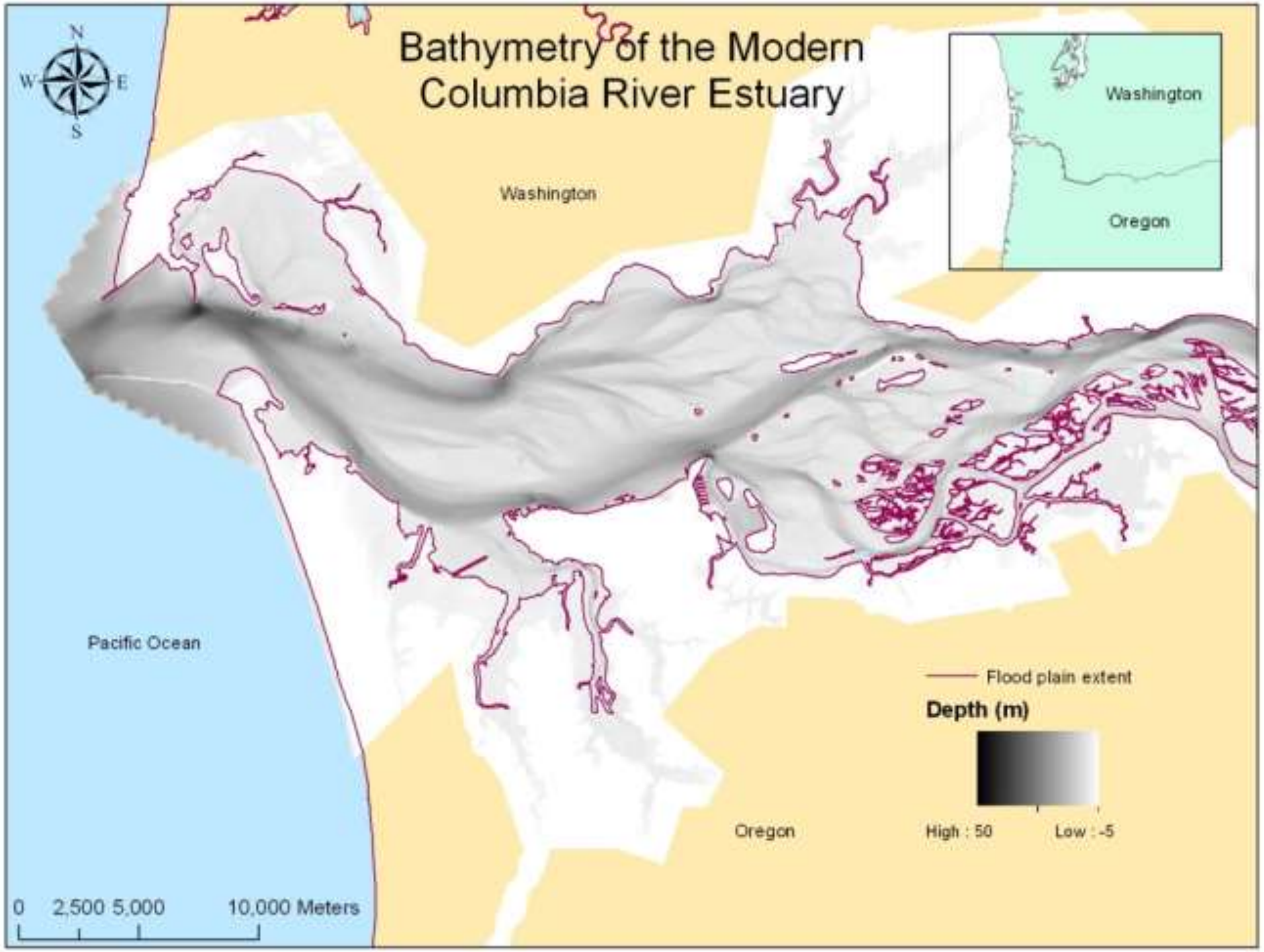
Modeling changes to the historic Lower Columbia River Estuary using Delft3D



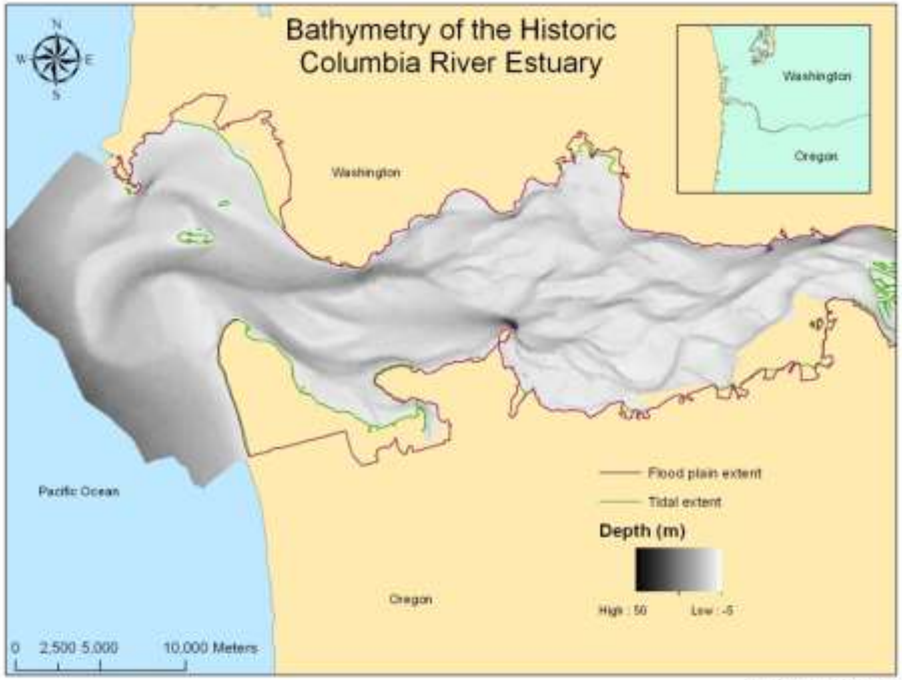
Drew Mahedy, 2013

Source: Unknown

Drew Mahedy
Lumas Helaire
Stefan Talke
David Jay
May 30, 2014

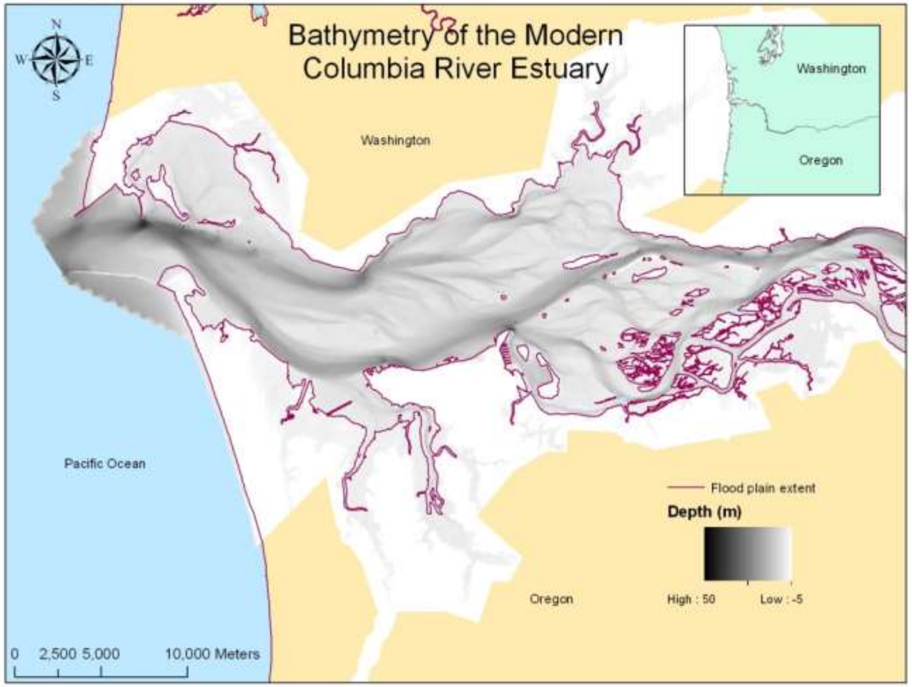
Portland State University

Comparison: Historic and Modern LCRE



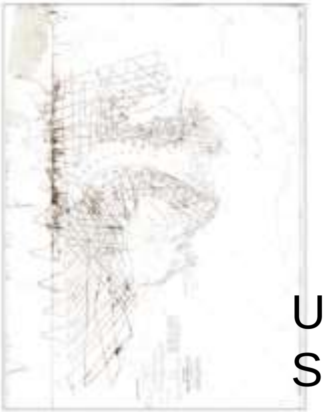
Drew Mahedy, 2013

Source: University of Washington Wetland Ecosystems Team



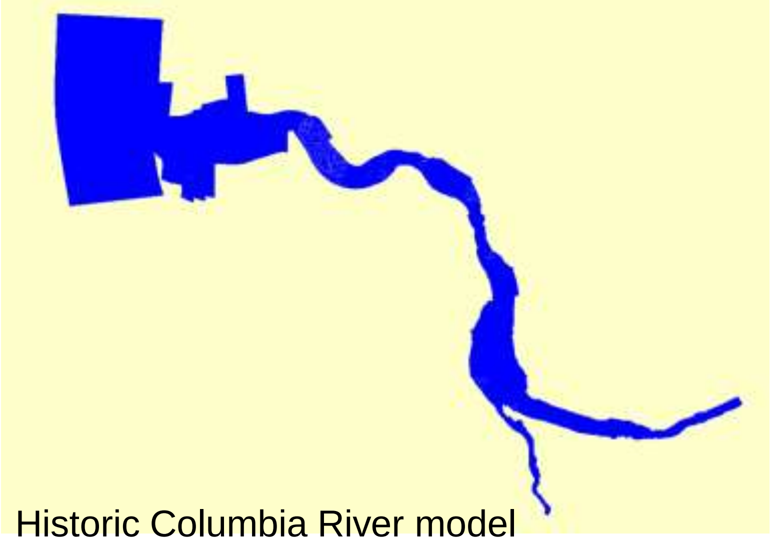
Drew Mahedy, 2013

Source: Unknov

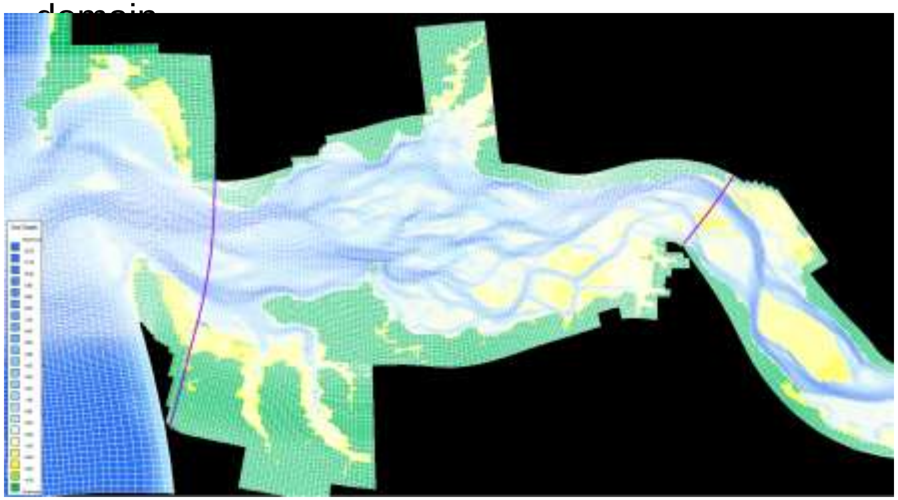


US Coastal Survey, 1868

Historic 19th century Digital elevation model for the Columbia exists (digitized by Jen Burke et al. at U. Washington)



