Is flood risk in the Sacramento-San Joaquin River Delta increasing?

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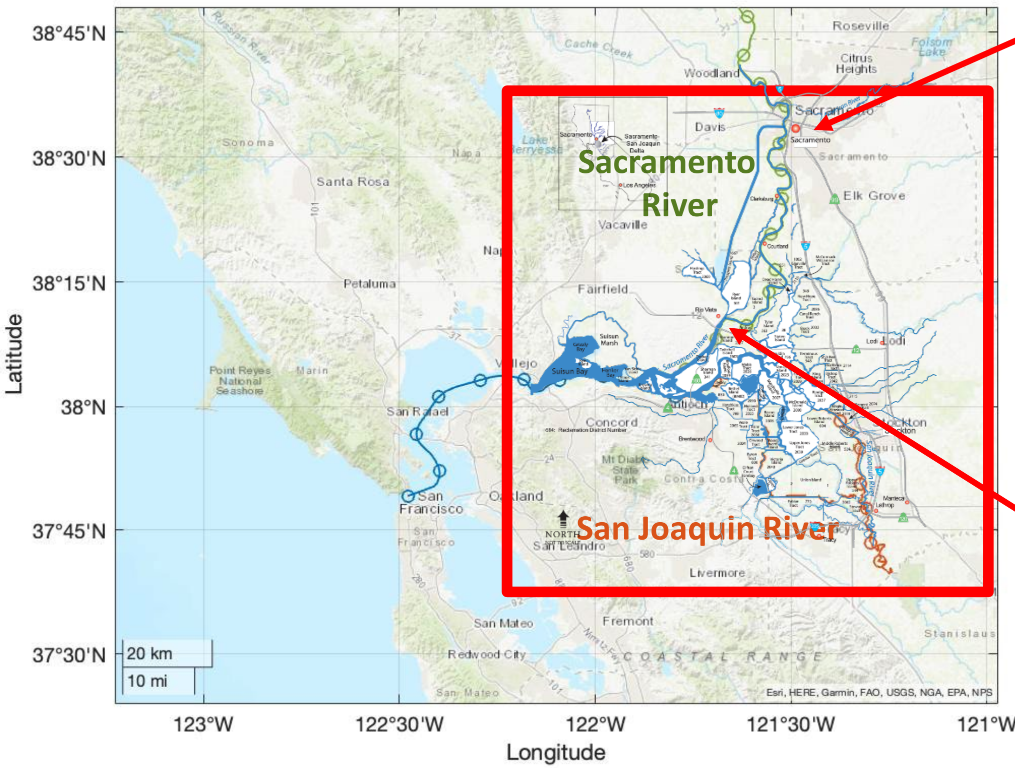
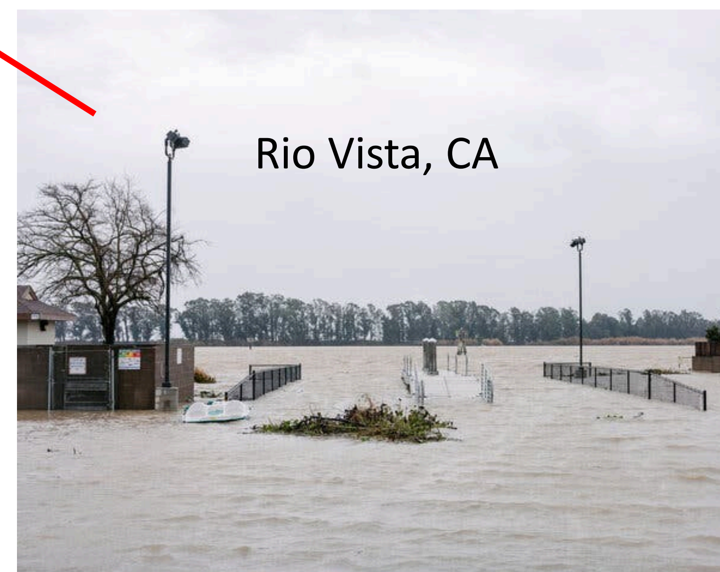
The Delta is influenced by both rivers and coastal processes

