Extreme Events and Historic Tide Data, 1853 to 1876

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FLOWS laboratory

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Objectives –

- Use historic tide data to explore 19th century extreme events:
  - Astoria, OR (1855-1876) from NOAA and National Archives
  - San Diego, CA (1853-1872) from Archives and Gunnar Roden
  - San Francisco, CA (1854-1876) from Peter Bromirski

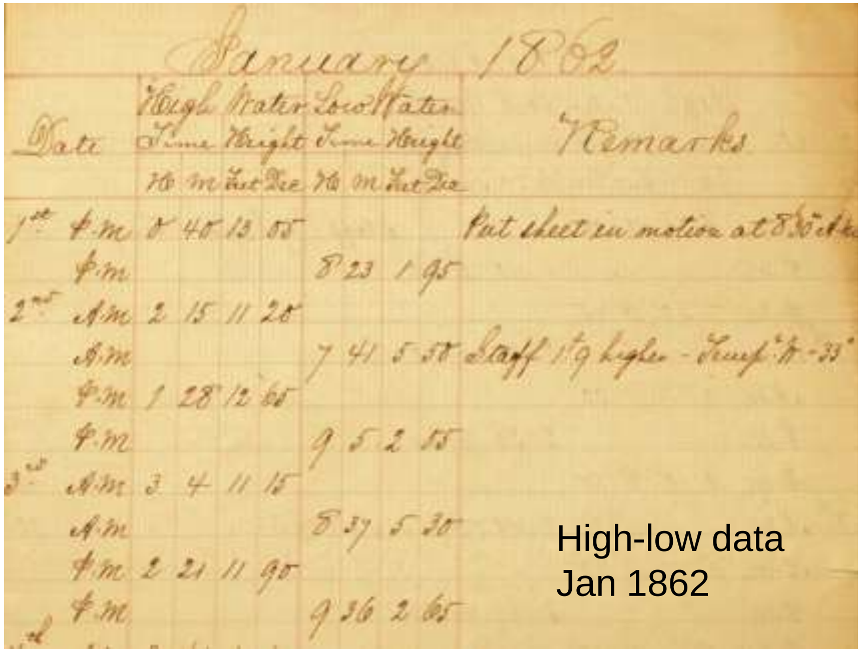
- Use CWT_Multi to explore 19th century extreme events:
  - Astoria, OR (1855-1876) from NOAA and National Archives
  - San Diego, CA (1854-1872) from Archives and Gunnar Roden

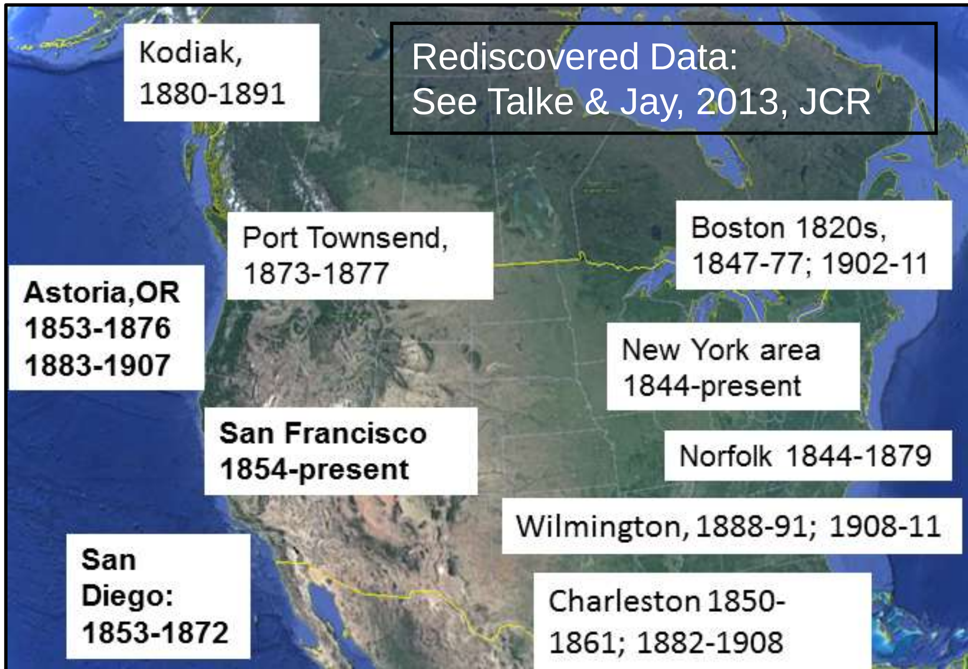
- How much of the data are good, and how do we know?
  - Is it a spike, or is it an event??

- How do tidal variability and tidal interactions vary along the US West Coast?

Tidal Data Recovery –

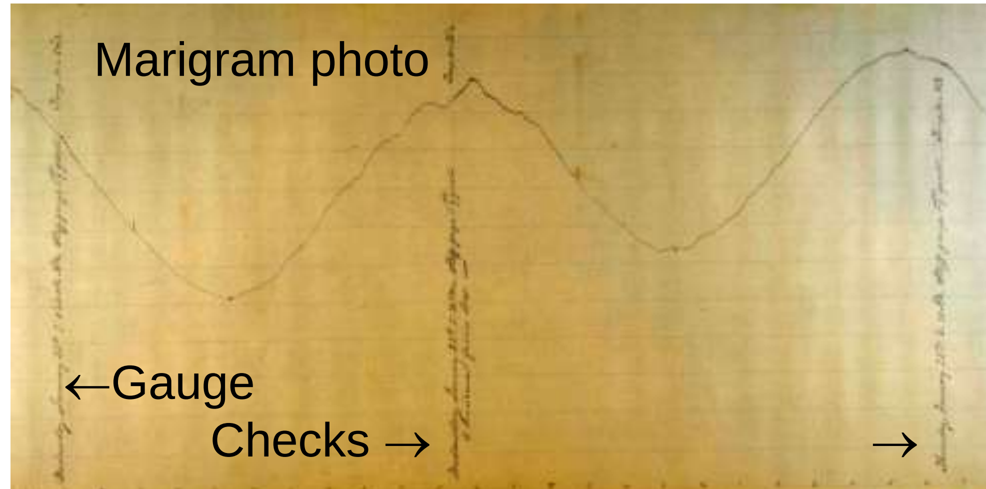
- Types of 1820s-1900 data:
  - Marigrams with gauge checks
  - Hourly and high-low listings, weather data
  - Metadata (datum history, gauge history)
- From Coast Survey, Corps of Engineers, Weather Bureau, cities, and businesses
- Much sleuthing & labor needed!
- Focus on Astoria (Ast), San Francisco Bay (SFB), and San Diego Bay (SDB)