Historic Columbia River model domain



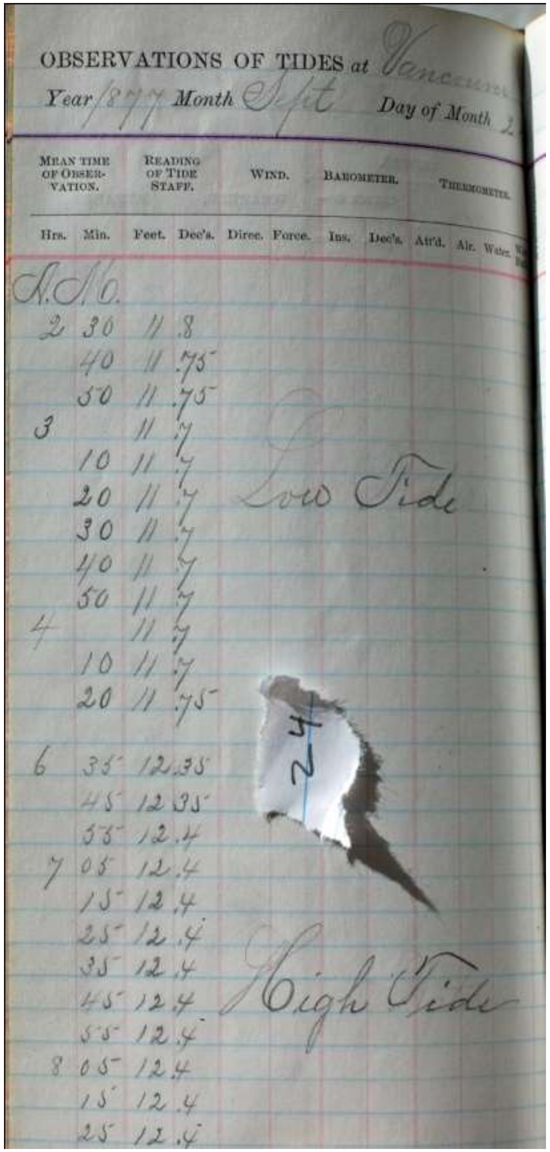
Sample HCR model depths in the estuary domain showing domain decomposition boundaries

Two Delft3D hydrodynamic models have been developed:

1. 21st century model based on 2005 bathymetry (modified from USGS model of Gelfenbaum& Elias (2012)
2. 19th century model based on Burke (2002) digitized bathymetry (bathymetric surveys from 1868-1900)

- 5 sub-domains
    - Shelf/estuary, estuary, lower, upper
- ~50-200 m grid resolution
    - More refined in the estuary and upstream near the Willamette River
- Tidal boundary condition
    - Along the shelf
    - M2, N2, S2, K1, P1, O1
- Discharge boundary conditions
    - The Dalles, 1878 USGS flow (Bonneville)
    - Oregon City, 1878 USGS flow (Morrison Bridge)

1877 Columbia River Tide Data
Temporal Coverage for calibration

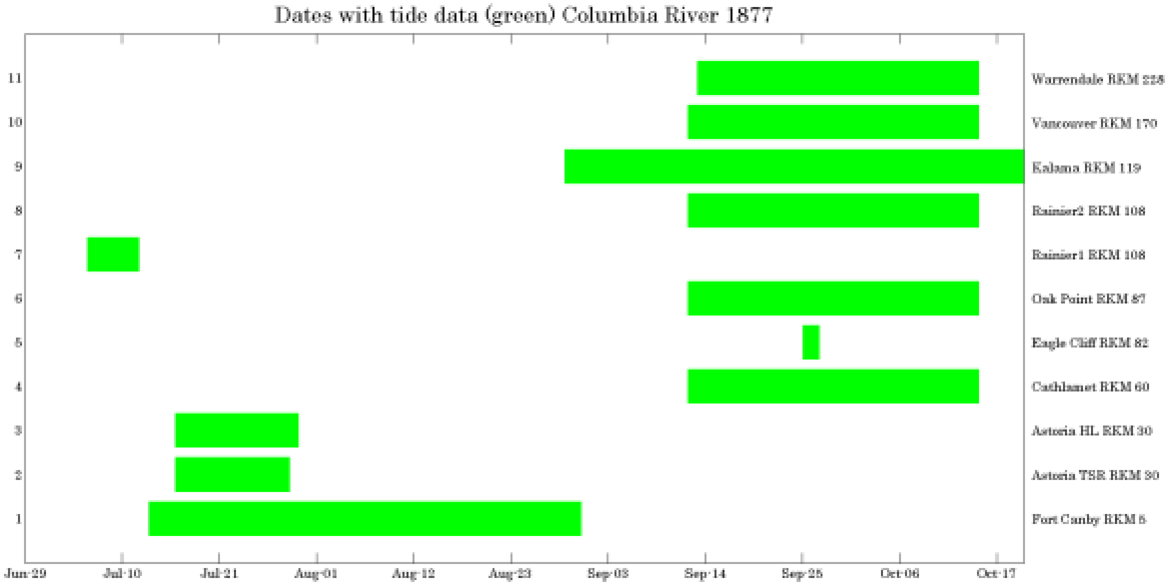


OBSERVATIONS OF TIDES at Vancou

Year 1877 Month Sept Day of Month 2

Mean time of Observation.		Reading of Tide Staff.		Wind.		Barometer.		Thermometer.		
Hrs.	Min.	Feet.	Dec's.	Direc.	Force.	Ins.	Dec's.	Att'd.	Air.	Water.
A.S.C.										
2	30	11	.8							
	40	11	.75							
	50	11	.75							
3		11	.7							
	10	11	.7							
	20	11	.7	Low Tide						
	30	11	.7							
	40	11	.7							
	50	11	.7							
4		11	.7							
	10	11	.7							
	20	11	.75							
6	35	12	.35							
	45	12	.35							
	55	12	.4							
7	05	12	.4							
	15	12	.4							
	25	12	.4							
	35	12	.4							
	45	12	.4	High Tide						
	55	12	.4							
8	05	12	.4							
	15	12	.4							
	25	12	.4							