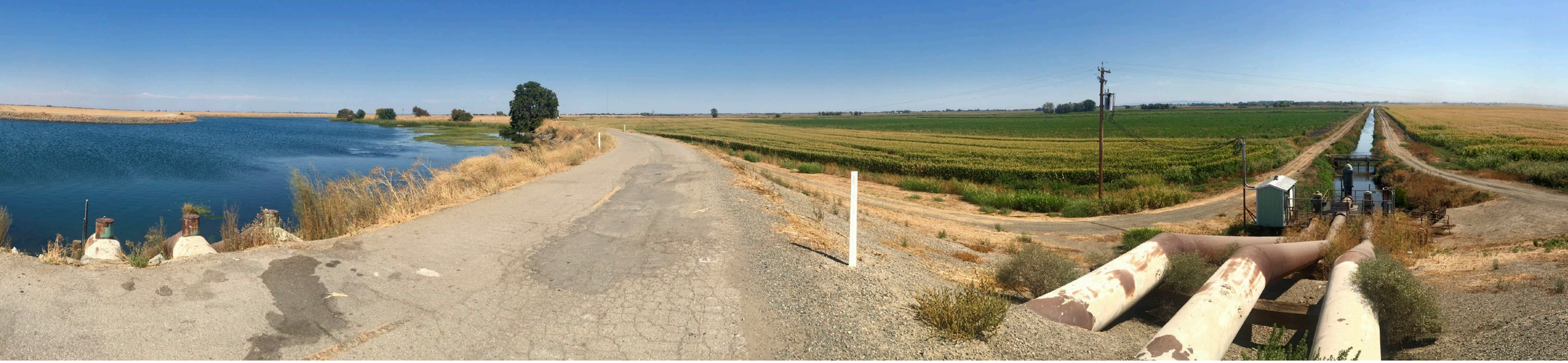


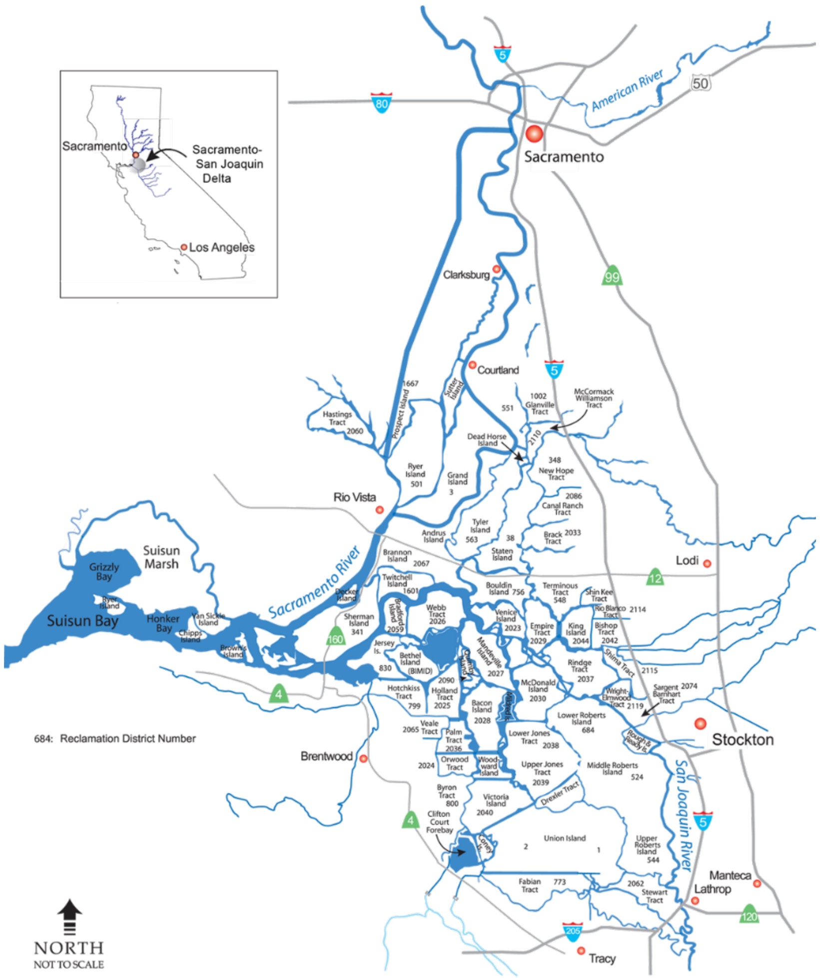
https://www.theguardian.com/us-news/2023/jan/14/california-storms-flooding-sacramento-county



https://www.nytimes.com/2023/01/17/us/california-weather.html

Will sea-level rise and more intense mega-storms increase water levels and flood risk?



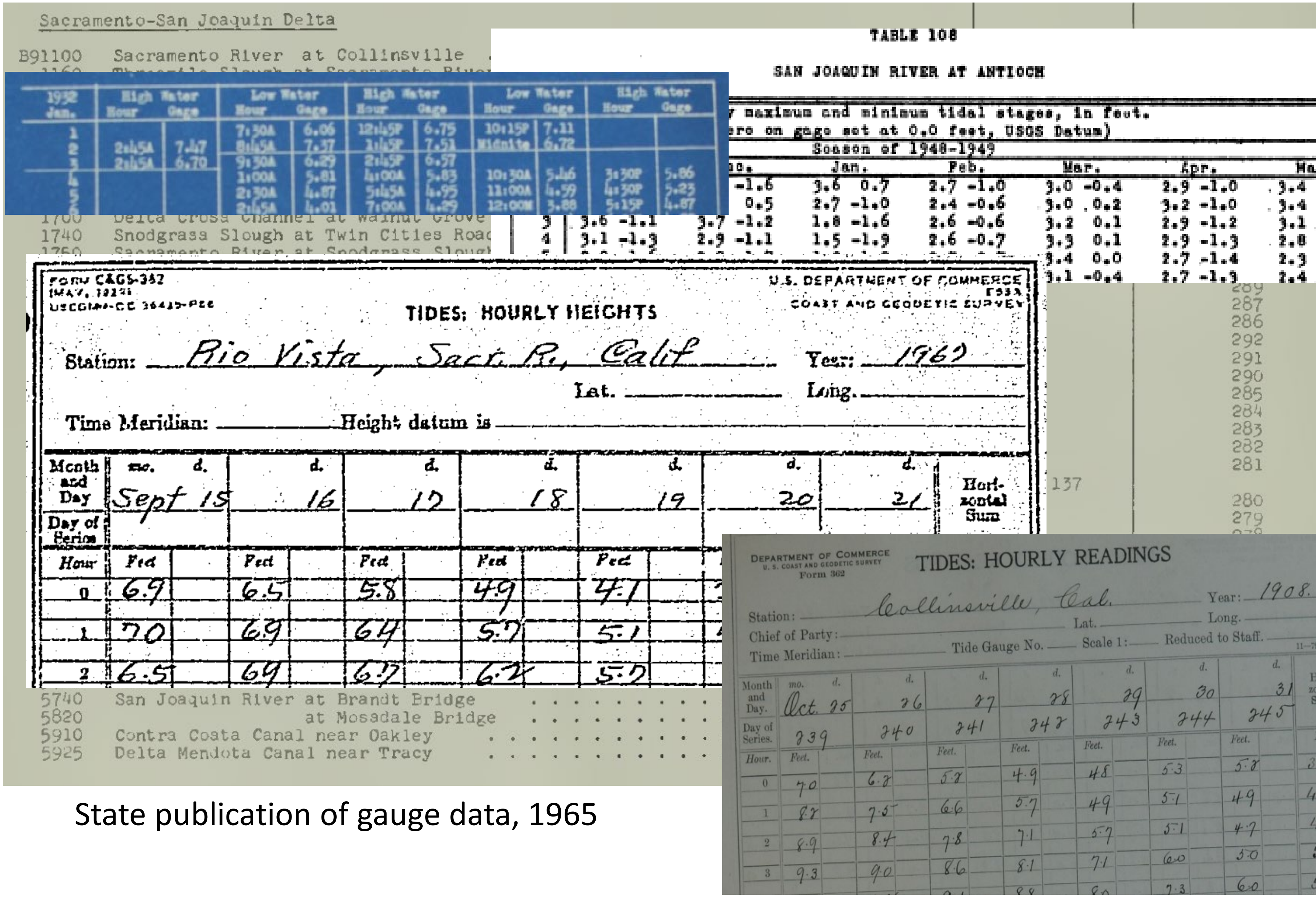


Approach:

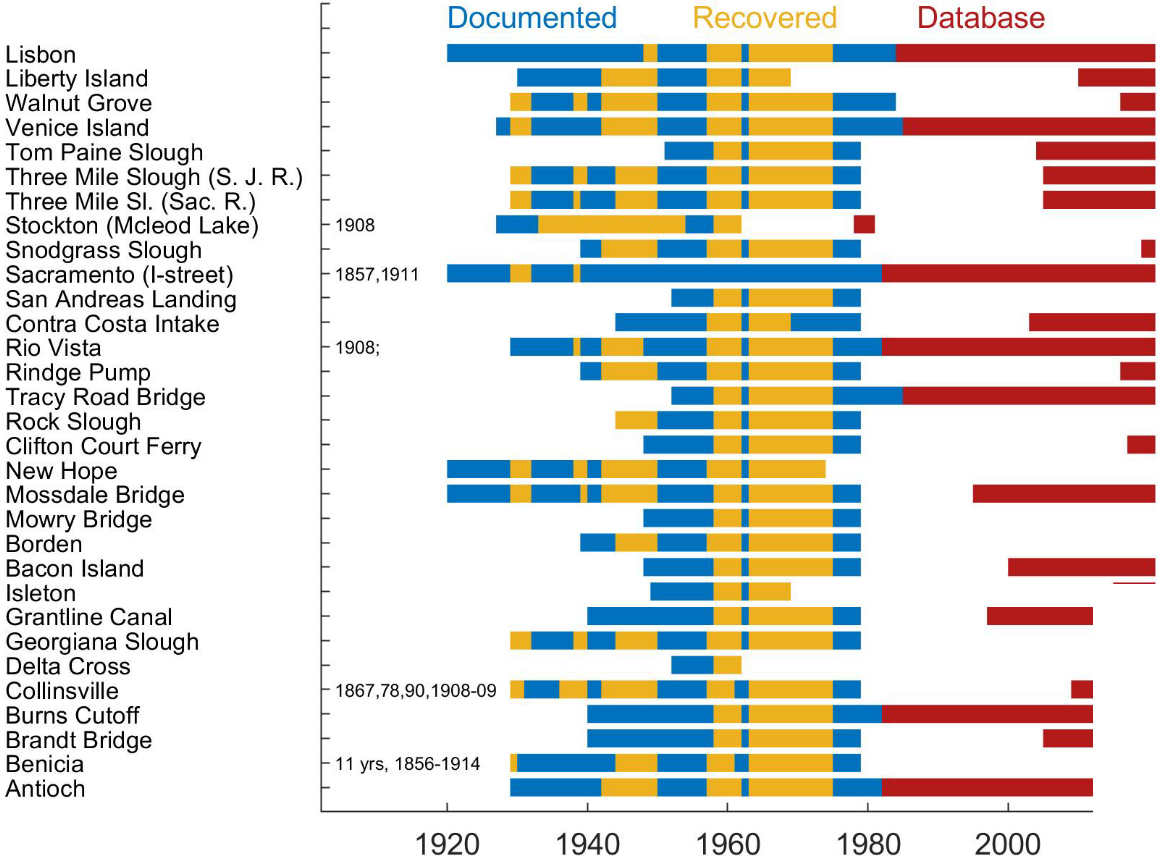
1. Analyze 100+ Water level gauges from 1982-present in the Delta to determine factors that influence water level
   --Nonlinear regression

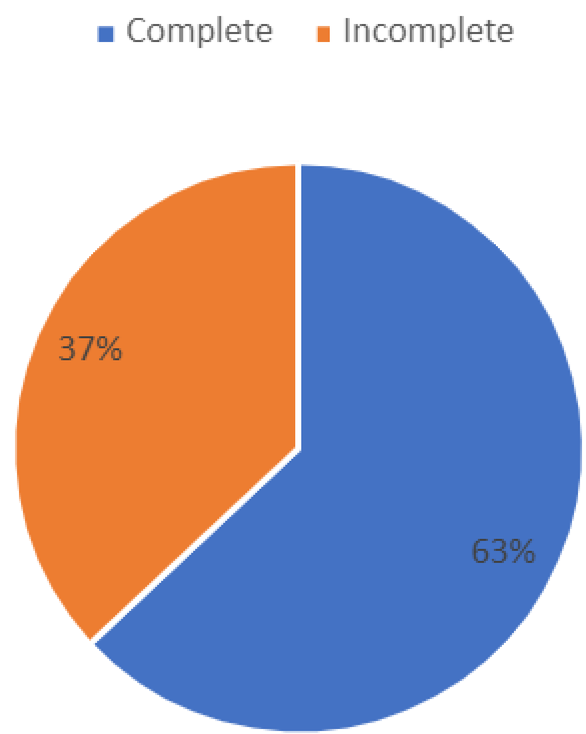
2. Recover and evaluate historical records back to the 1800s