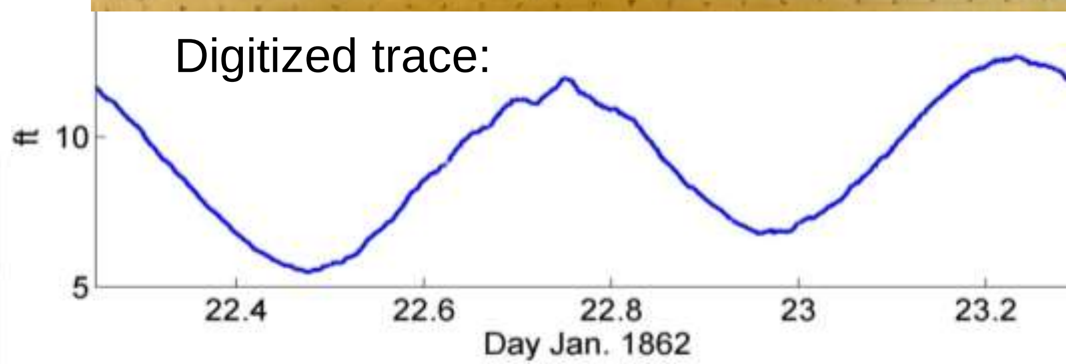


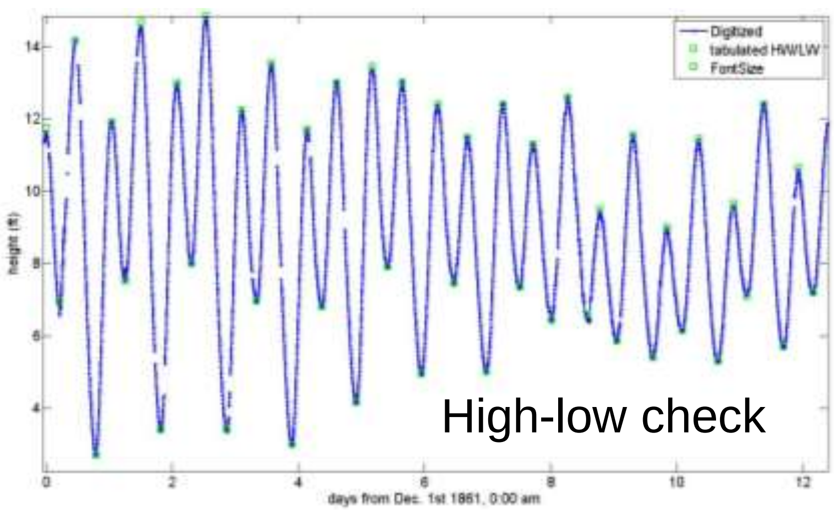


Tidal Data Recovery (More) –

- Some 20 yrs of Astoria marigrams have been photographed & digitized
  - ~16,800 images were corrected for distortion, digitized at 1 min resolution!
  - Change local time->GMT
  - Checked against high-low data, etc.
  - QA is iterative and never-ending…
- Benchmark research & recovery are integral to the process
- 100s of station-years of pre-1900 data were never digitized or have "disappeared."







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Datum Recovery

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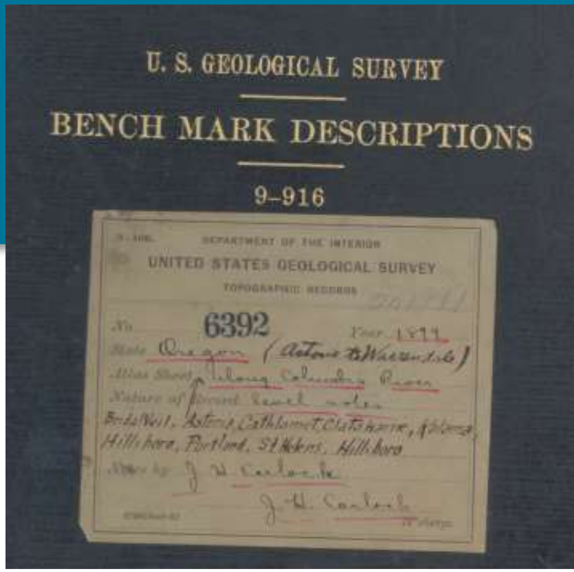
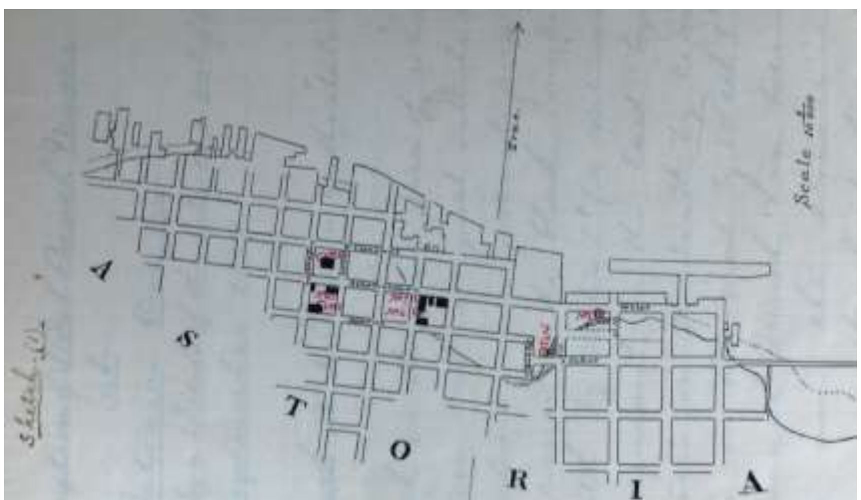
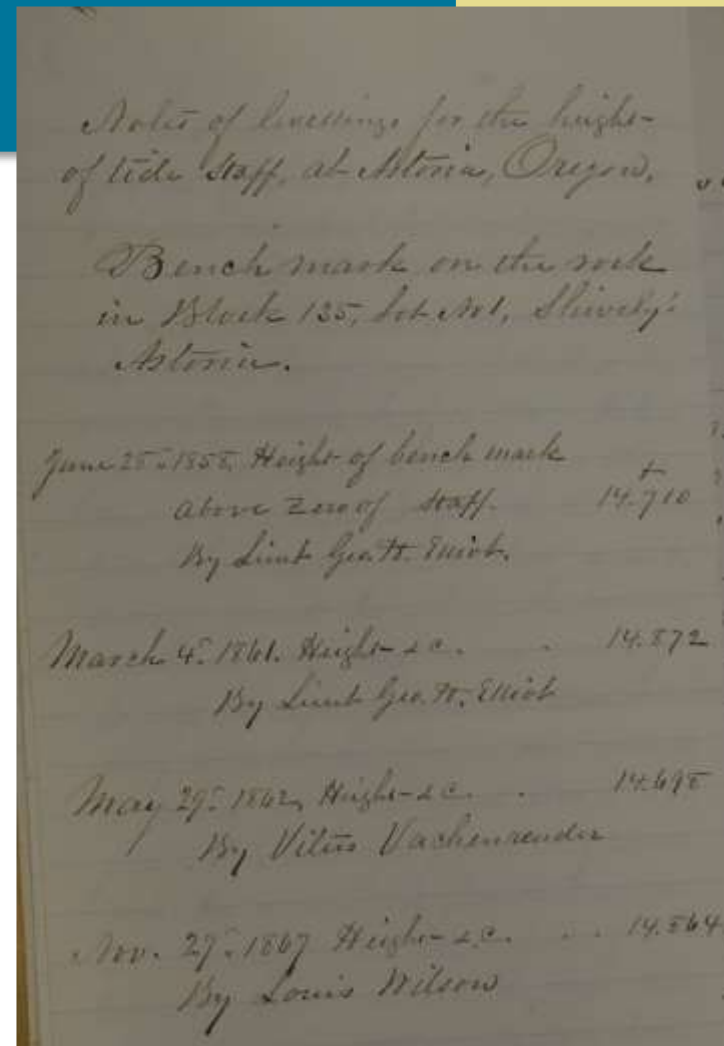