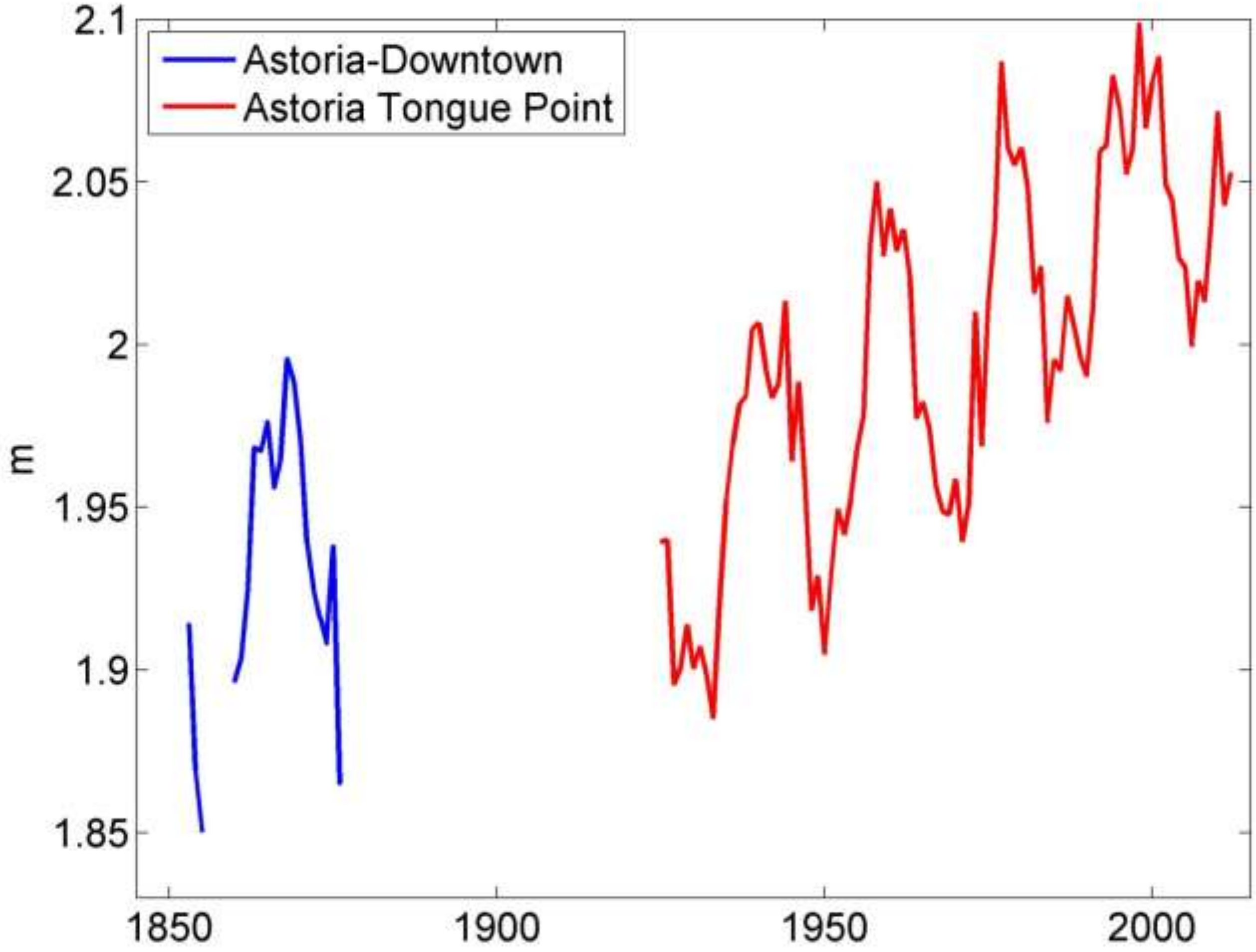
Vancouver, WA September 1877



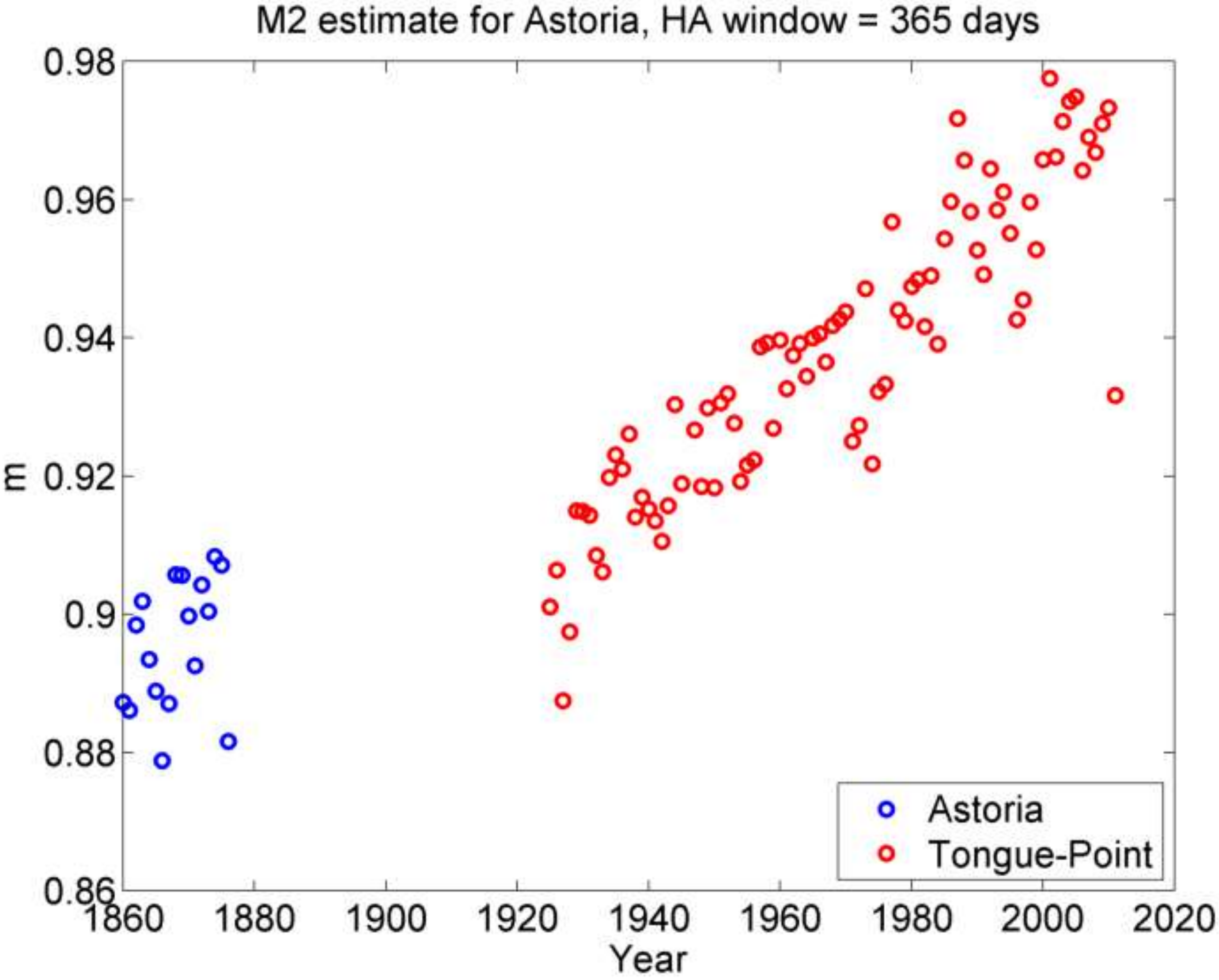
Data from US National Archives

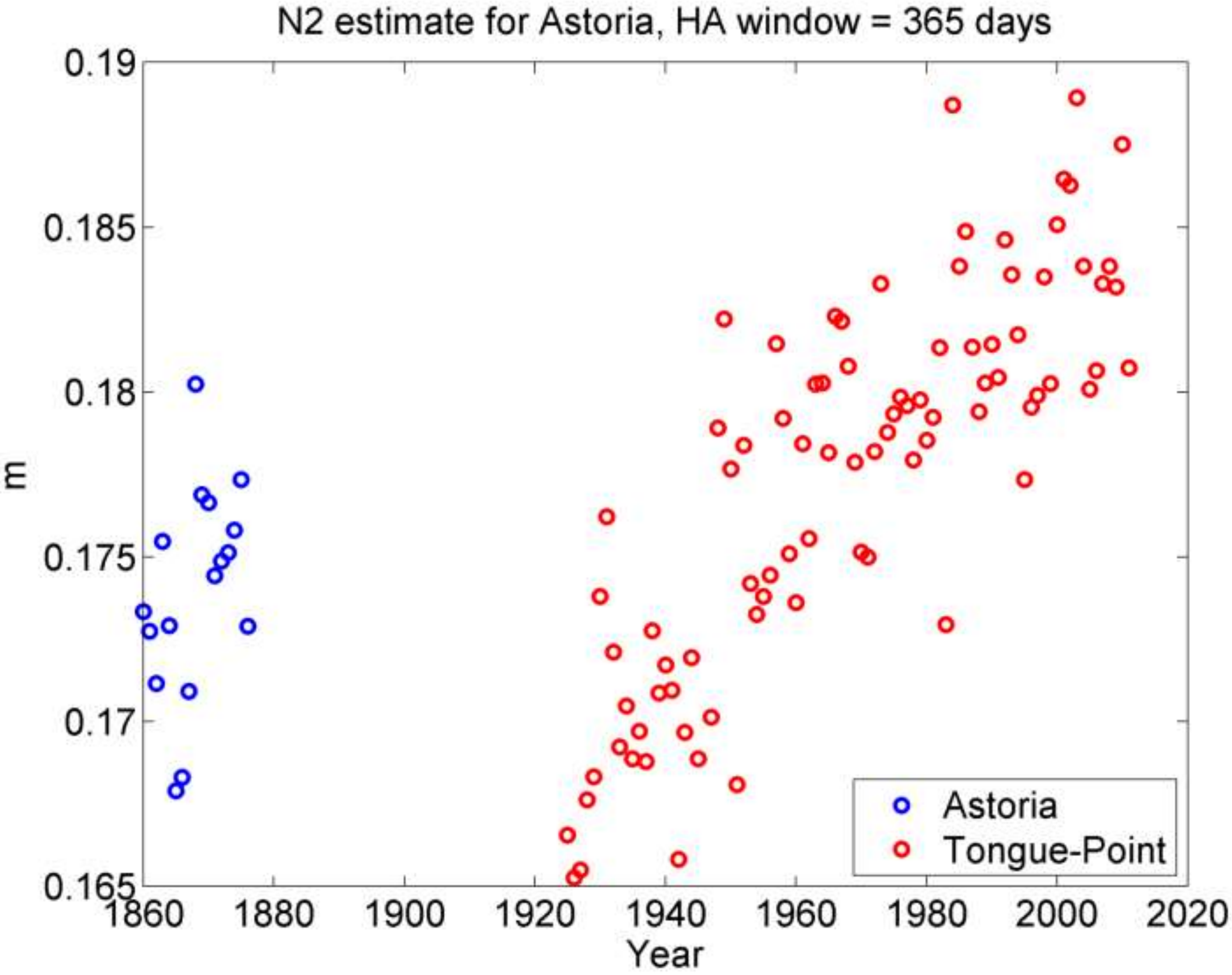
Long Data set from 1853-1876 available at Astoria

Tide Changes: Preliminary Results

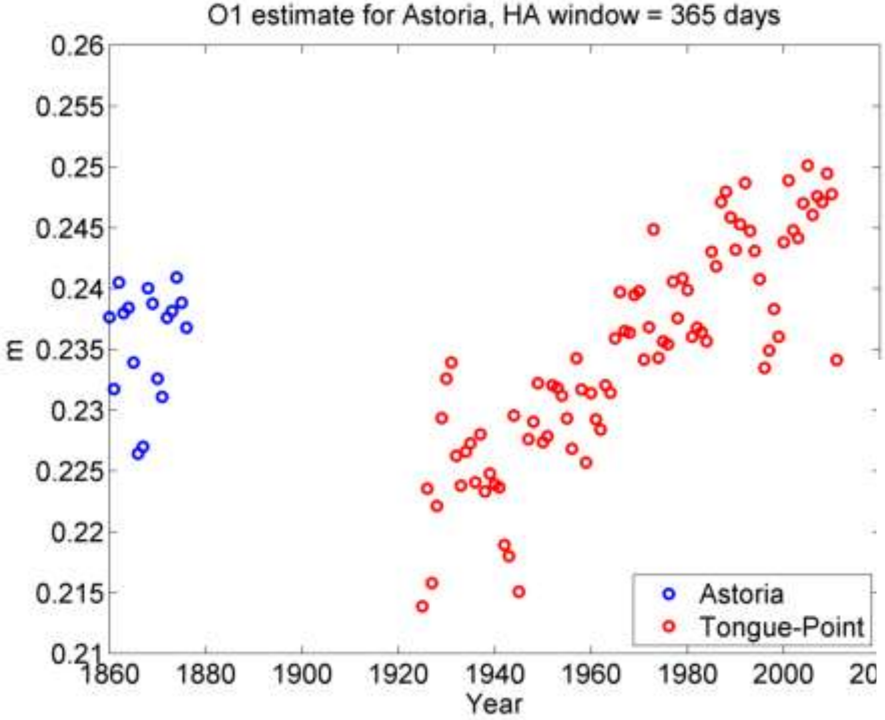


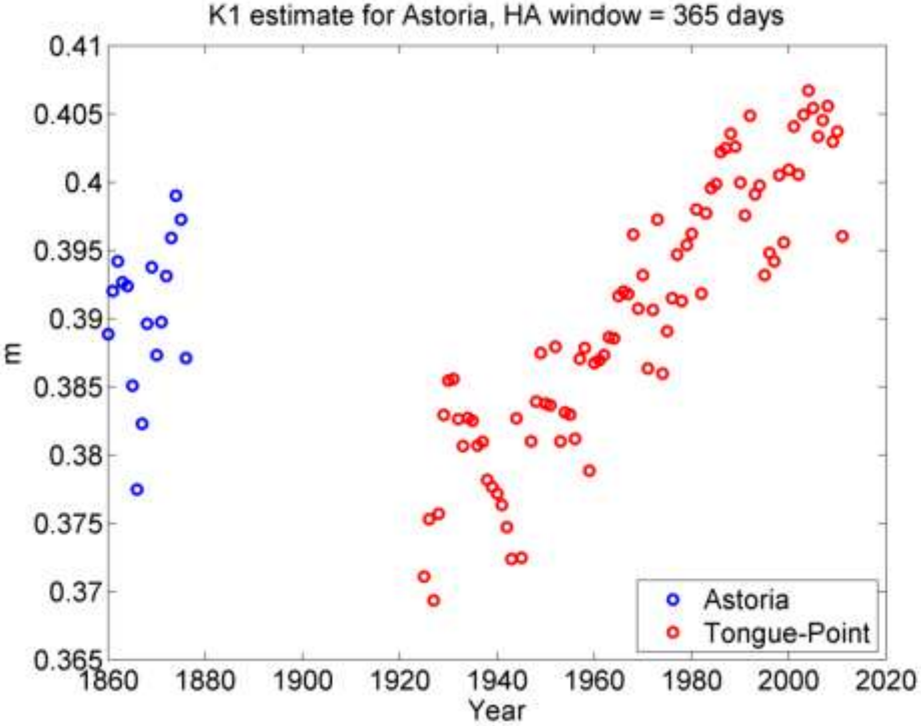
Mean Tidal Range
has increased
by half a foot

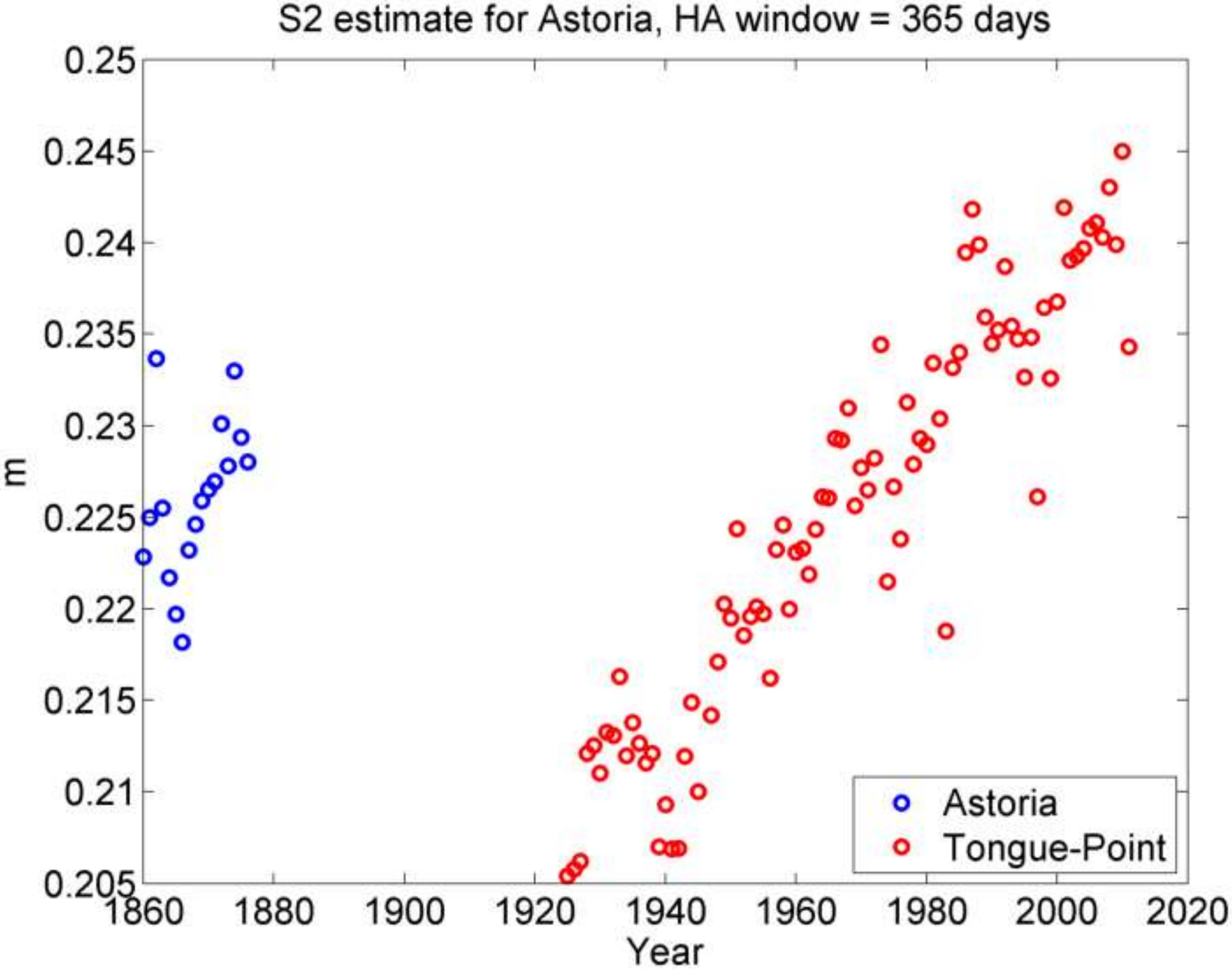

M2 estimate for Astoria, HA window = 365 days
m
0.98
0.96
0.94
0.92
0.9
0.88
0.86
Year
1860
1880
1900
1920
1940
1960
1980
2000
2020
Astoria
Tongue-Point