Strategy: Rescue, digitize, and analyze ‘lost and forgotten’ records



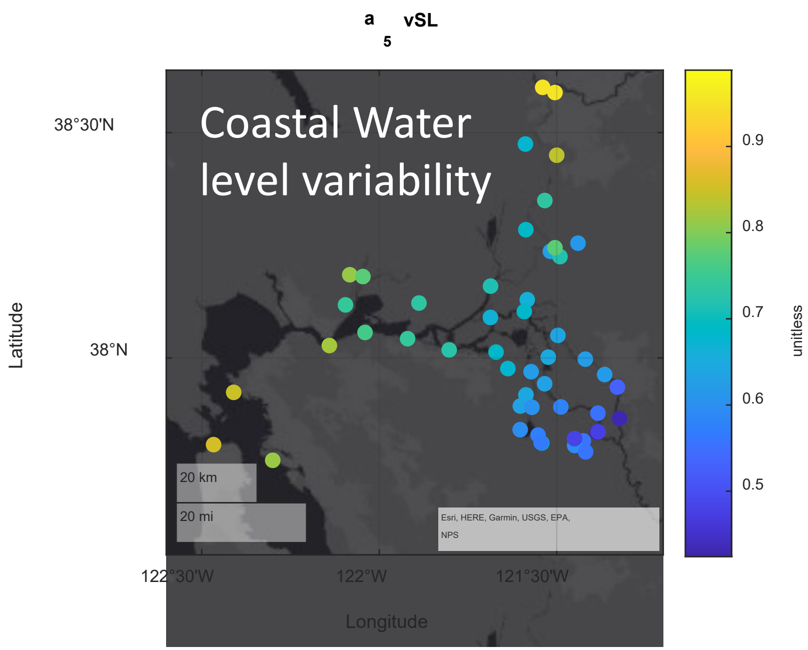
State publication of gauge data, 1965



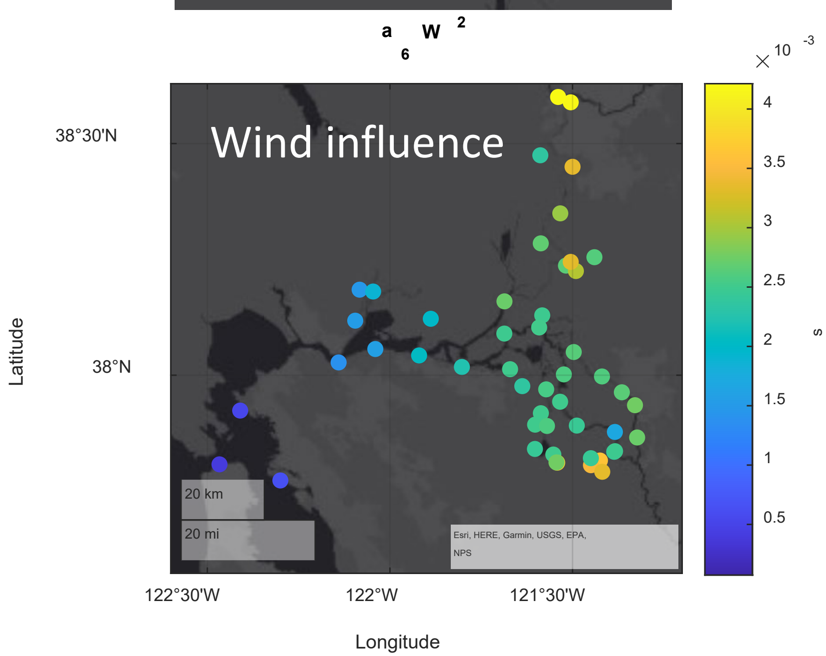


Years of Found/rescued data: >1800 years
Total digitized (4/10/2023): 1149 years

Factors that influence daily mean water levels

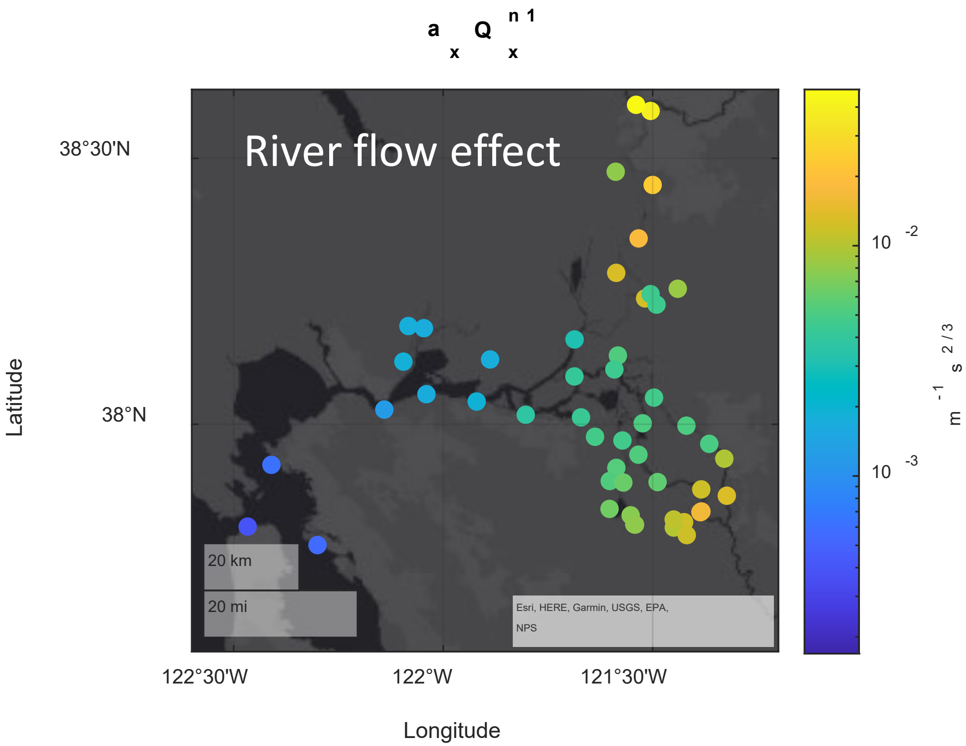


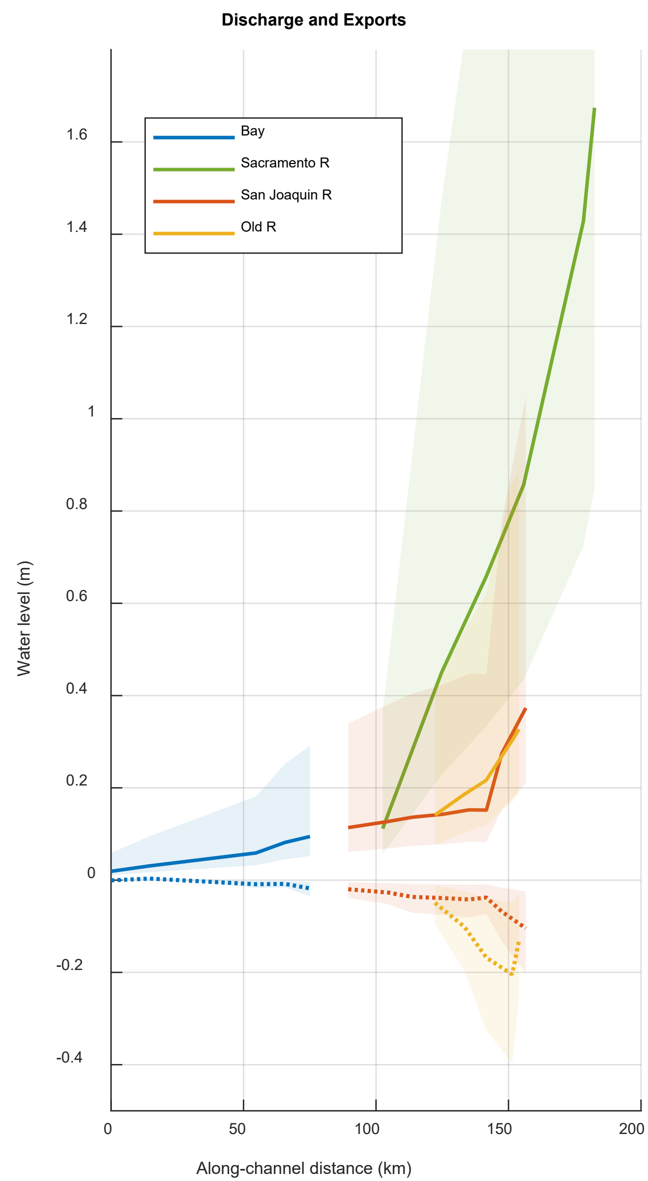
- 1 meter of storm surge in San Francisco = 0.5-0.9 meter of increased water level (WL) in Delta



- Westerly winds increases WL by up to 20 cm (average ~ 5cm)