USGS Archives

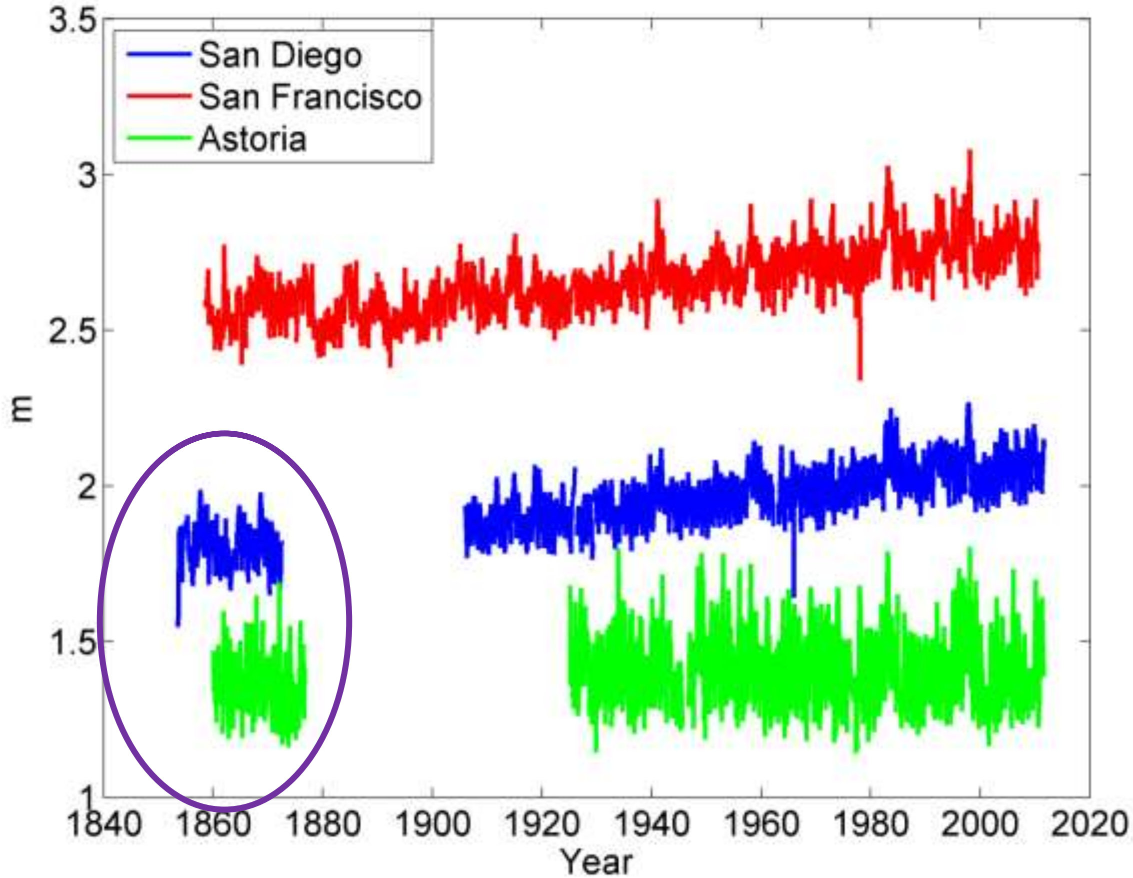


Benchmark Survey, 1887;
US National Archives, MD



Leveling Synopsis
US National Archives, San Bruno

Sea-Level: Preliminary Results



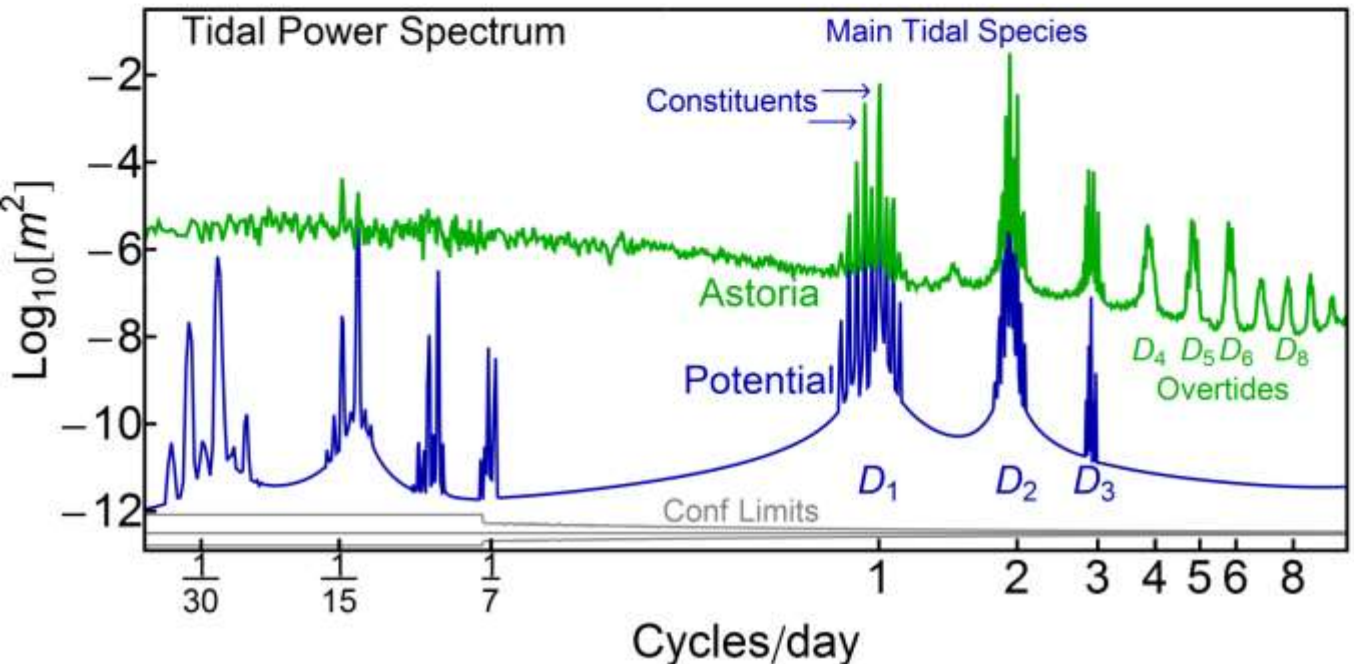
Data recovered by Talke &Jay

Original 1853 Astoria benchmark on backside

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

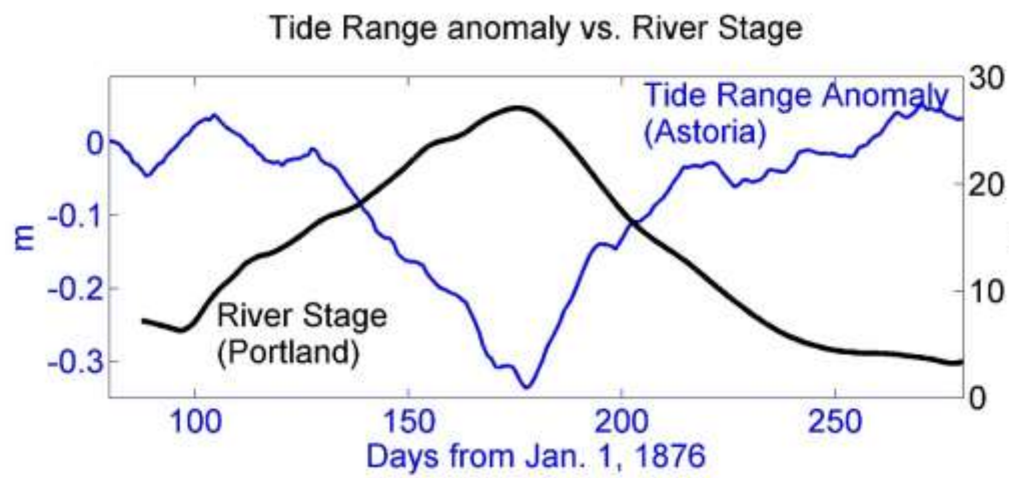
Tidal Species and Constituents –

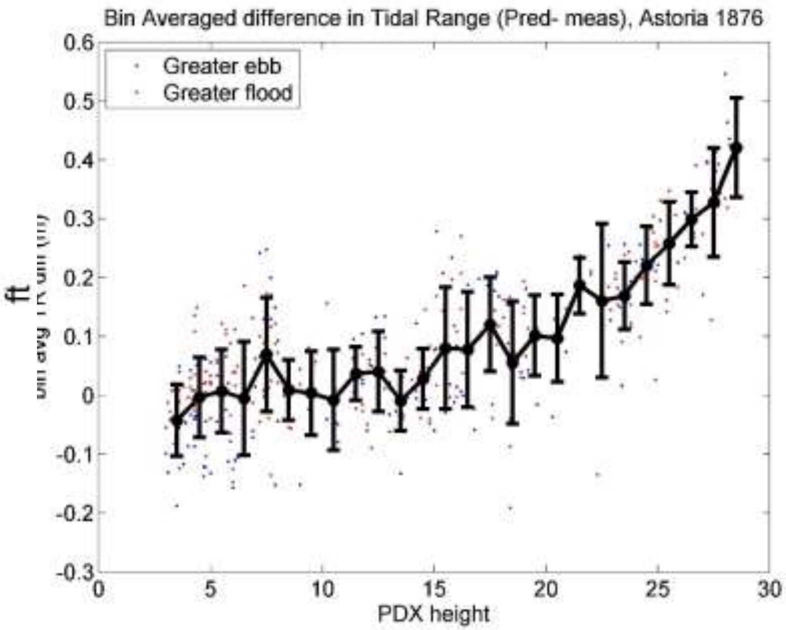
- Tidal species are groups of tidal constituents:
  - Once daily (D_1 or diurnal), twice-daily (D_2 or semidiurnal), etc.
  - D_1 and D_2 each have 20 to 30 constituents
- Astronomical forcing (the tidal potential Ω) occurs at D_1 to D_3, and subtidal (7, 13-15, 28-31 d)
- Overtides are generated by nonlinear, shallow-water processes
- Background spectral noise is caused by river flow and weather



A spectral view of Astoria tides and the tidal potential

River Flow