N2 estimate for Astoria, HA window = 365 days
m
0.19
0.185
0.18
0.175
0.17
0.165
1860
1880
1900
1920
1940
1960
1980
2000
2020
Year
Astoria
Tongue-Point

Tide Changes: Preliminary Results



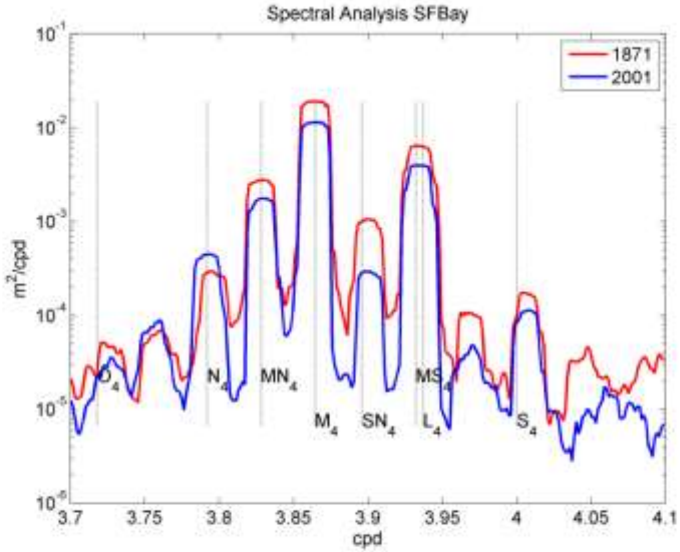




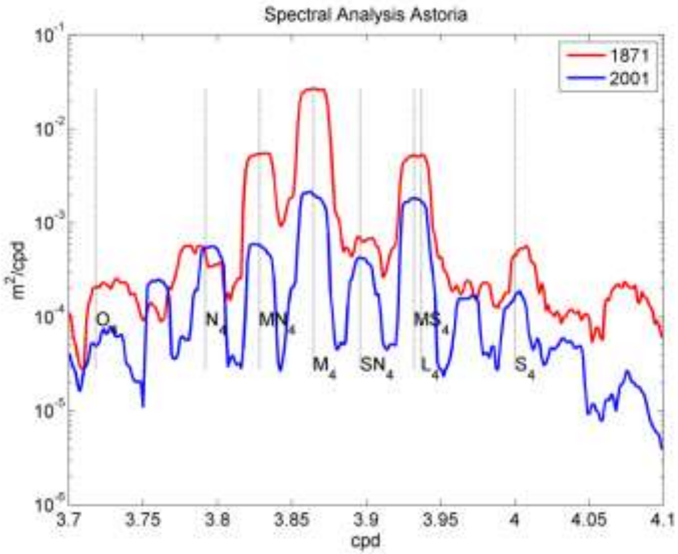
S2 estimate for Astoria, HA window = 365 days

One way to tease apart local and basin-scale changes is to look at the locally produced, non-linear shallow-water overtides

SF Bay



Astoria



Friction on a tide wave is larger when:

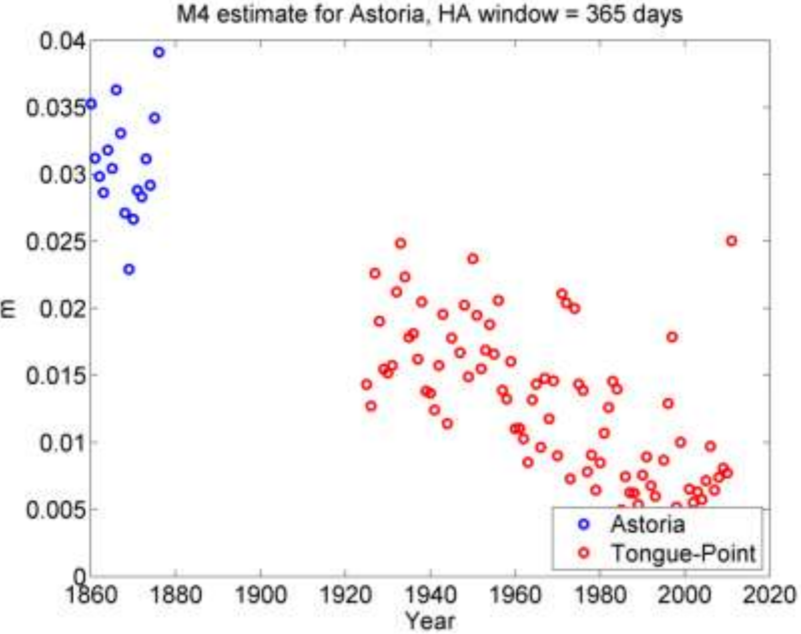
(1) Water is shallow (e.g. tidal flats)
(2) Bathymetry (e.g., dunes) is pronounced
(3) River Flow is larger
(4) Internal shear larger

Friction extracts energy from tidal constituents and puts it into higher ‘harmonics’, or ‘overtides’. For example, the twice daily M2 lunar tide produces an M4 (4 times daily) overtide.

Both SF and especially Astoria were much more ‘frictional’ in the past.

Spectral energy at the 4 cpd frequency much larger in the 19th century

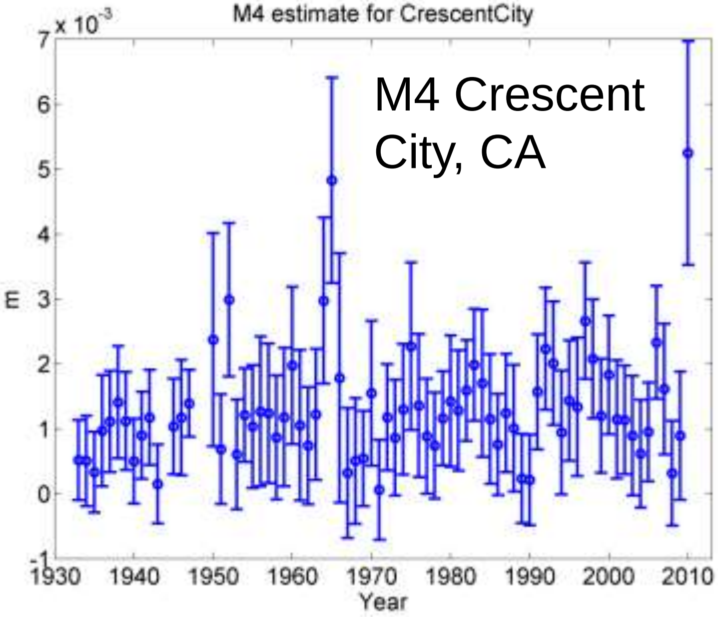
Overtide variation



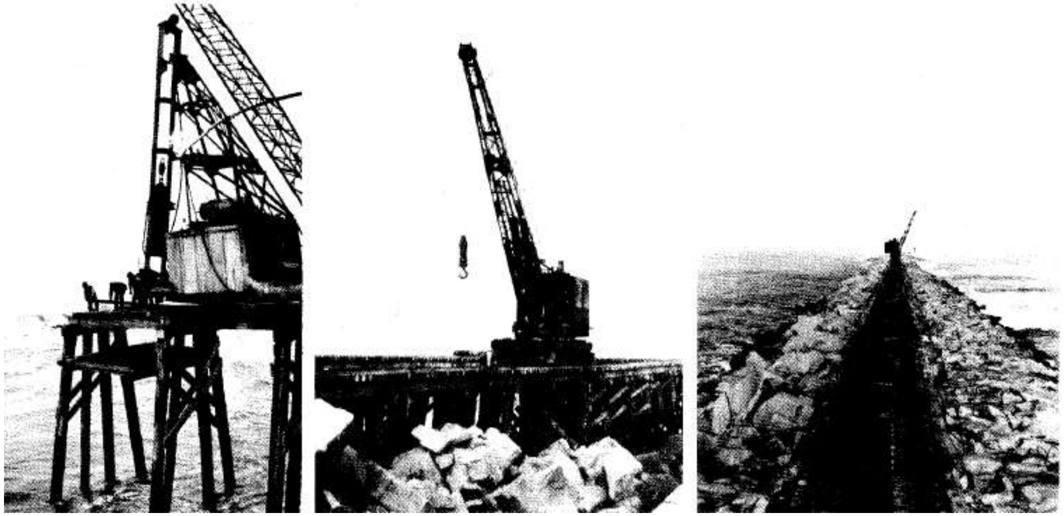
M4 overtide in Astoria decreased from 2 cm to 5 mm during the 20th century

Nearby Ocean stations show little variation

Why???



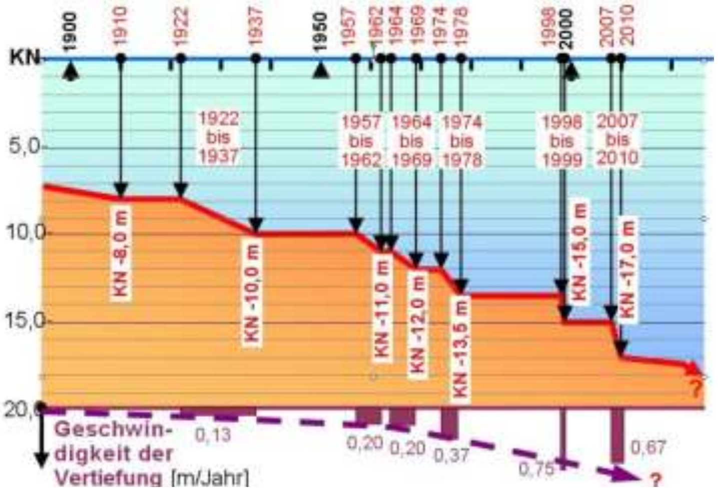
M4 Crescent City, CA



Local effects: construction of the Columbia Bar, dredging, deepening, etc.

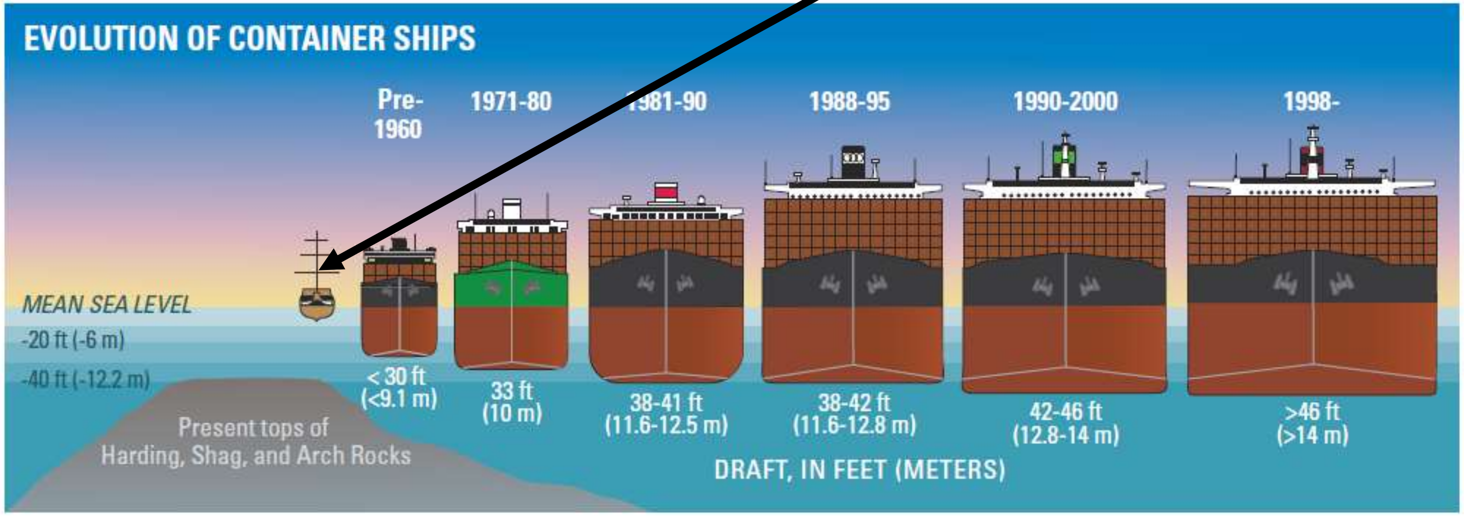
One hypothesis

Deepening of the Elbe River, Germany since 1900

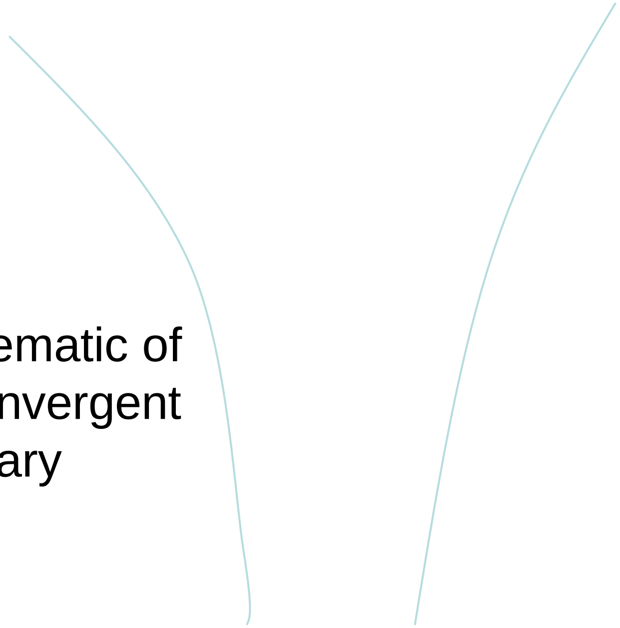


Local, anthropogenic effects such as channel deepening and streamlining are in many cases a primary cause of long-term change.