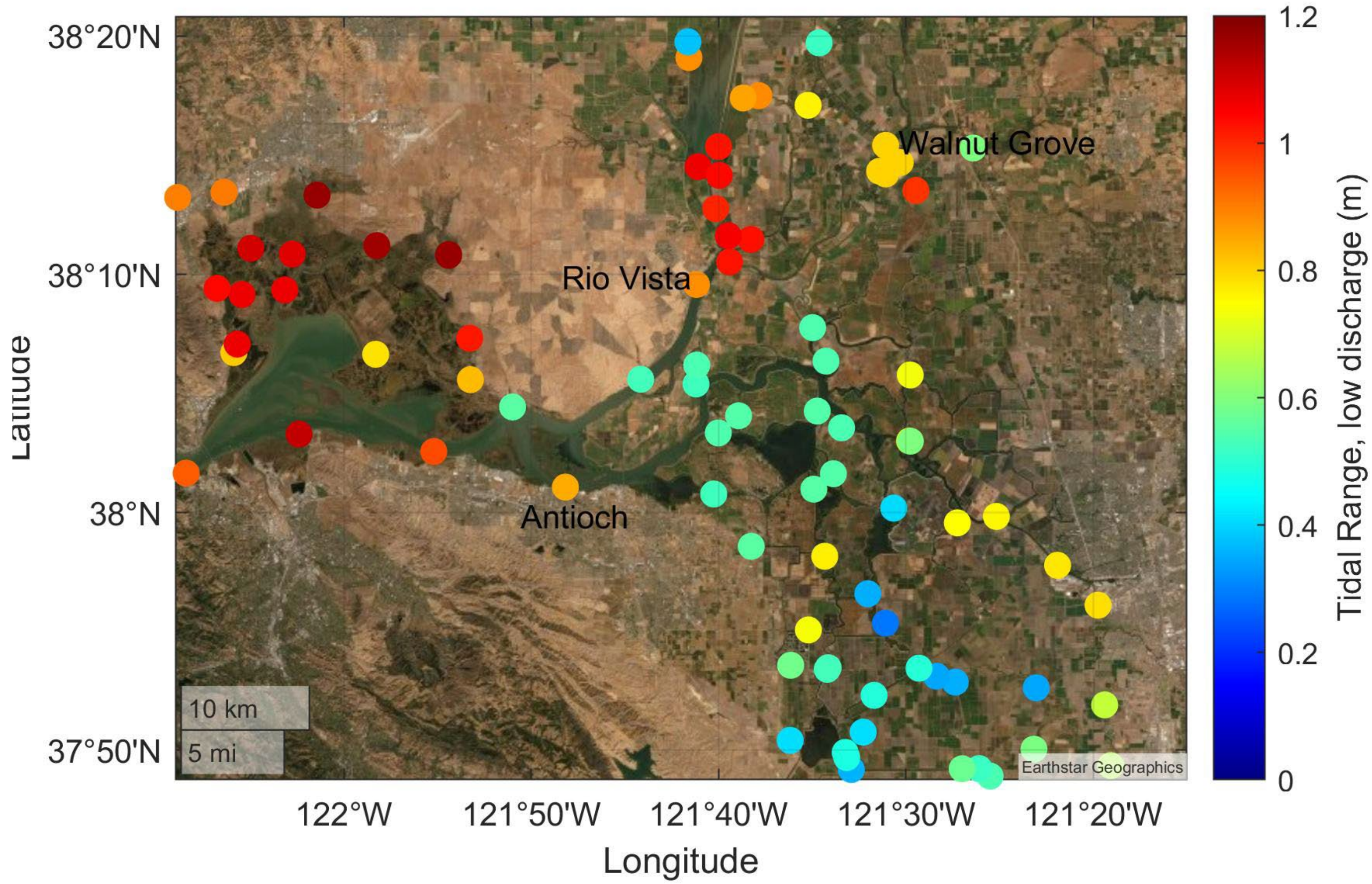
Factors that influence daily mean water levels





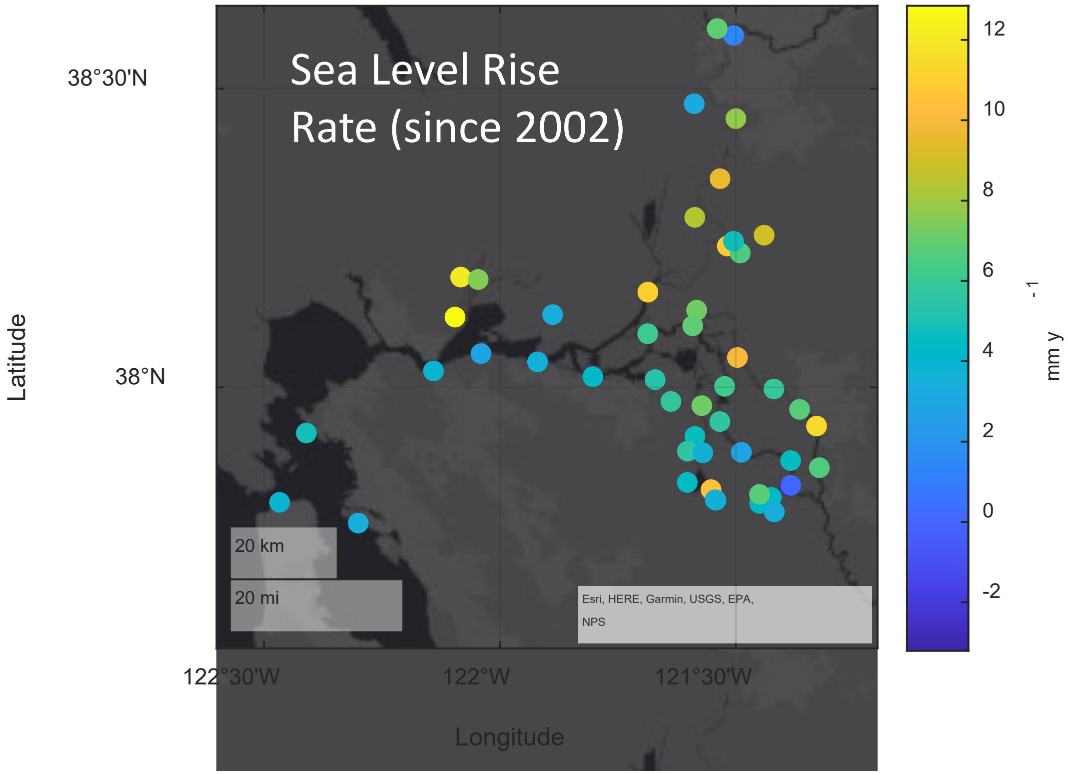
- A large flood raises water levels much more in eastern Delta than in western Delta and Bay
- Exports to water project a minor influence in southwestern delta
- Not shown: Spring-Neap tide variations of up to 20 cm in daily mean. (Water stored in delta during periods of large tides)

Factors that influence daily mean water levels



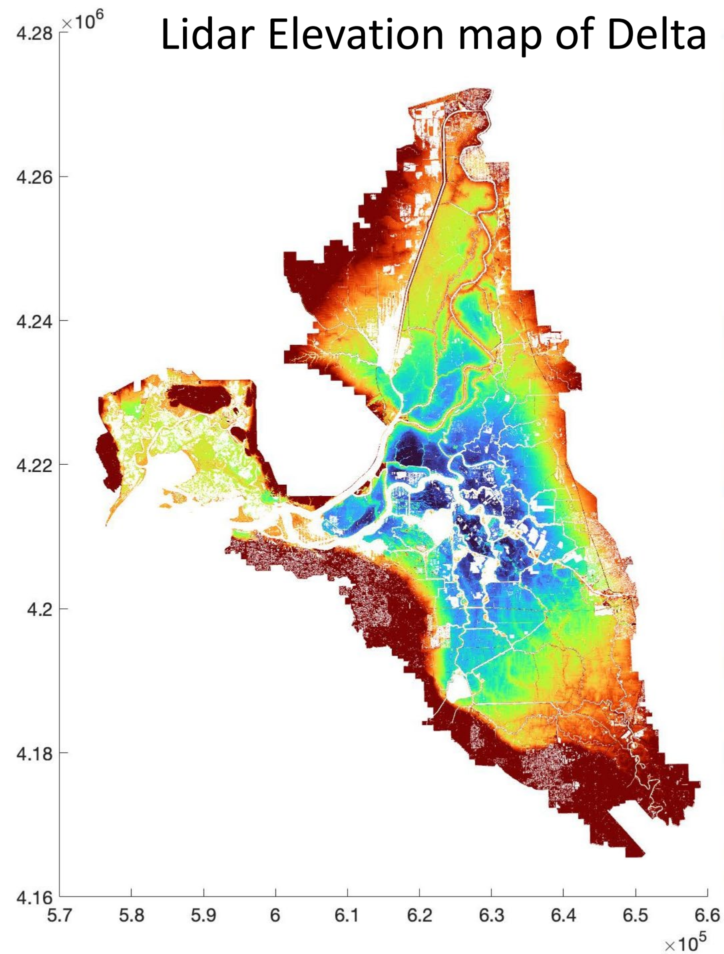
Tidal Range varies hugely!