The different tidal amplitudes combine to make the tide range.

However, an inherent challenge: tides are non-stationary, and tide range decreases as river flow increases.

A Need for Better Tidal Analysis Methods –

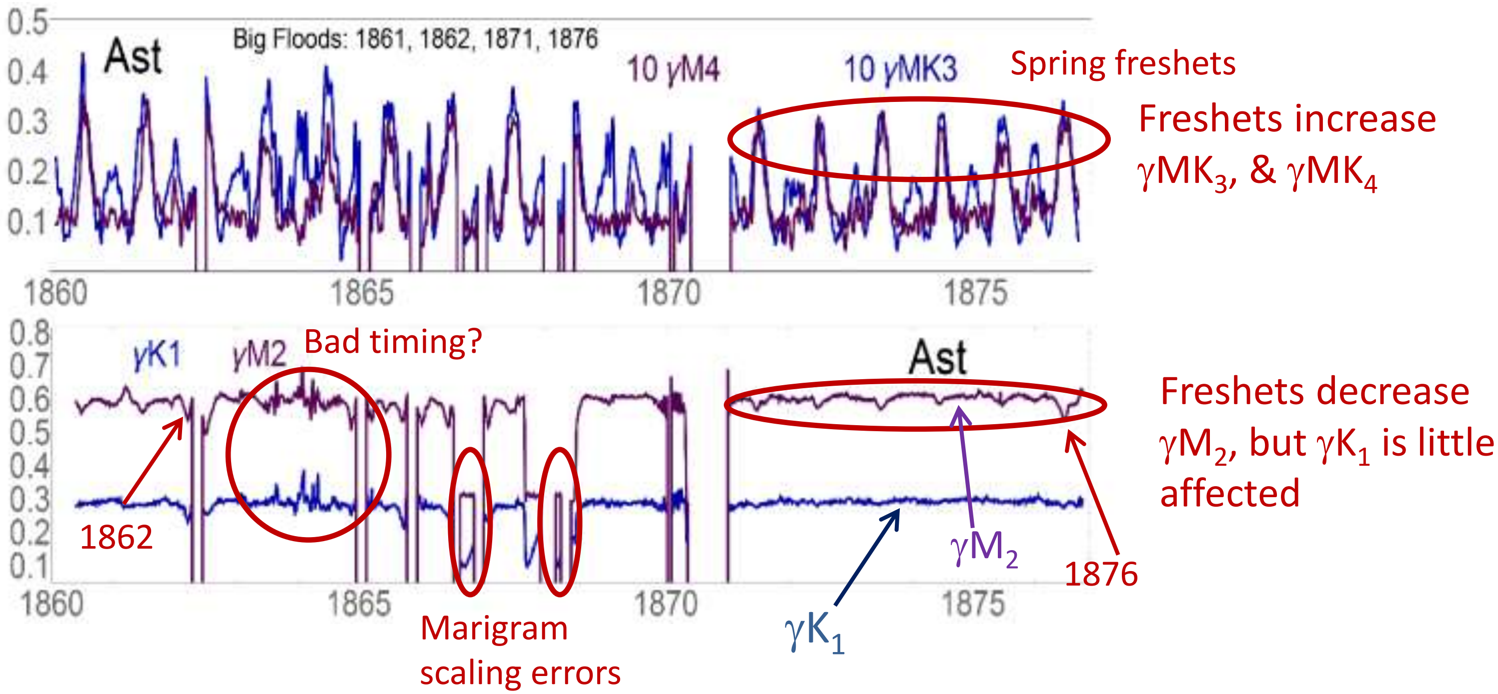
- Tidal constituents in a species respond individually to forcing
- Harmonic analysis (HA) separates constituents, but does not capture evolving frequency content (like extreme events)
  - Can't resolve what the tides are doing during a surge
  - HA is a nonlinear filter, so behaves in unpredictable ways
- Continuous wavelet transform (CWT) analysis captures time variations, but resolves only tidal species
- Need to resolve evolving frequency content AND multiple constituents in each species
- CWT_Multi is a wavelet based tidal analysis method that resolves time-varying constituent behavior using:
  - The linearity of wavelet filters
  - Multiple filters of different lengths for each constituent
  - Systematically cheats on the Heisenberg Principle

