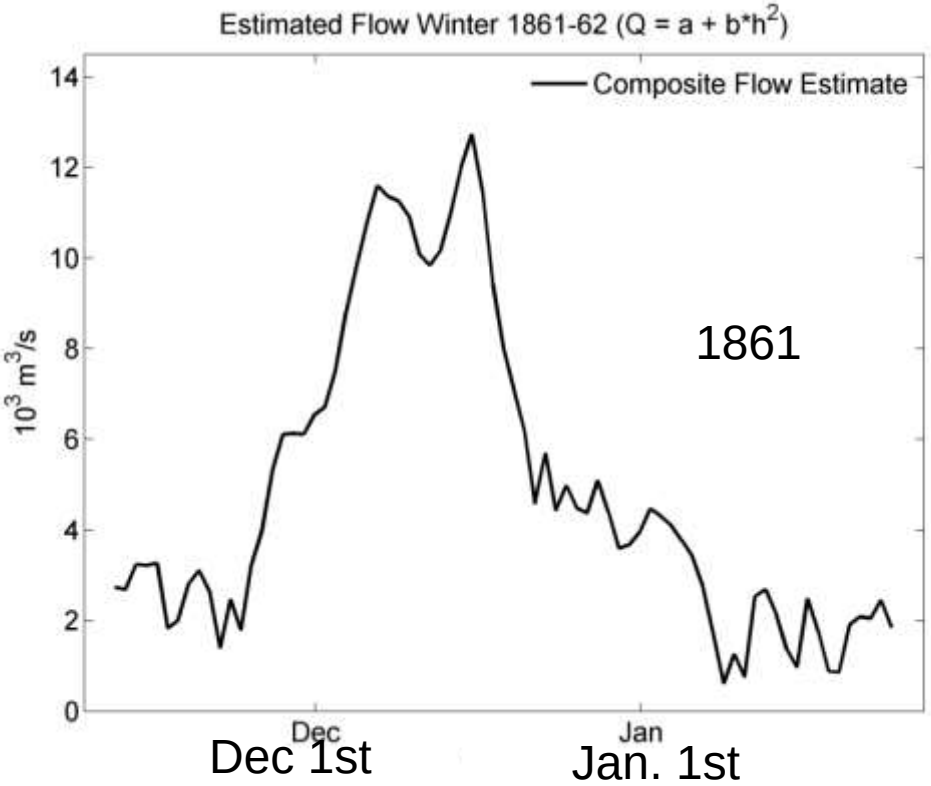
10 Year Flood

(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



Dec 1st

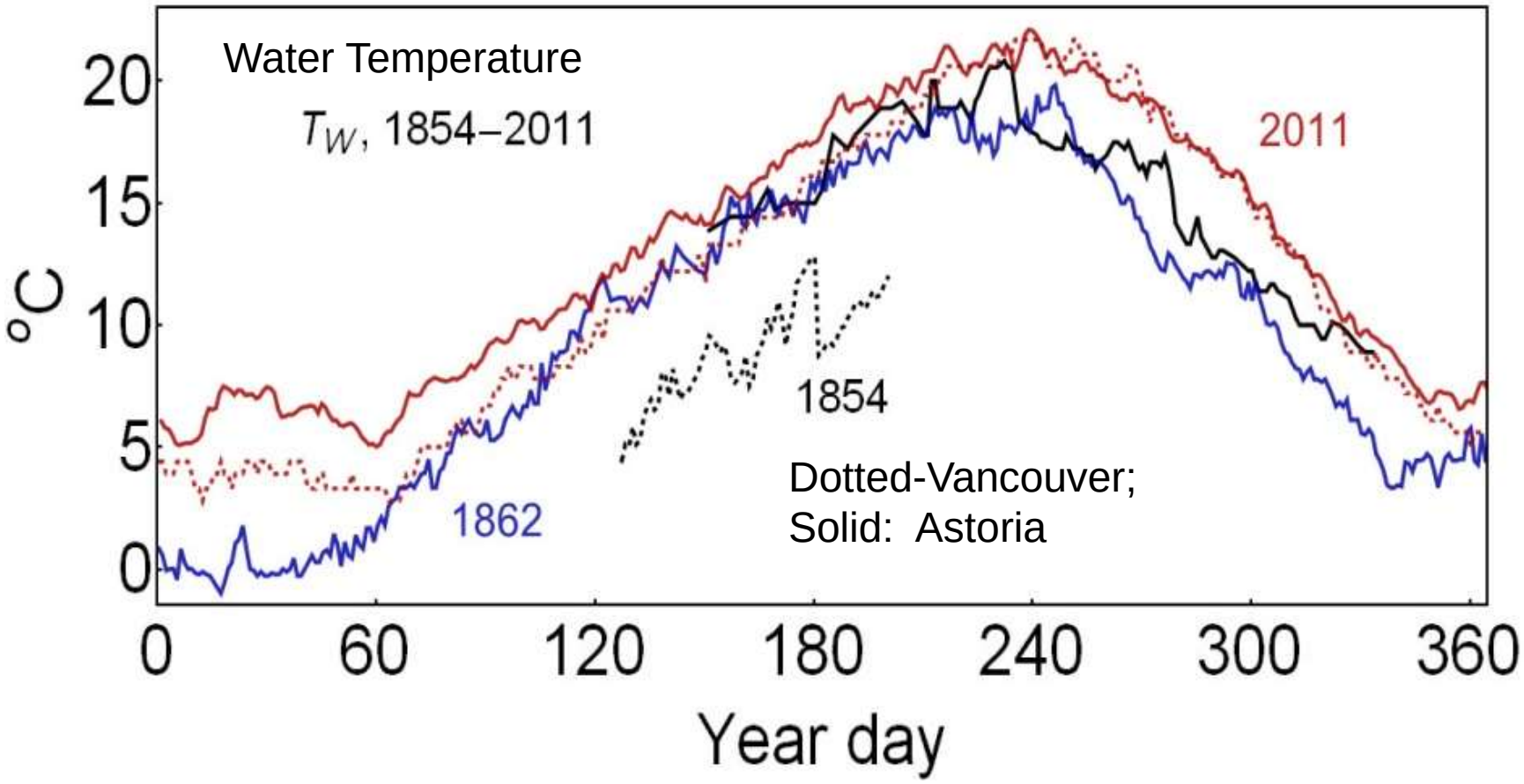