Factors that influence daily mean water levels



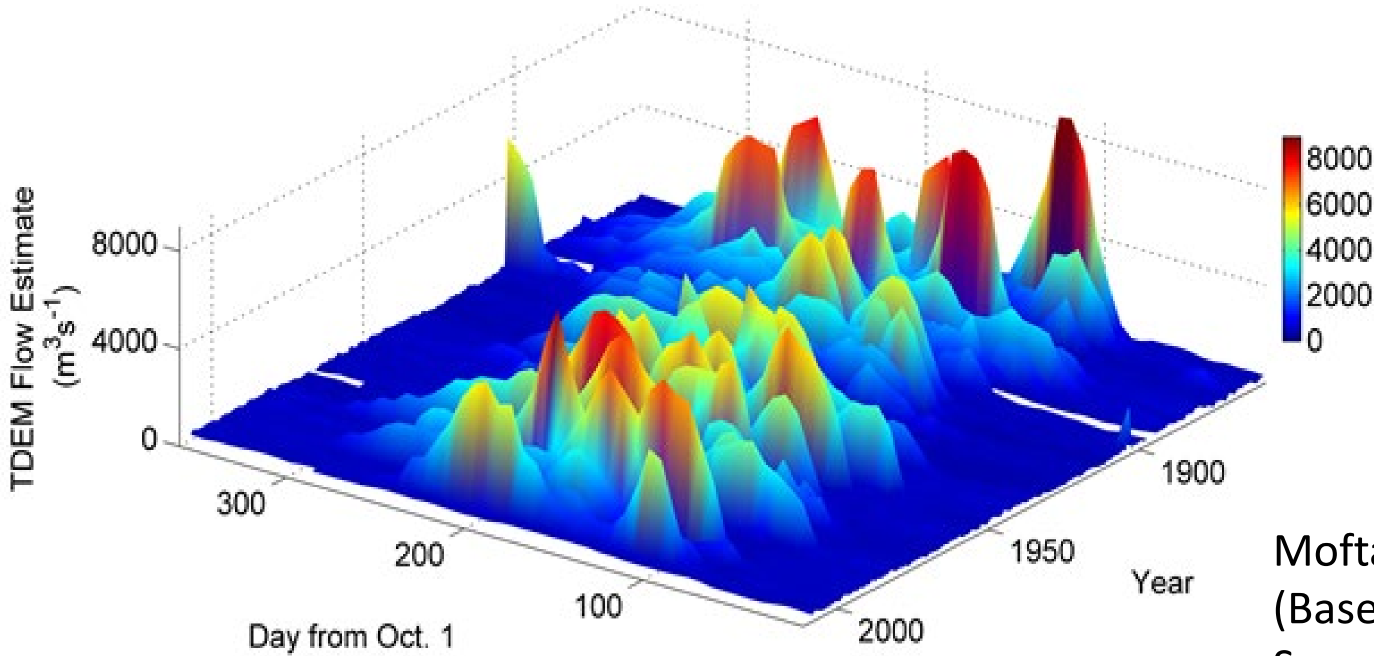
- Sea Level Rise is highly variable in Delta
  - ~ -1 to 11 mm/yr
  - Rio Vista: 7.2 mm/yr
  - Antioch: 1.6 mm/yr
  - San Francisco: 3.5 mm/yr

(Global rate: ~3.5 mm/yr)



Reason for variation: Subsidence!
Many parts of Delta are sinking.

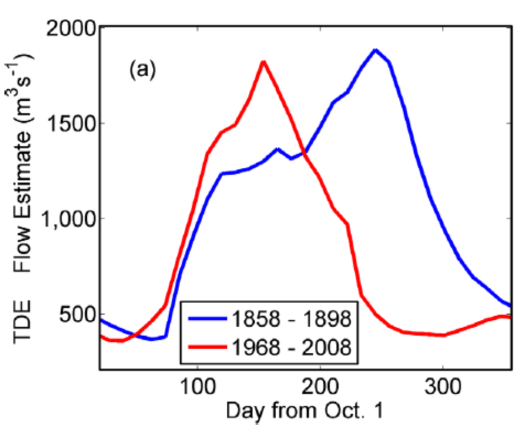
How forcing is changing: River Flow



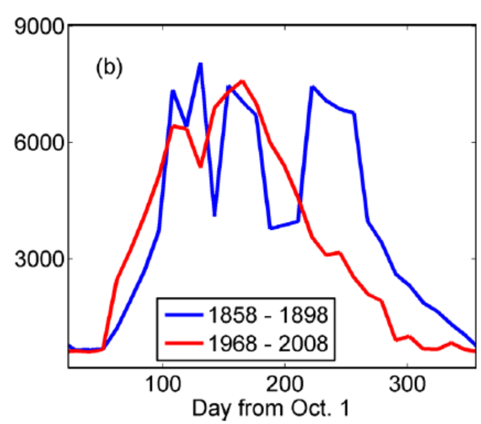
Net Delta Outflow

Moftakhari et al., 2013, 2015 (Based on SF tide gauge and Sacramento river gauge)