Outputs from CWT_Multi –

- Instead of the usual tidal constituents, CWT_Multi outputs weekly estimates of:
  - The non-dimensional ratio (γ) of each constituent in a data record to the constituent in the tidal potential Ω
  - A constituent is a complex number, represented as an amplitude and phase
  - CTW_Multi outputs an amplitude ratio and phase difference
  - We will look at the amplitude ratios, because they are less affected by small timing errors
  - CWT_Multi outputs are weekly
- Using γ values helps eliminate the effects of unresolved, small constituents on the constituents estimated.
- For today, we will look at γK_1, γM_2, γMK_3, & γMK_4 (the largest constituents and overtides)

Overview by Station – Astoria

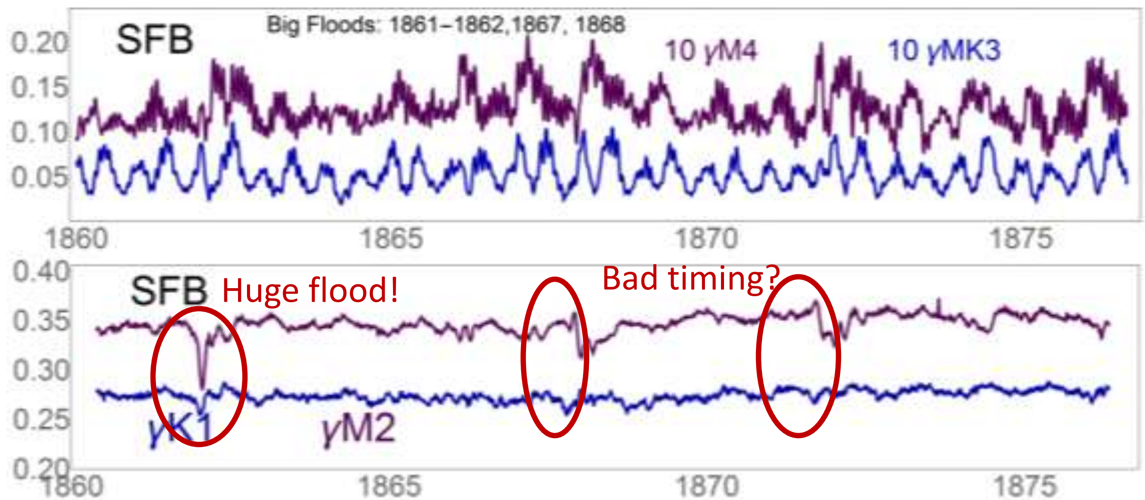
- Data available 1853-1876; early years are rough
- Astoria: γM_2, γMK_3, & γMK_4 show freshets; γK_1 is less affected
- Still need to fix gaps & errors



- Dec 1861 Willamette River flood is only a blip; 1862 flood data partly missing
- The 1876 flood is obvious, and flow can be estimated from changes in tides
- Gauge was in Downtown Astoria

Overview by Station – San Francisco

- The most obvious event in the SF record is the 1862 flood:
- Flows can be estimated from tides, as in Astoria

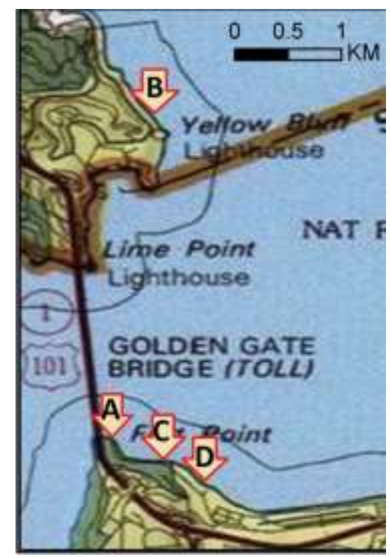


γM_4 has two cy/yr, instead of one; smaller than at Astoria and weakly affected by flow

Both γM_2 & γK_1 show flood effects, e.g., the great 1861-62 flood

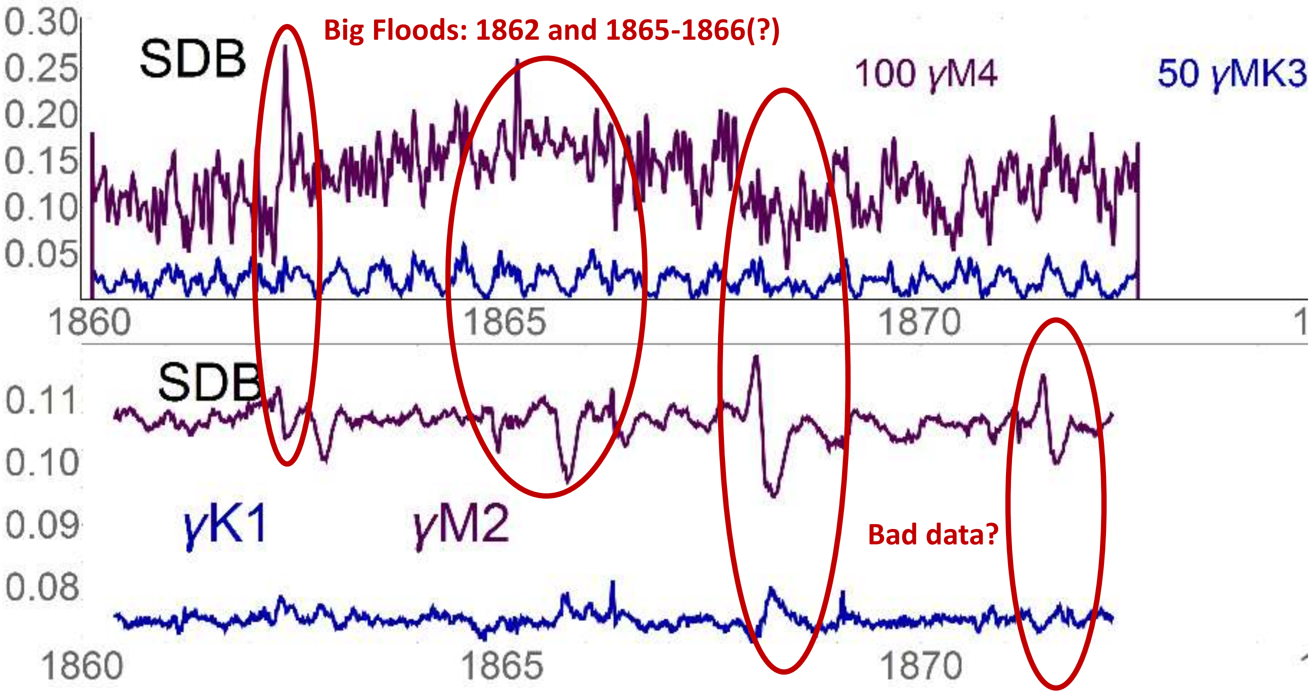
- γK_1 is more variable than at Astoria – probably due to changes in stratification and/or shelf processes