Depth driven by ship size



What do other studies suggest is important?



Schematic of a convergent estuary

In many convergent estuaries, the first order momentum balance is between the pressure gradient and friction (e.g., Friedrichs & Aubrey, 1994):

$$0 = -g\frac{\partial \zeta}{\partial x} - F\,.$$

$$F = \frac{8}{3\pi}\frac{c_d U}{\overline{h}}u = r\,u$$

Tidal heights become a balance between the amplifying effects of convergence and the damping by friction.

→ Observation: Increasing depth has a similar dynamical effect as decreasing drag coefficient

But tides in estuaries are complicated. Factors important to tidal propagation and overtide production include:

1. Nonlinear tidal asymmetry (production of overtides) is controlled by the ratio of acceleration/friction:

   ψ= Ianiello # = $\omega H^2/K_m$

   (Ianniello, 1977; this is the inverse Strouhal number of Burchard 2009)

2. Resonance $\lambda = 4L_T\ \omega/(gH)^{1/2}$

3. Internal tidal asymmetry (Simpson #)

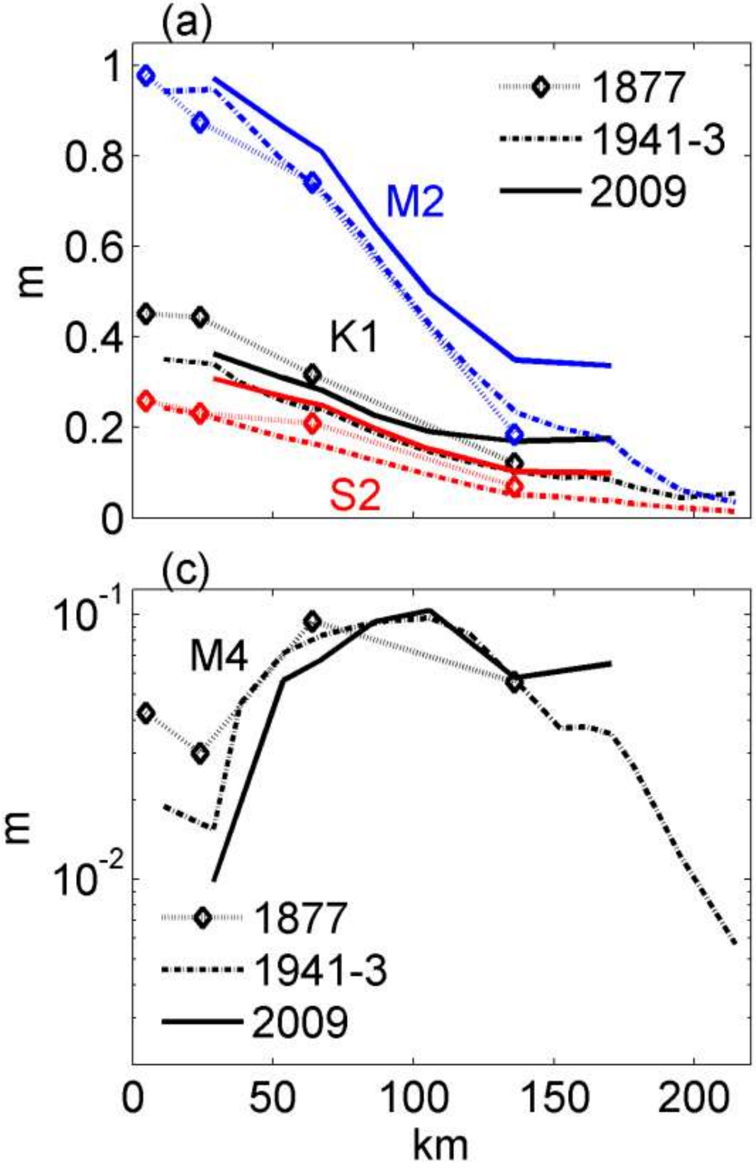
   $$Ri_x = \frac{\beta g H^2}{C_d U^2}\frac{ds}{dx} \sim \frac{\beta g S_o H^2}{C_d U^2 X_2}$$

4. Other factors such as ratio of intertidal flats/channel volume (Friedrichs and Aubrey, 1988) and ratio of nonlinear to local acceleration (Ianiello, 1979) can be important

Similarly , diurnal and semidiurnal constituents ought to have a different reaction to deepening

Effects of increasing depth/decreasing friction have same dynamical effect

Observations in Columbia River



1. M2 increased in estuary (km 0-30) between 1877 and 1941

2. M2 and S2 increased in the tidal river between 1941 and the present

3. Overtides decreased in estuary between 1877 and 1941

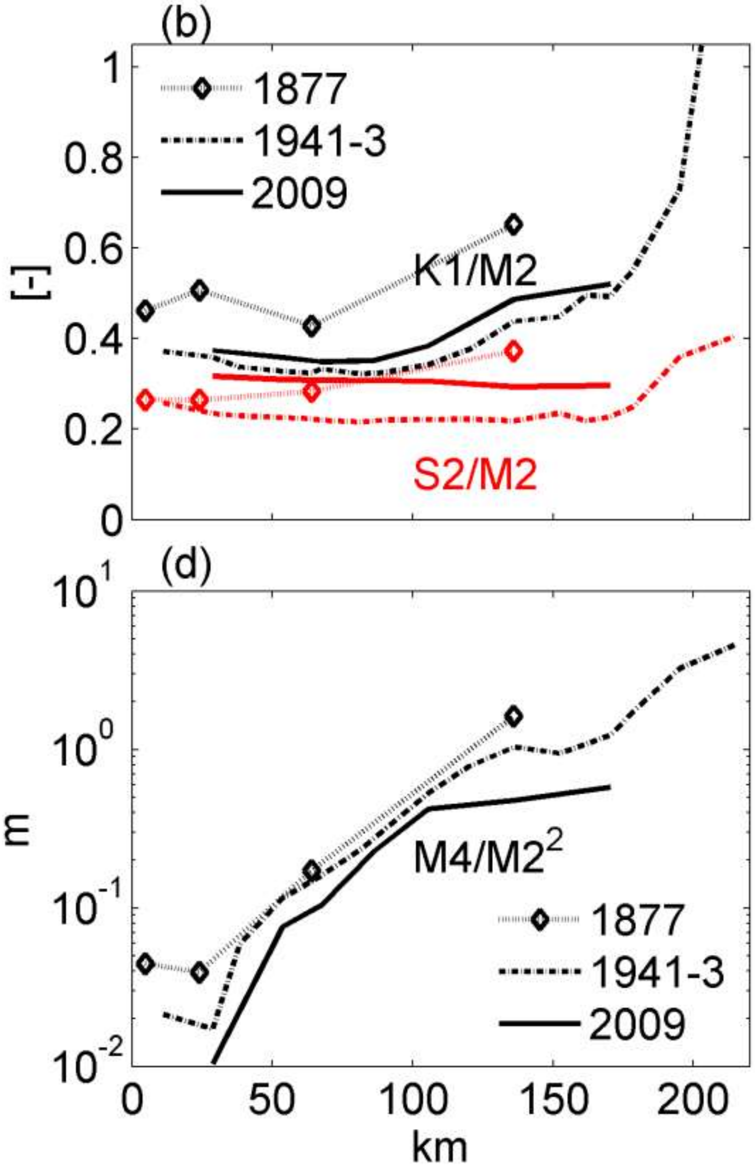
4. The ‘overtide’ maximum shifted upstream

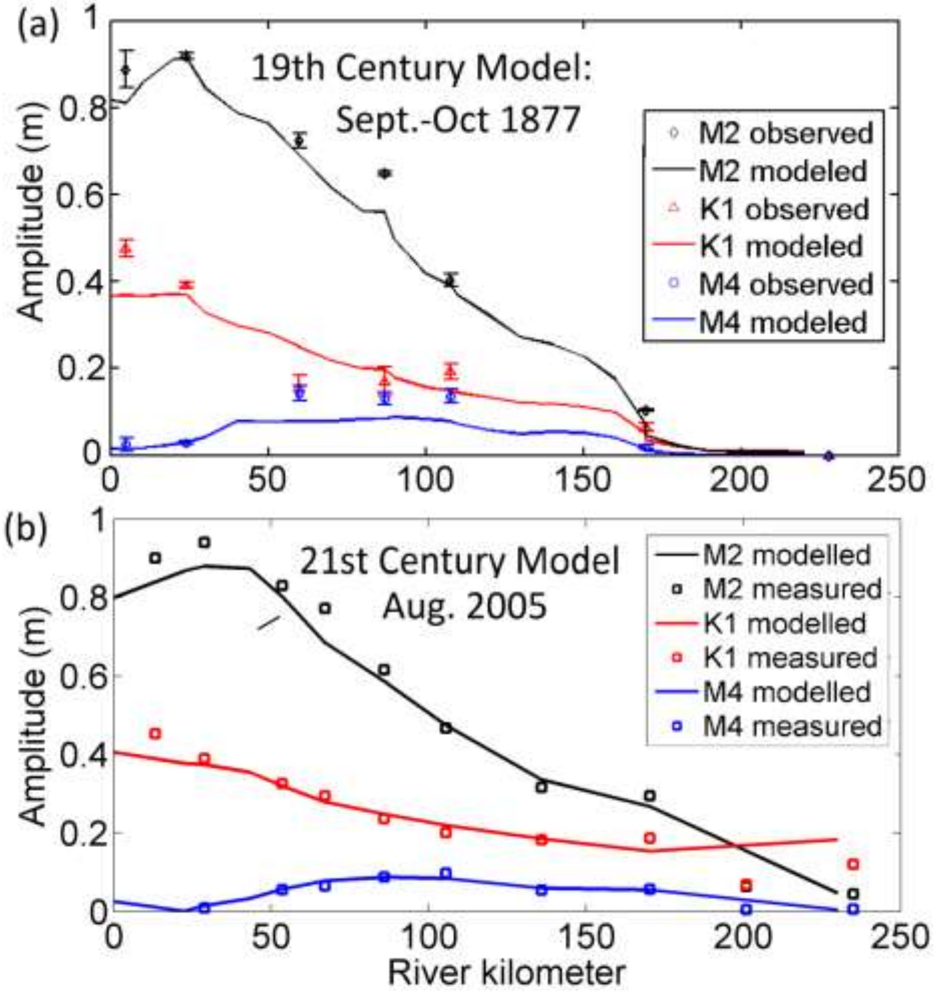
The changed constituents produce altered tidal behavior

1. The system is less frictional, as observed in the M4/M2^2 ratio

2. Spring-Neap ratio has increased
   (As system becomes less frictional, S2 becomes less damped by M2; see e.g. Godin, 1997)