Jan. 1st

Peak flow ~13k m^3/s

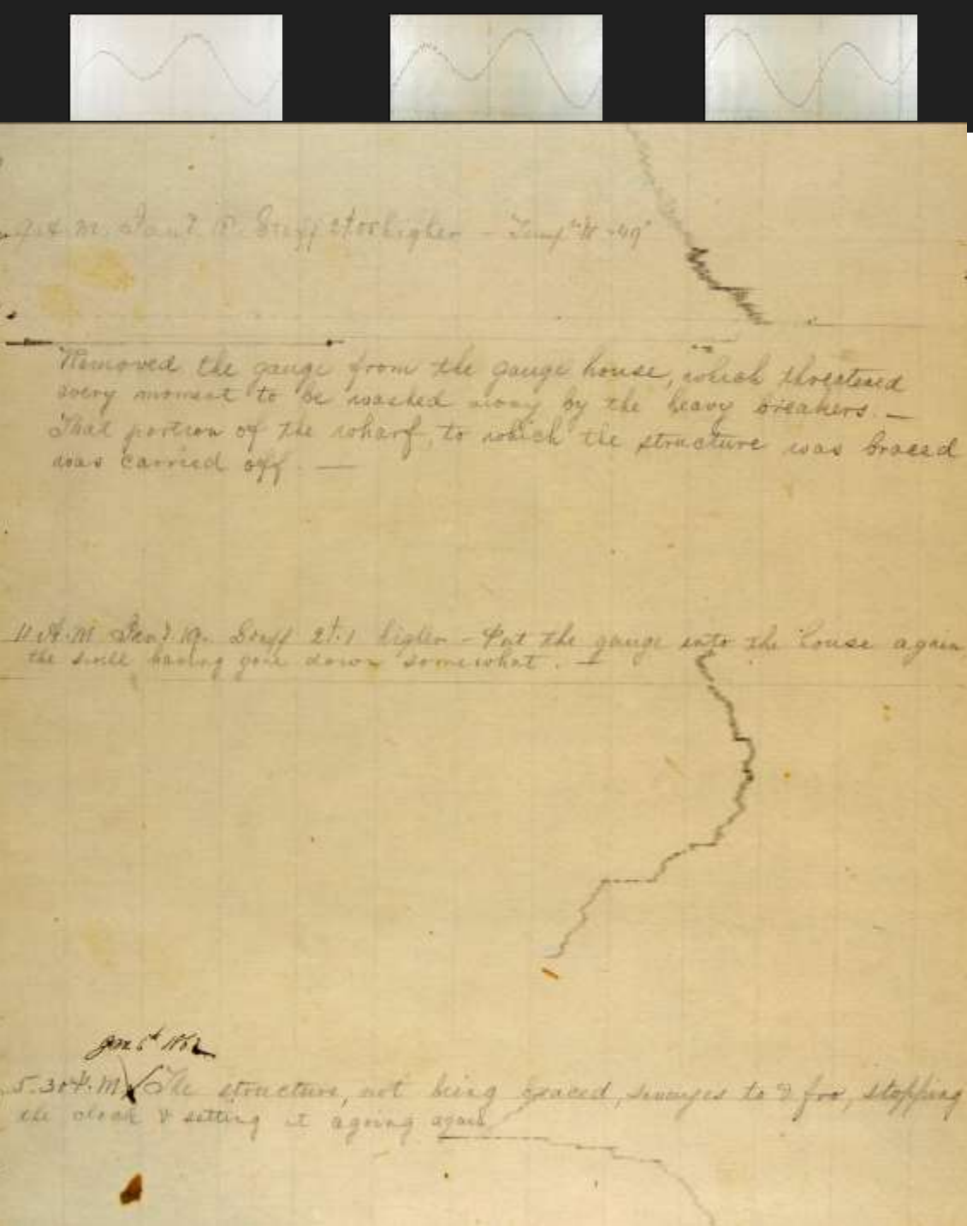
Minimum Flow < 1 k m^3/s

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…..