Gauge was at Ft Point (A):



Overview by Station – San Diego

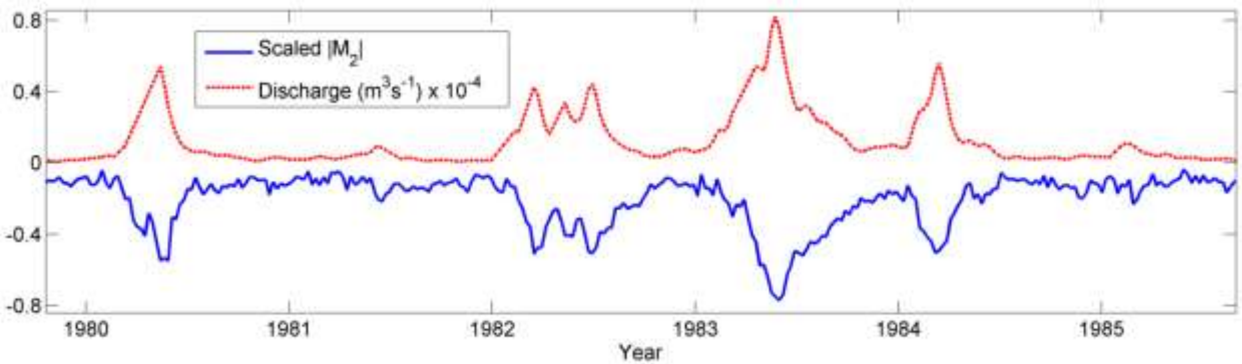
- Data available only up to 1872; 1859 is missing
- SD Bay doesn't have a river now; it did in 1862



- Overtides are much smaller than in Astoria
- Variability in γK_1 may be related to shelf processes

River-Flow Effects on Tides –

- River flow and tides interact through quadratic bed friction
  - Can be used to hindcast river-flow from tidal records
  - When flow goes up, γM_2 decreases and $|M_4|/|M_2|^2$ increases
- We have applied this to the Columbia and Fraser Rivers and SF Bay (Moftakhari, 2013, 2015, 2016)
- Example from SF Bay:



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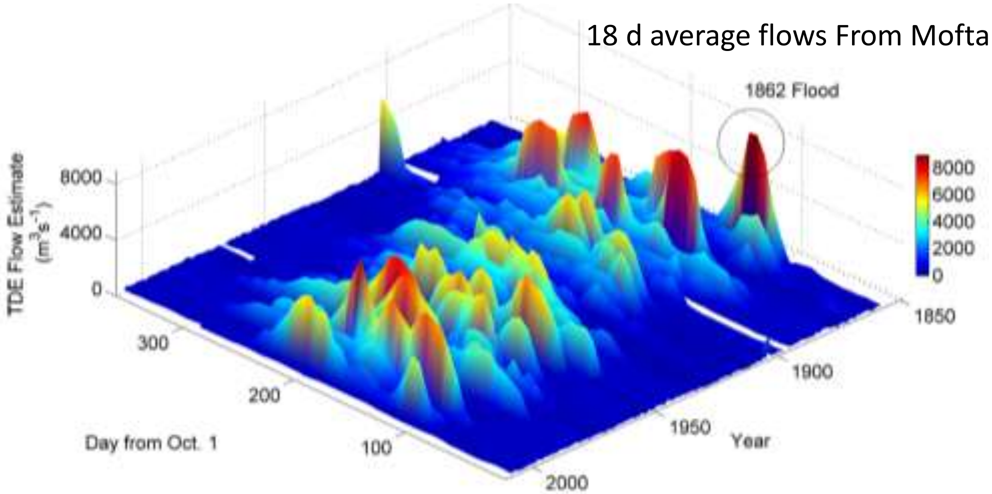
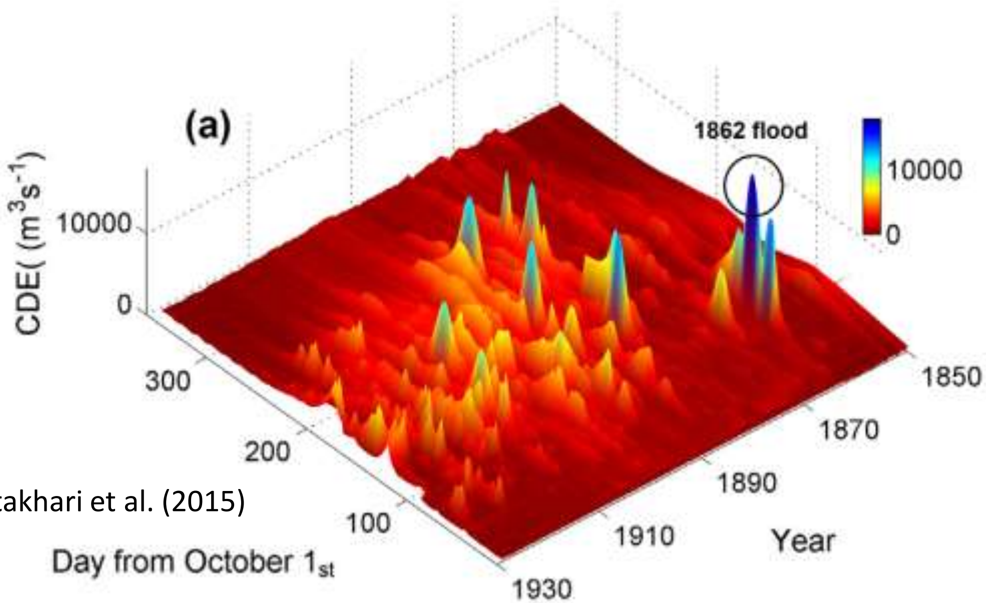
Hindcasting River Inflow to SF Bay 1858-1928 –