3. The K1 behavior is mixed. More analysis needed





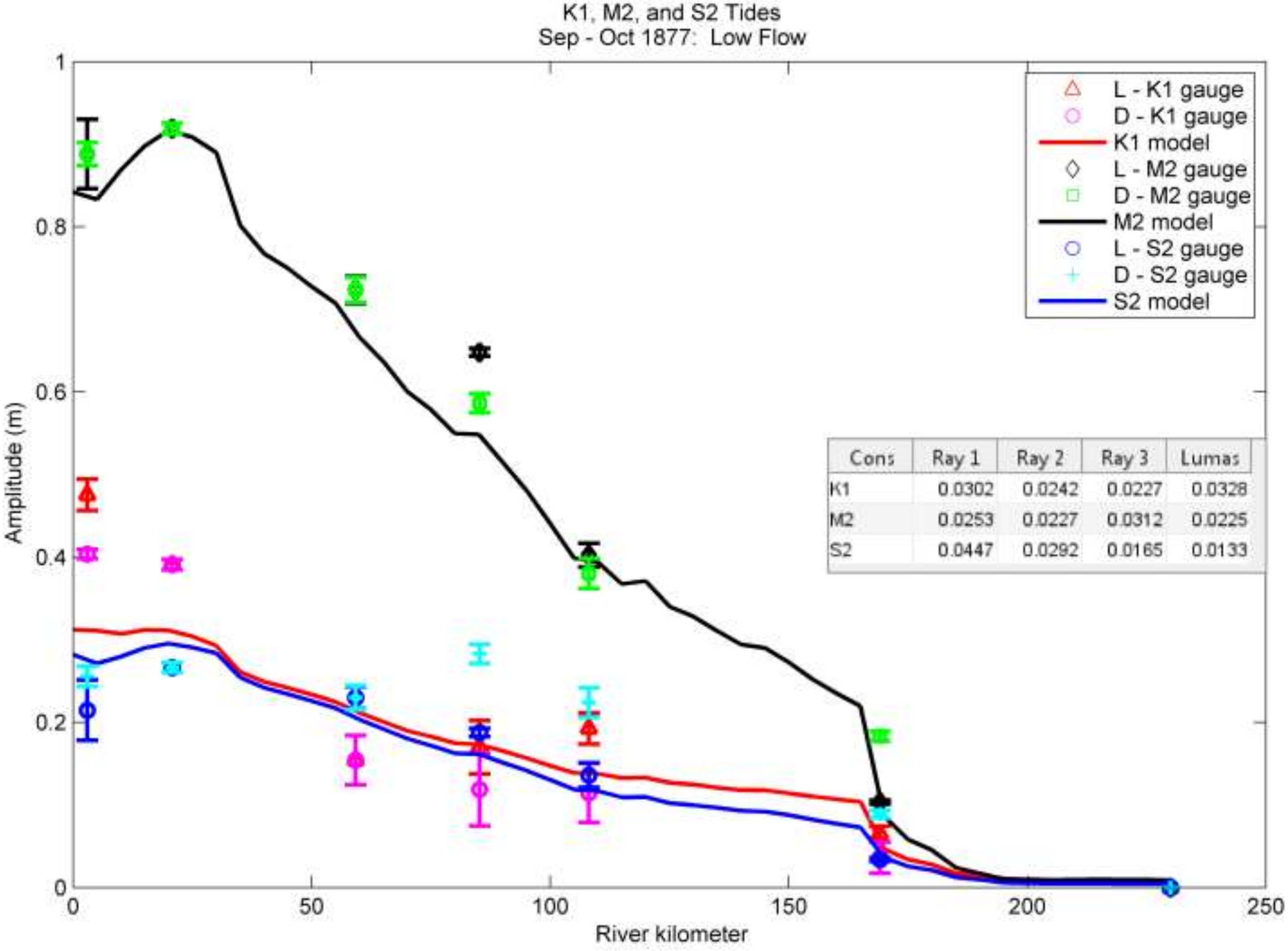
Barotropic Model Run…

Model: A Delft3D model is being made to determine the causes of change.

The model is currently calibrated to tide data and does as well as the modern model.

Note: The M2 maximum has moved upstream from Astoria towards Astoria Tongue Point/ Cathlamet Bay.

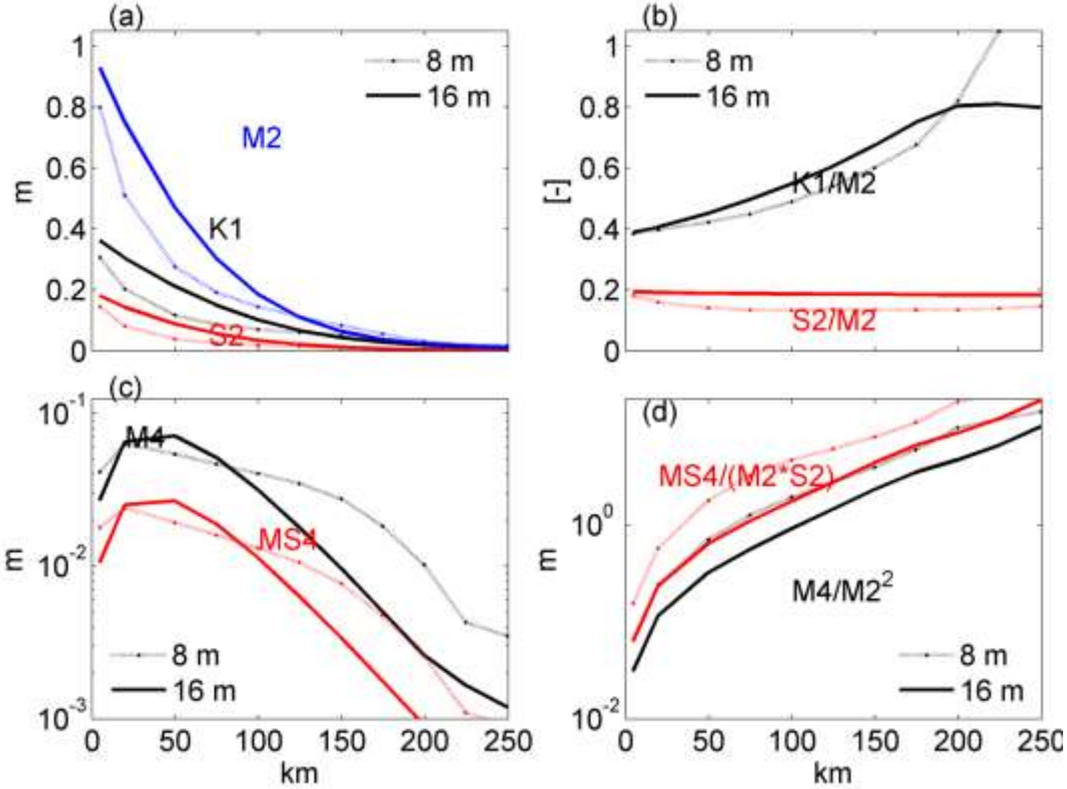
Hence: The Tongue Point tide data has actually changed *more* than the prevous graphs suggested.



Cons	Ray 1	Ray 2	Ray 3	Lumas
K1	0.0302	0.0242	0.0227	0.0328
M2	0.0253	0.0227	0.0312	0.0225
S2	0.0447	0.0292	0.0165	0.0133

Baroclinic Model Calibration

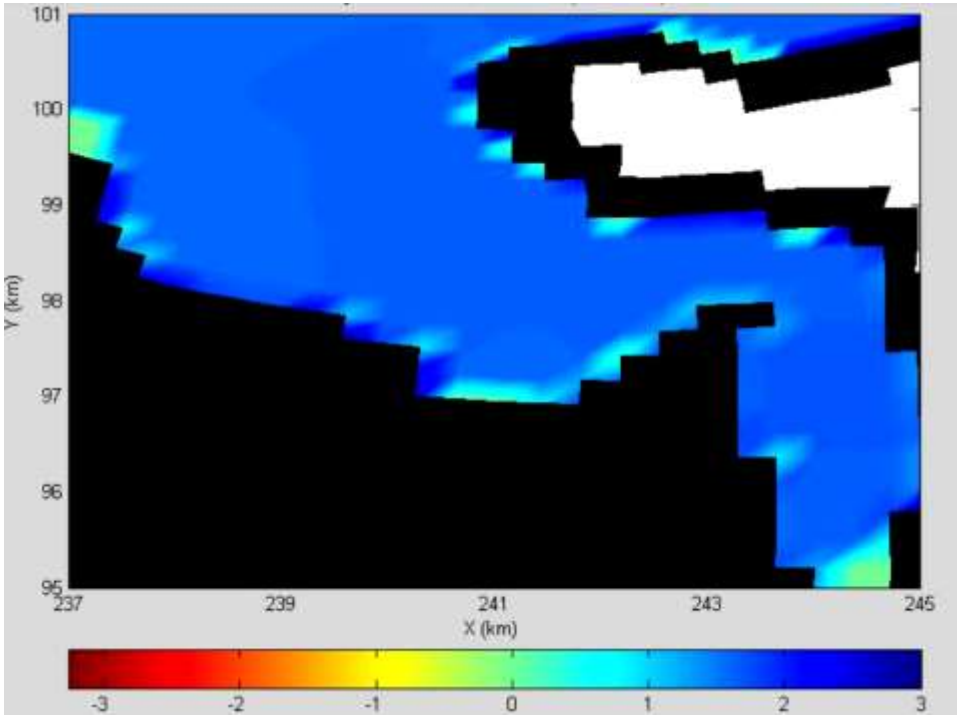
Preliminary Results



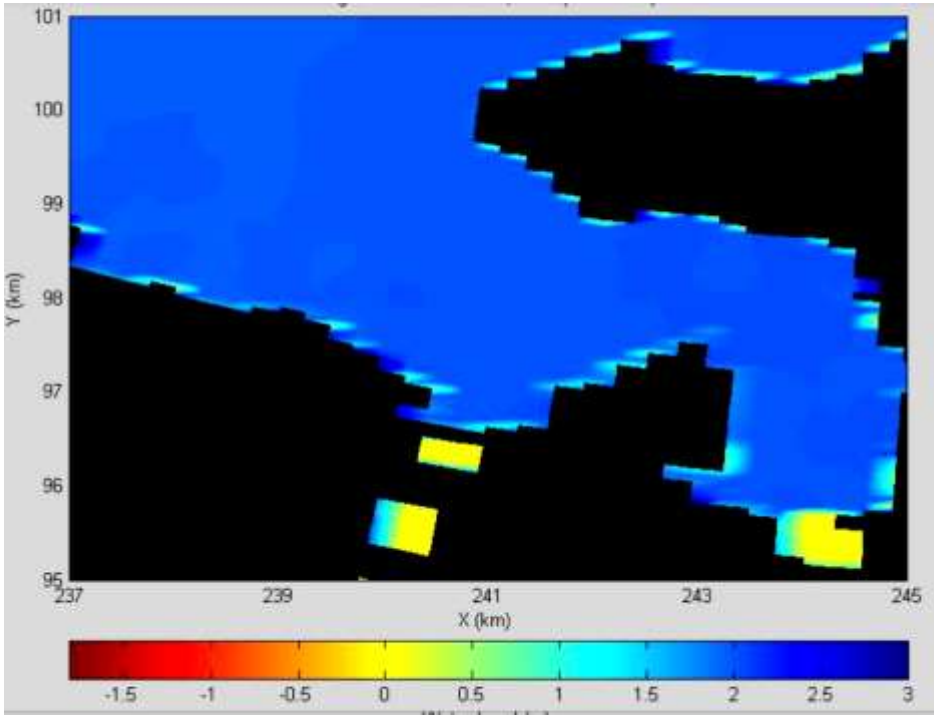
Results from an idealized version of the 19th cnetury model:

1. Increasing depth produces greater constituent amplitudes
2. Overtide maximum is moved upstream
3. M4/M2^2 ratio forced downwards everywhere
4. Spring Neap ratio increased
5. System more diurnal, but not everywhere.