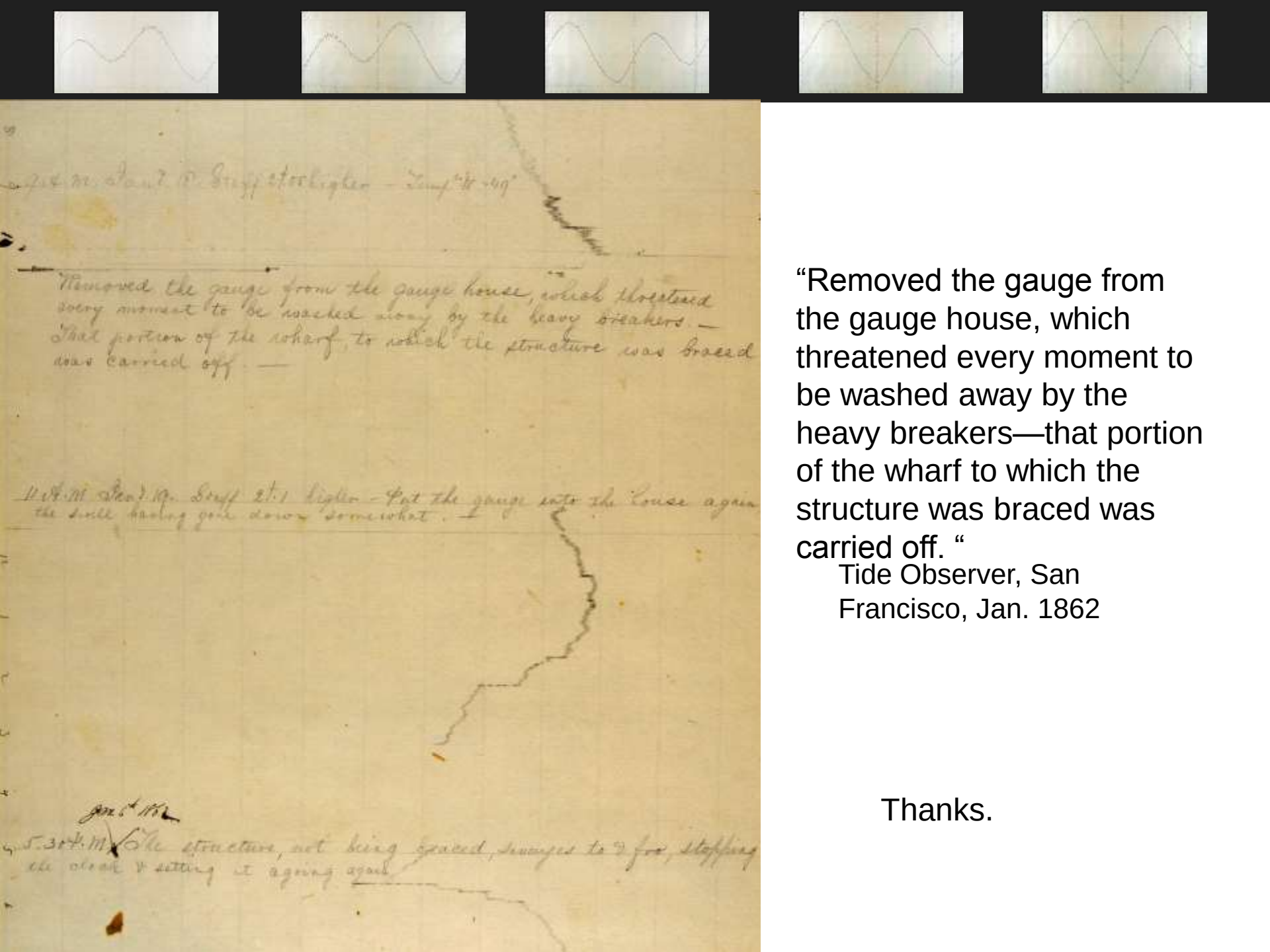
Conclusions

--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.



“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.