Average Flow

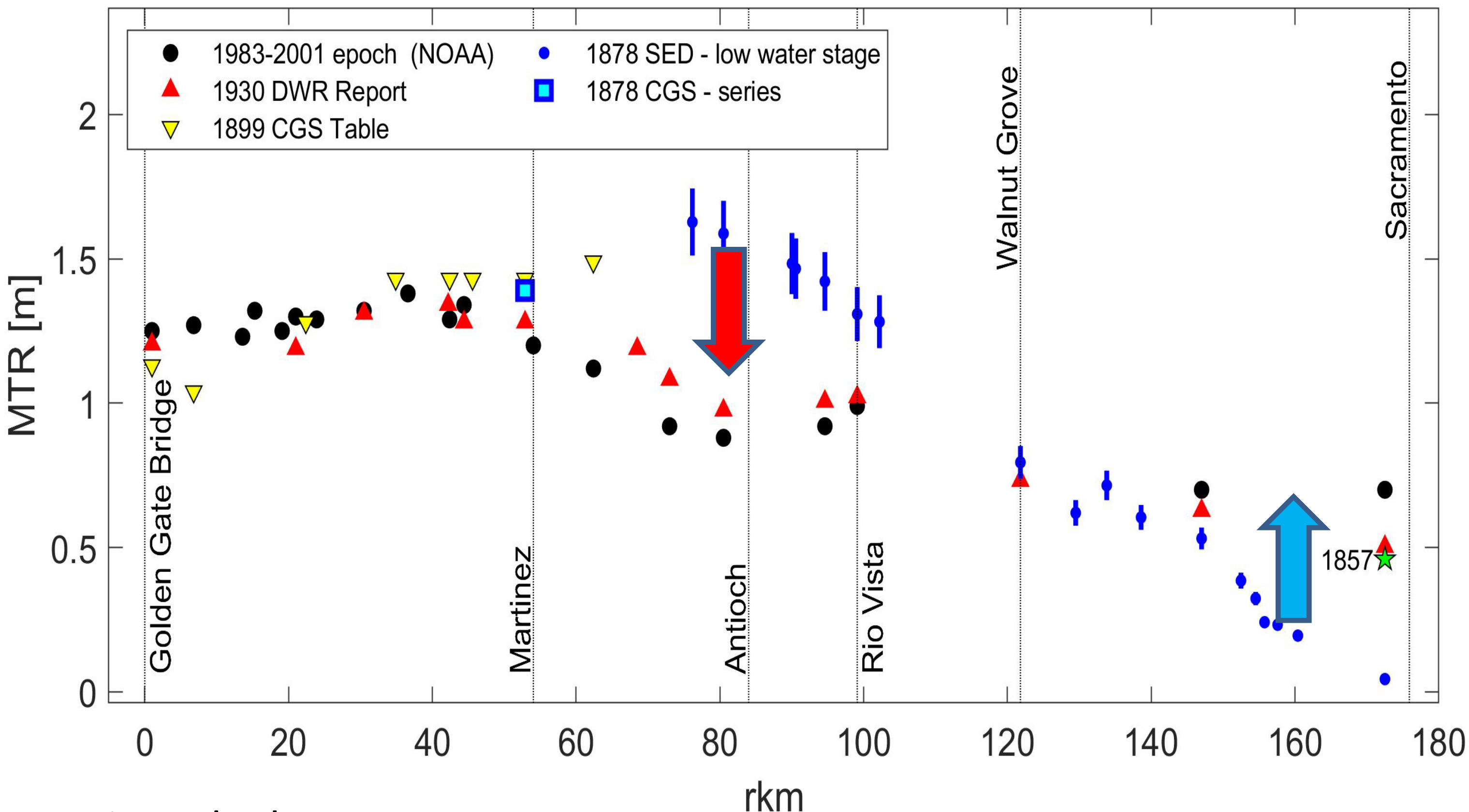


95% flow



- Average flow has shifted to winter from spring-melt
- No evidence (yet) for increasing winter floods
- 25-30% decrease in total volume to ocean
- 1862 flood the largest on record

Changes to Mean Tidal Range (MTR)

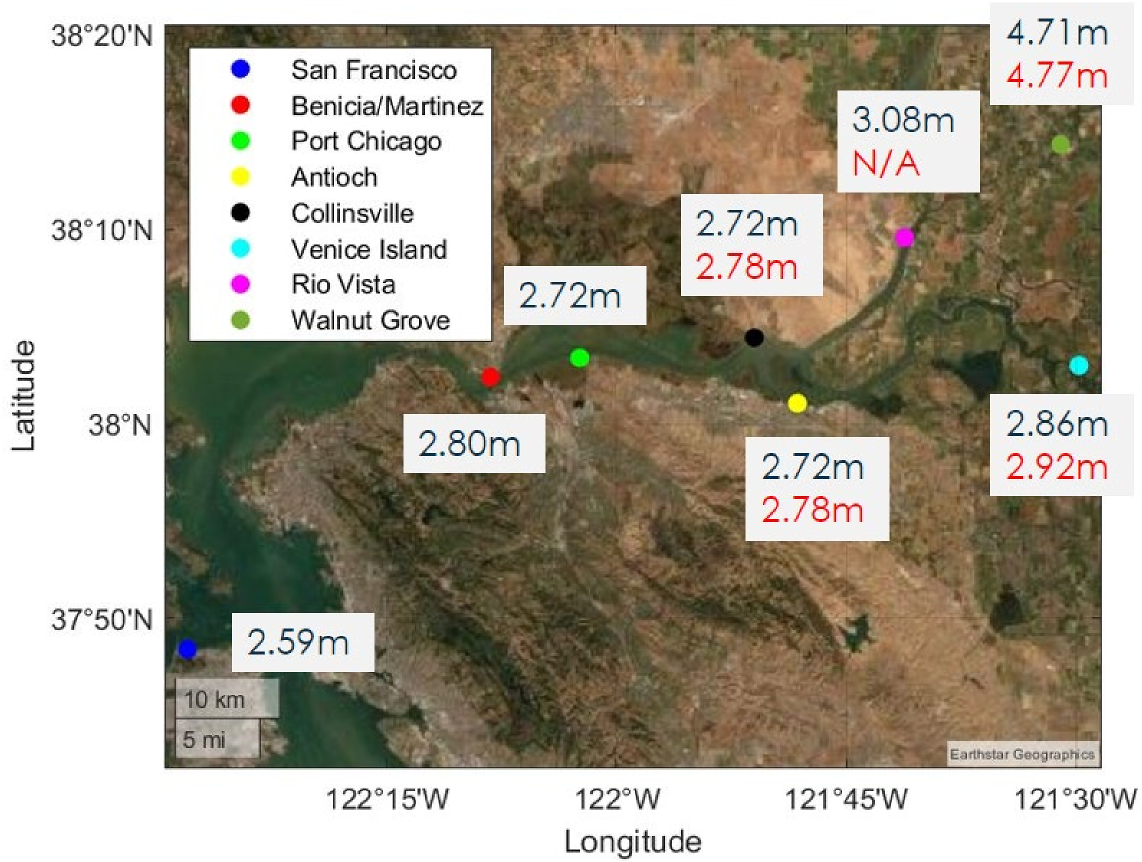


Since the late 1800s…

- Tidal Range appears to have decreased in the western delta
- Tidal Range has increased in the eastern delta
- Increase of ~7%/century in SF (Jay 2009)

Reasons: End of hydraulic mining sediment pulse, channel deepening, wetland reclamation

Is there evidence of change to flood risk?