Spring Tide inundation

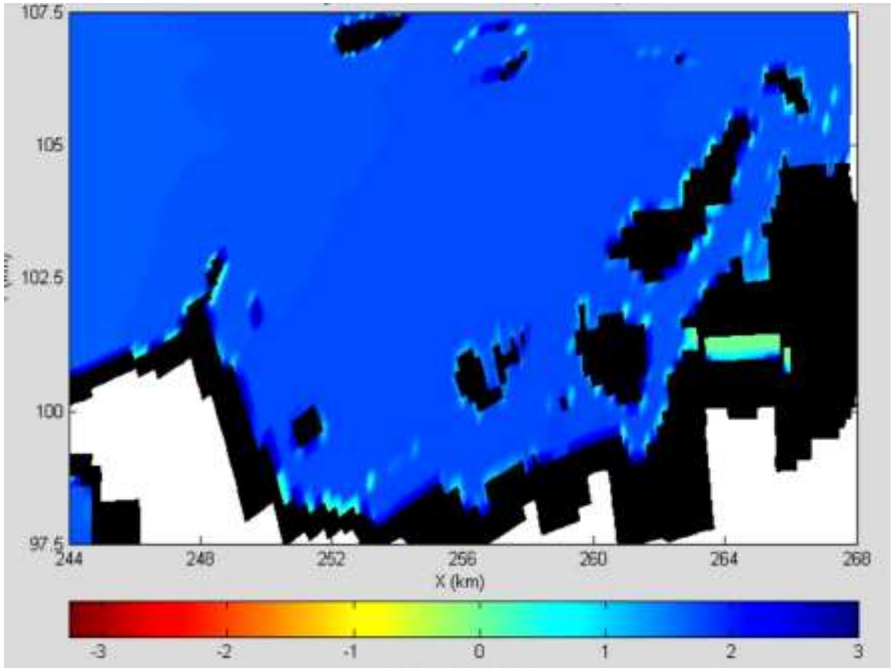


Youngs Bay, Modern Inundation

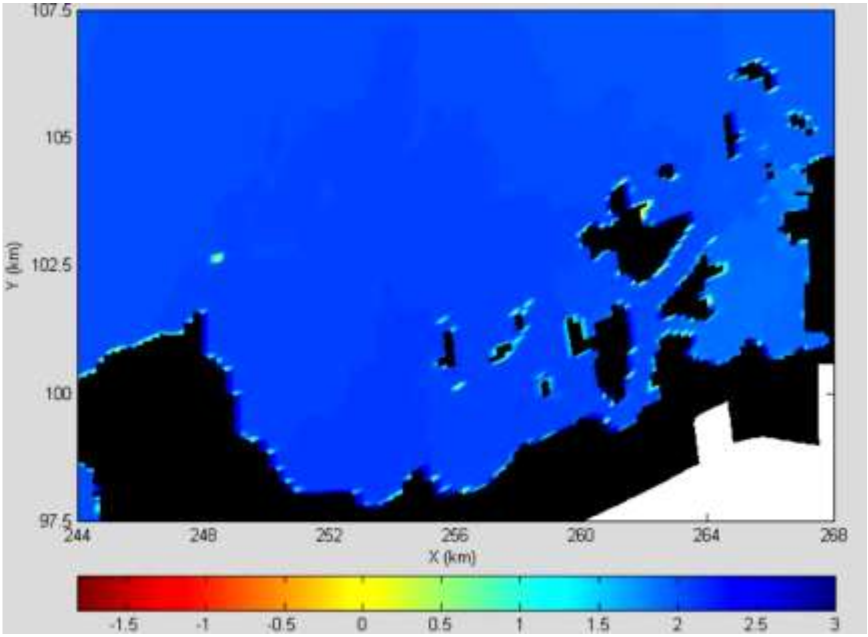


Youngs Bay, Historic Inundation

Spring Tide inundation



Cathlamet Bay, Modern Inundation

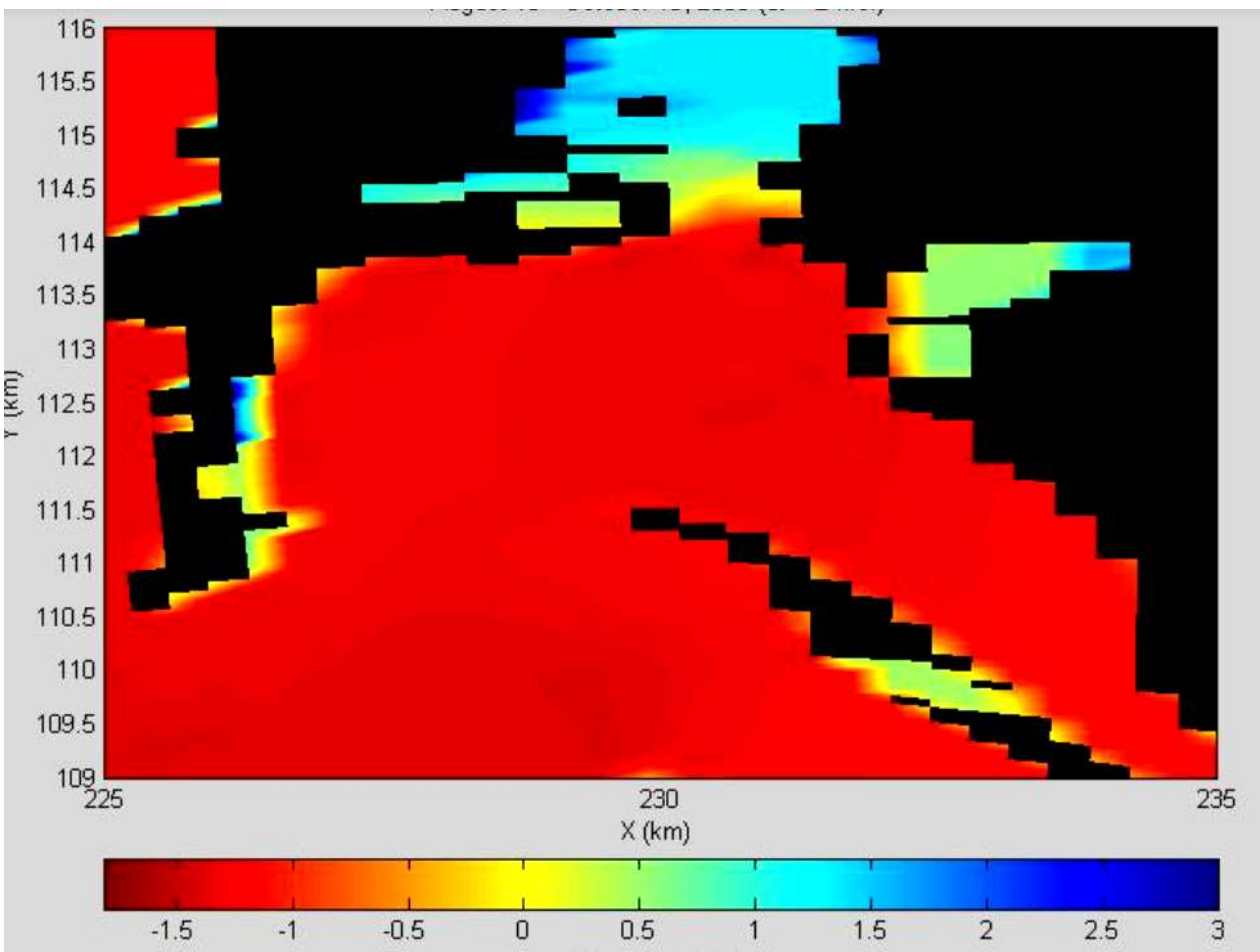


Youngs Bay, Historic Inundation

Preliminary Results

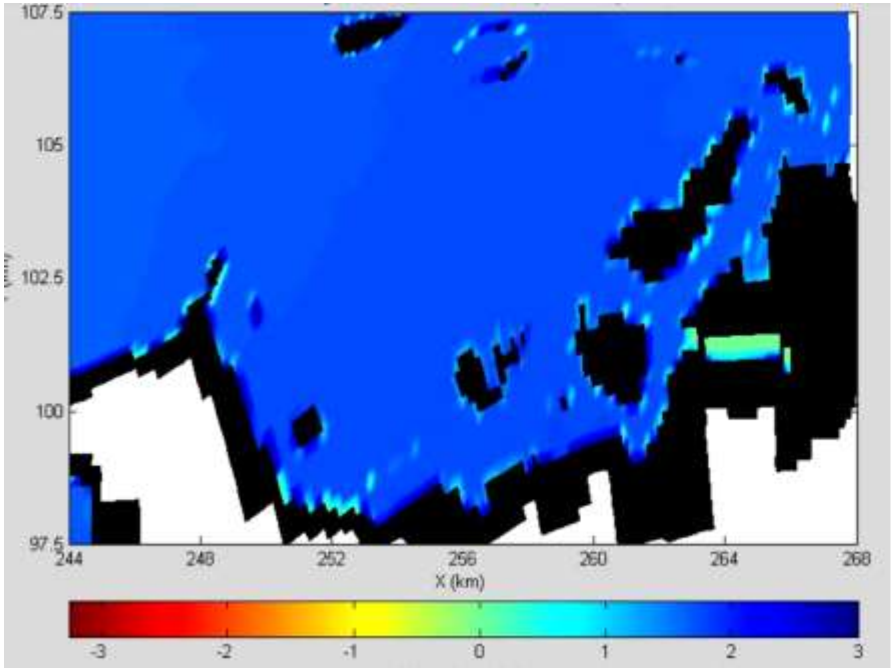
3 Videos:

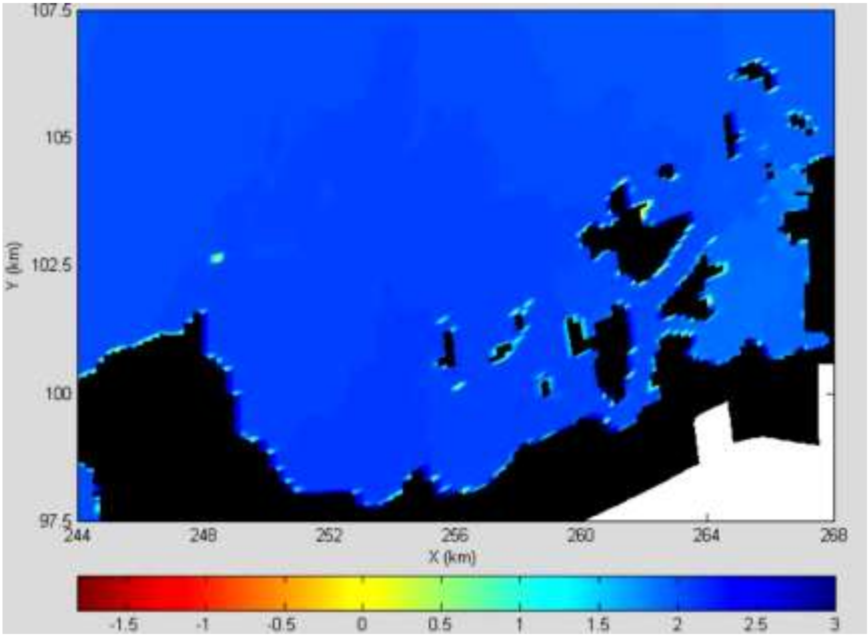
1. Water levels
2. Salinity
3. Bed stress