- Instrumental flow record for SF Bay begins in 1929, tides observed since 1854
- Flow based on tidal discharge estimation (TDE) are ~18 day averages
- This is the first instrumentally based estimate of the 1862 flood:

18 d average flows From Moftakhari et al. (2013)



- This is a later version, combining a recovered Sacramento gauge record starting in 1849 with TDE; flows scaled to daily:



Daily flows From Moftakhari et al. (2015)

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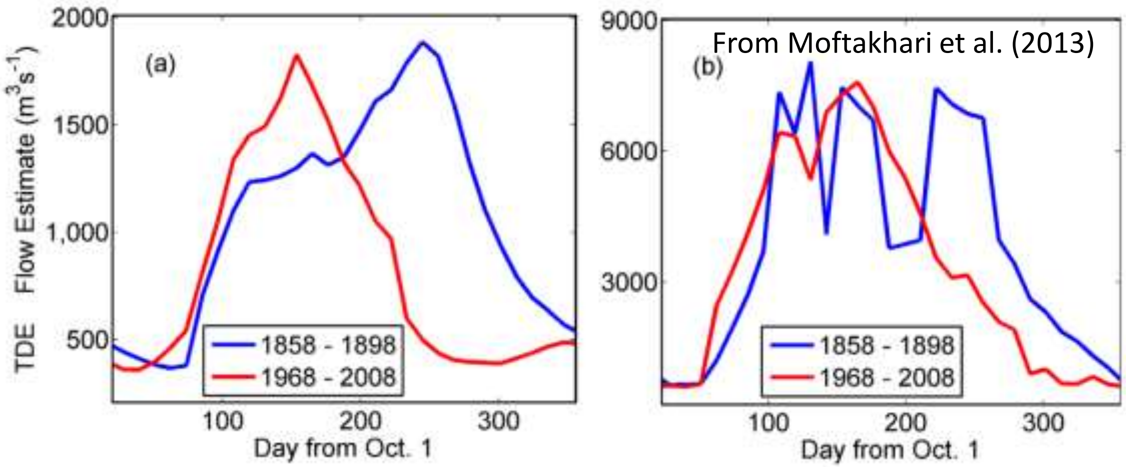
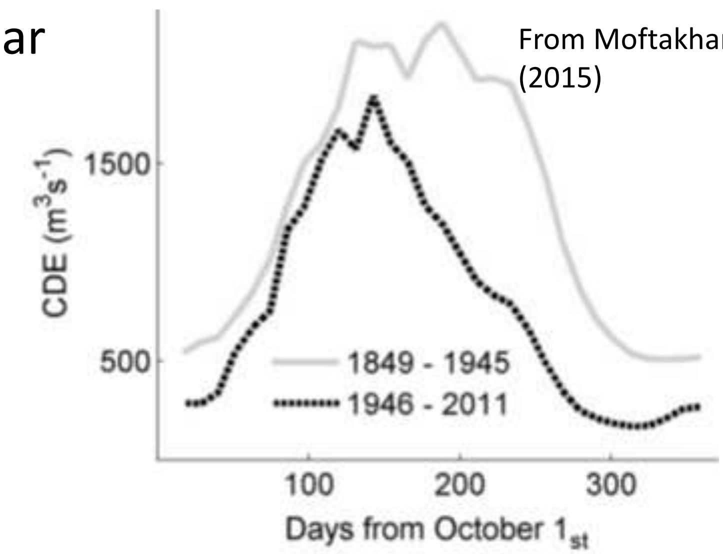
Hindcasting River Inflow to SF Bay 1858-1928 –

- SF Bay flow seasonality has also changed greatly:
  - More flow in winter since, less in the spring



  - Modern flows also appear to be ~30% lower



From Moftakhari et al. (2015)

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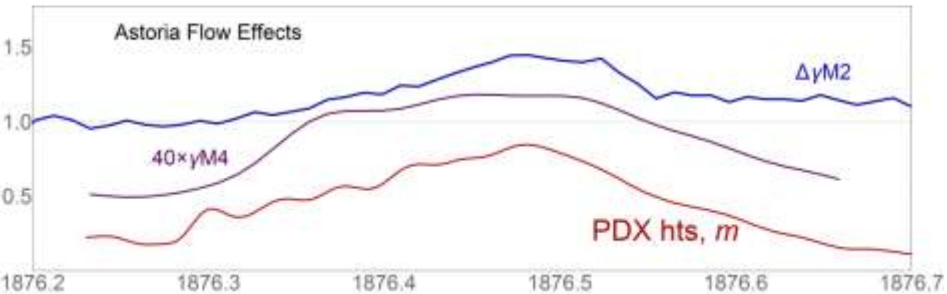
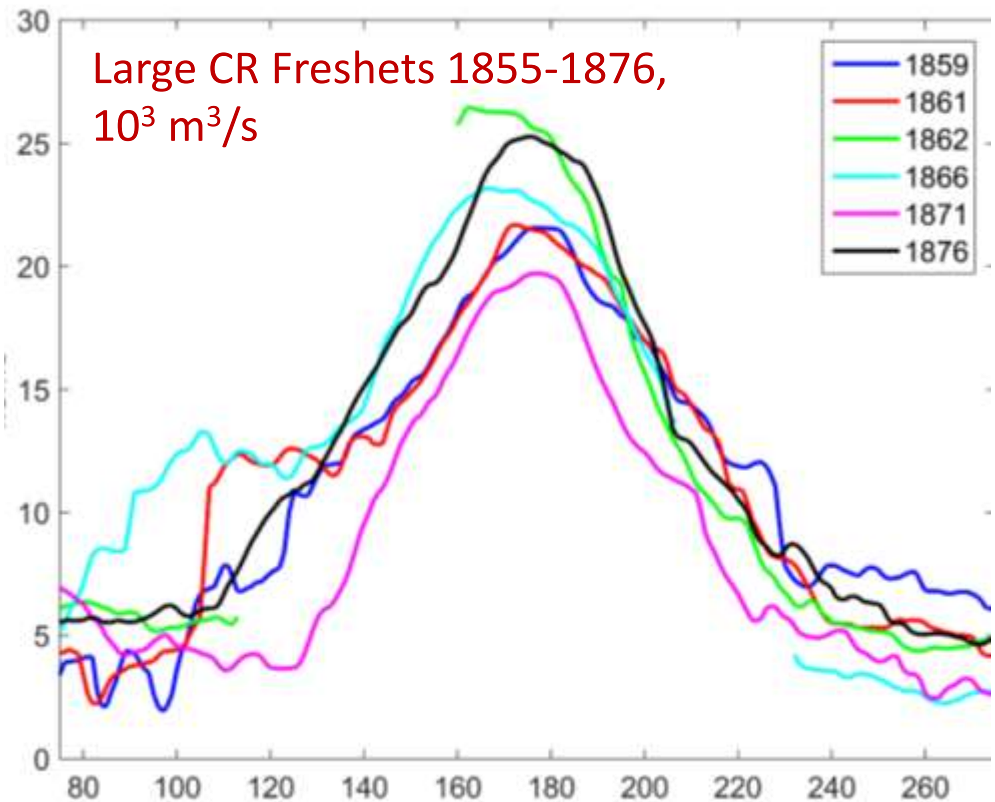
Hindacasting CR River Flow 1855 to 1876 –

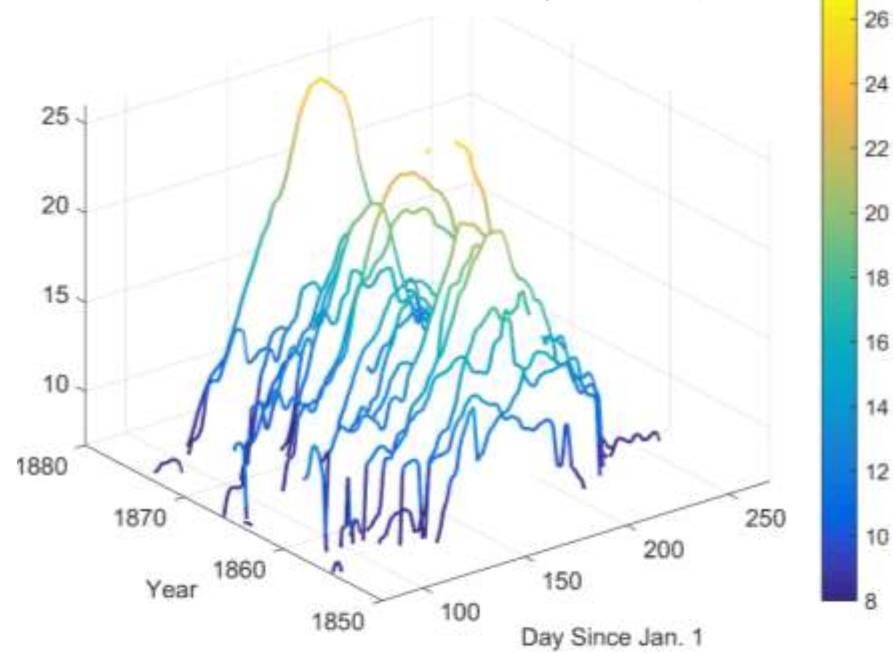
- River flow damps tides via non-linear friction. Quantify this to hindcast flow from tidal amplitude variations (Jay and Kukulka, 2003; Moftakhari et al., 2013, 2015)



Compare upriver stage with flow hindcasts: γM_2 flow works better than γM_4



All CR Freshets 1855-1876, 10^3 m^3/s



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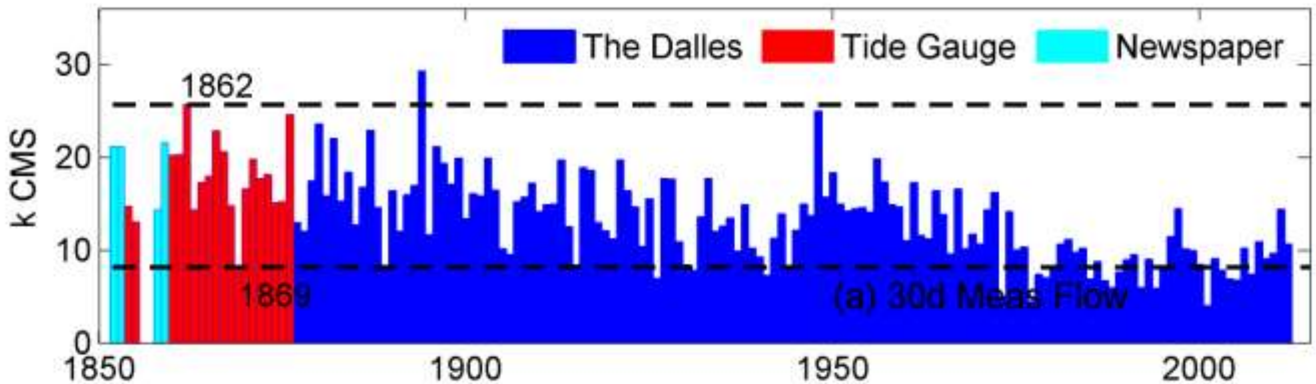
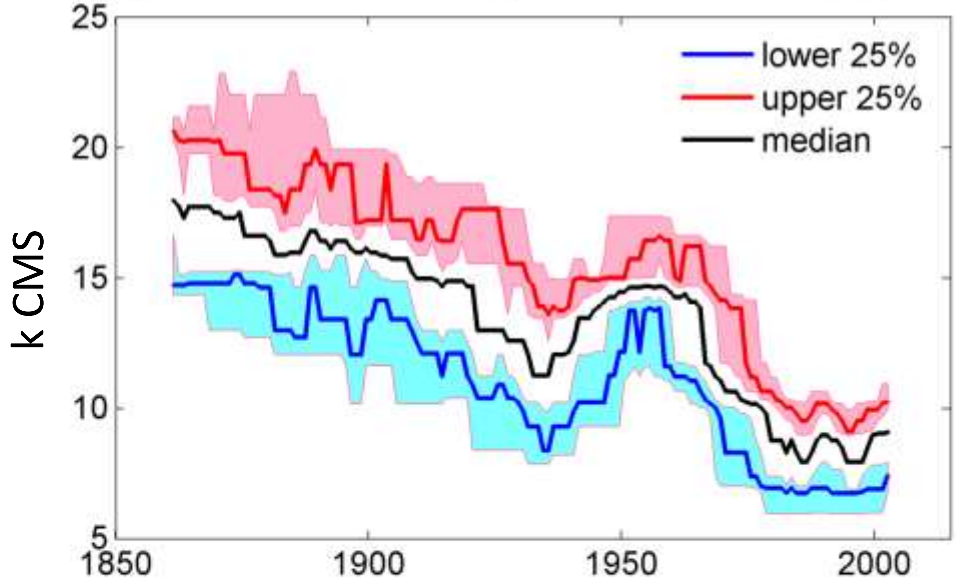
Long term trends in Columbia River Flow since 1850



Measured annual peak



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

Conclusions –

- There are multiple layers of tidal data before the modern era
- These data have many uses:
  - MSL analysis, inundation risk and storminess
  - understanding system trajectories & long-term changes in tides
  - Hindcasting flows (cf. Moftakhari et al., 2013, 2015 for SF Bay)
  - But there is some difficulty in distinguishing real tidal variability and bad data
  - Careful QA is needed
- CWT_Multi is useful for analysis of non-stationary data & QA
- Tidal admittances (the γ's) should be the usual tidal analysis output