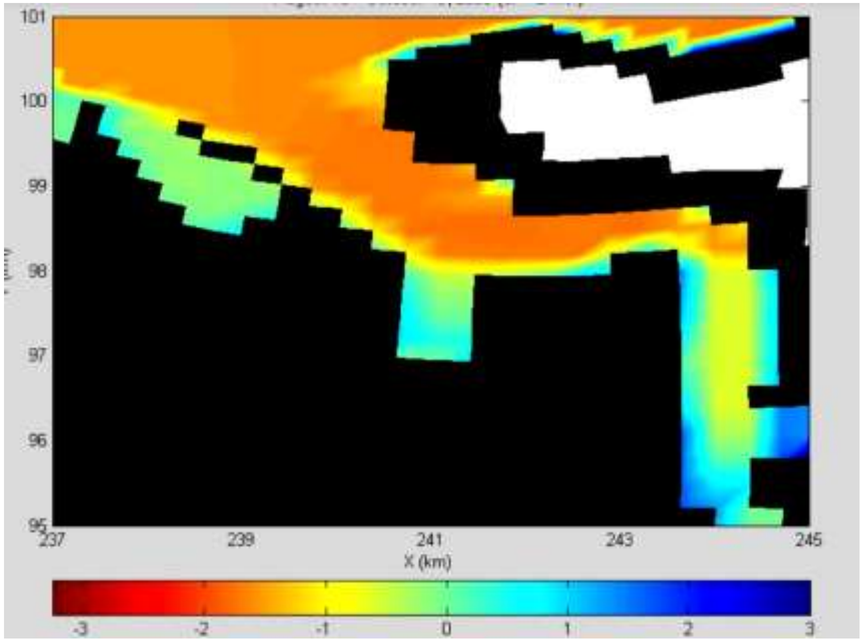
Baker Bay

Next Steps

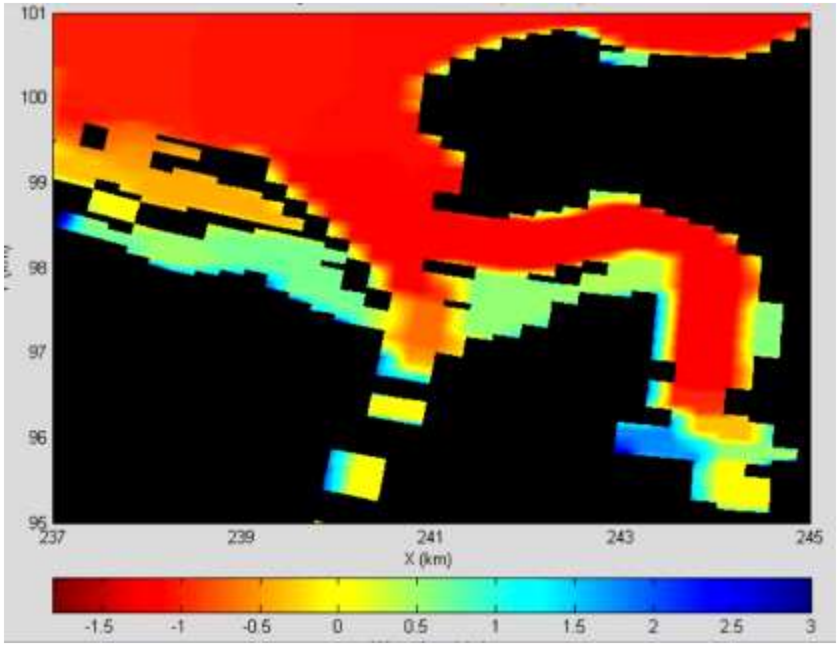




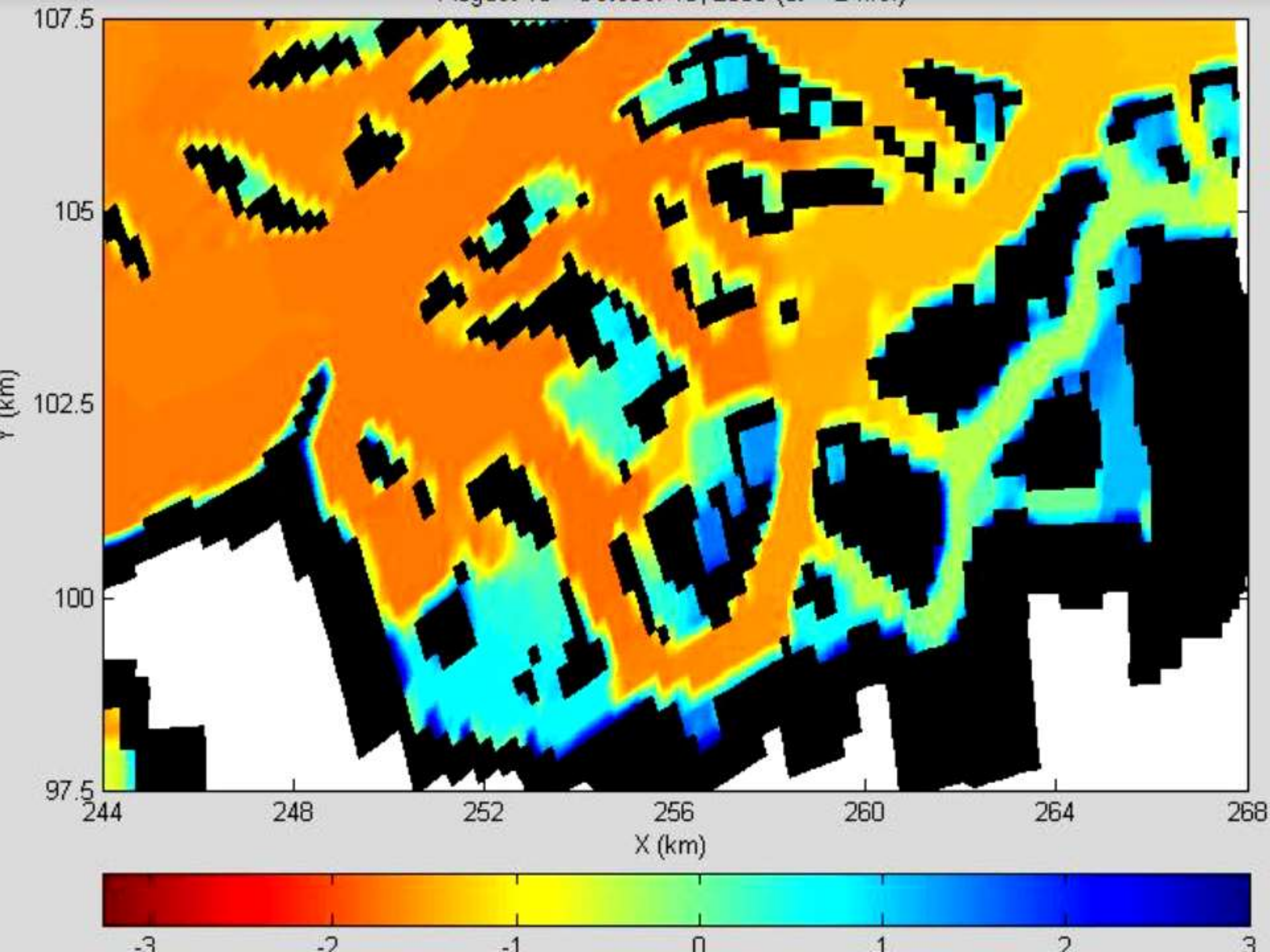
1. Determine how much tides have affected wetland habitat, and where
2. Determine the primary reasons for altered long-wave behavior

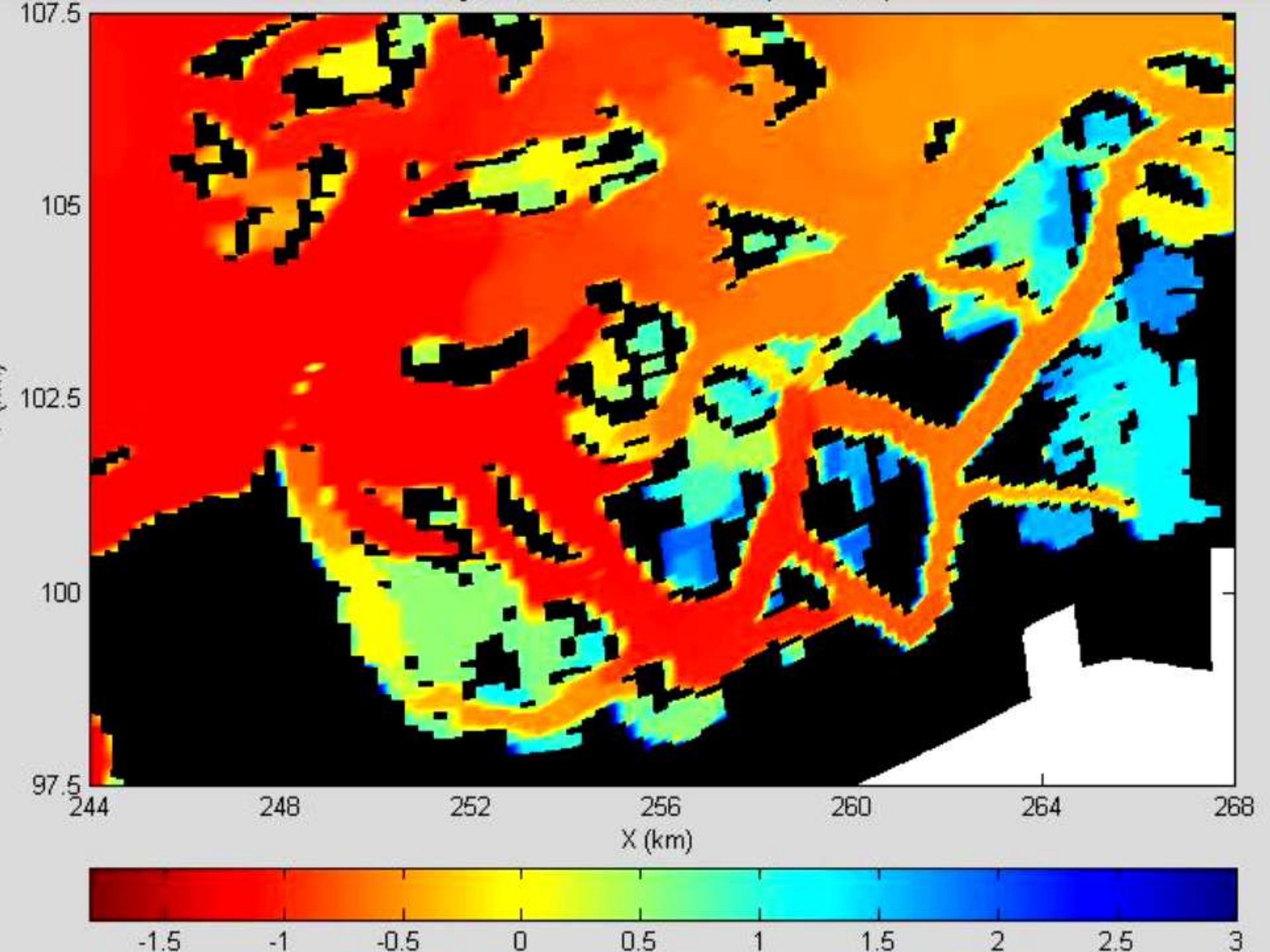


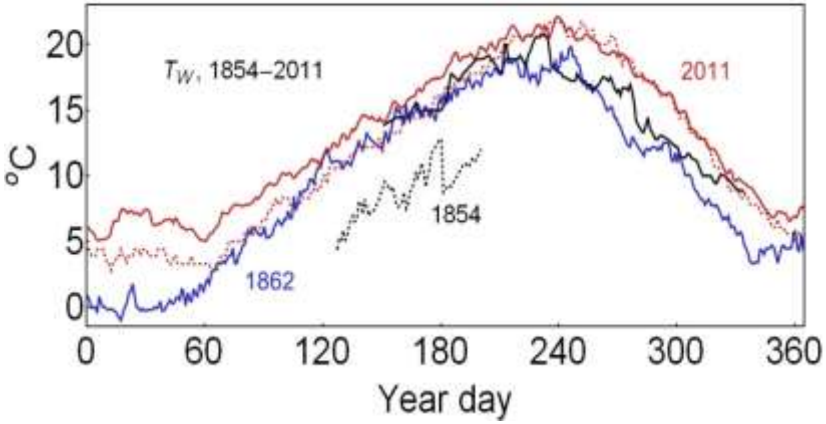
Modern



Historic


107.5
105
102.5
100
97.5
Y (km)
244
248
252
256
260
264
268
X (km)
-3
-2
-1
0
1
2
3


107.5
105
102.5
100
97.5
244
248
252
256
260
264
268
X (km)
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3



Dotted-Vancouver;
Solid: Astoria

Water Temperature much larger than 1850s…

Gradient between upriver and estuary switched (river used to be colder)

Future Steps:

--Change bathymetry and see what happens.
-- Simulate extreme events (e.g., 1876 flood).
What would that flood look like today, under both ‘virgin’ flow and regulated scenarios?

--Water Temperature and Salinity Intrusion
Although we do not have salinity data, we have a treasure trove of temperature data, including top/bottom from Ft. Canby, 1883-1888.

Point would be: How has the temperature/salinity climate of wetlands changed over time?

Finally: What lessons are there for climate change?

Final thoughts (some things to think about)

An incomplete list of long-term changes to estuary boundary conditions includes:

- --tides
- --sea level
- --Meteorological changes (e.g., NAO index)
- --river flow
- --sediment input
- --nutrient input
- --bathymetry
- --habitat
- --????

Changes may be quite obvious, or be subtle and occur over a long time (e.g., changes to Columbia tidal components).

Changes often produce a non-linear cascade of events. Everything affects everything.

Moreover, both natural and anthropogenic change are often wrapped together.

Tide data are the oldest oceanographic data sets that can address these issues → Recovery of these data is important

Tide Changes: Preliminary Results

Approximate Maximum Tide amplitude, 19th century: M2 +S2 +N2 + O1 +K1

1.92m

(Maximum Difference of 3.84m between high and low tide)

Approximate Maximum Tide amplitude, 21st century: M2 +S2 +N2 + O1 +K1

2.05m

(Maximum Difference of 4.1m between high and low tide)

Greater tidal range is as much as 1 foot larger now than in 19th century.
Impacts both the high and the low waters.

However, This needs to be considered within the spatial variation of tides in the estuary.