Black: 1976 Army Corps analysis of risk, based on 1930-1970s data

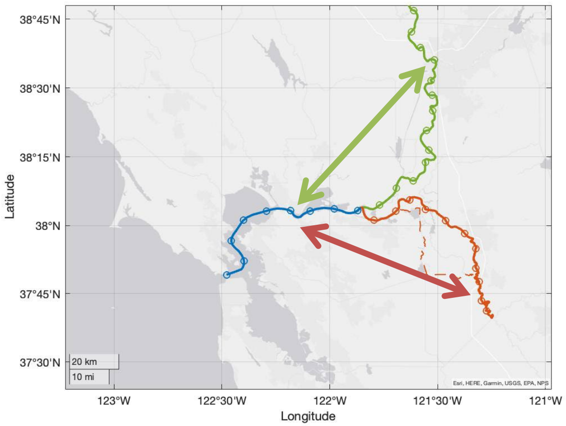
Red: Preliminary Analysis of 100 y flood level, using modern data

See McGuire 2022 thesis

Take Home: No Evidence yet for changed flood risk. More work needed to quality assure and evaluate historical records

But…

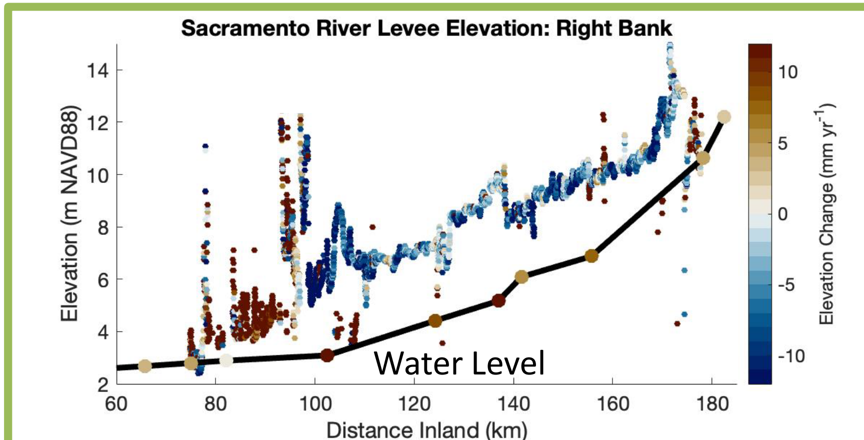
Some high waters are now very close to levee crests

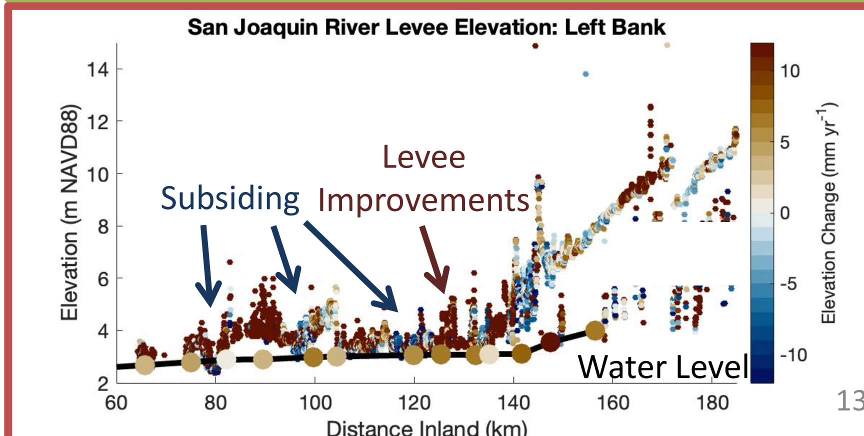


- Sacramento River
  - Subsidence in many levees, but…
  - Lots of freeboard in many places because….
  - Upstream reservoirs reduced high water relative to pre-1940 situation

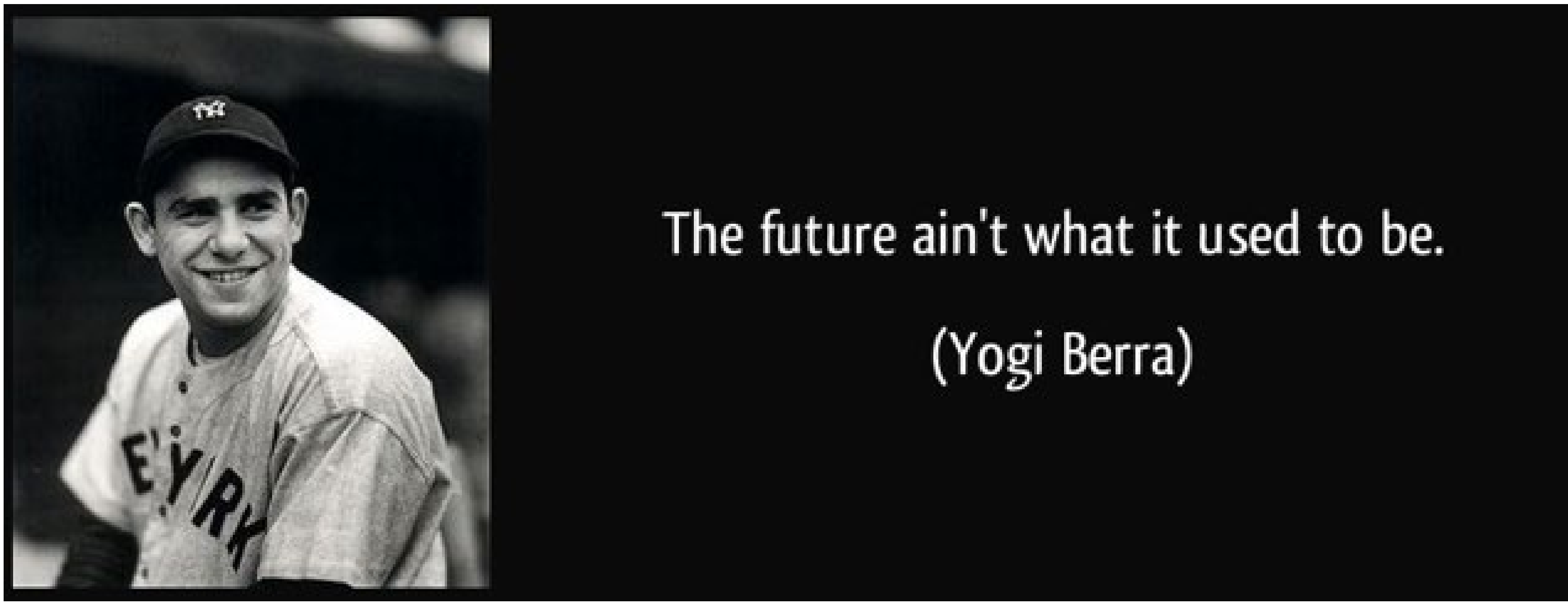
- San Joaquin River
  - Regions of subsidence exist, but
  - High water close to levee crest
  - Flooding more likely

Blue: subsidence between 2007 and 2017 Lidar survey

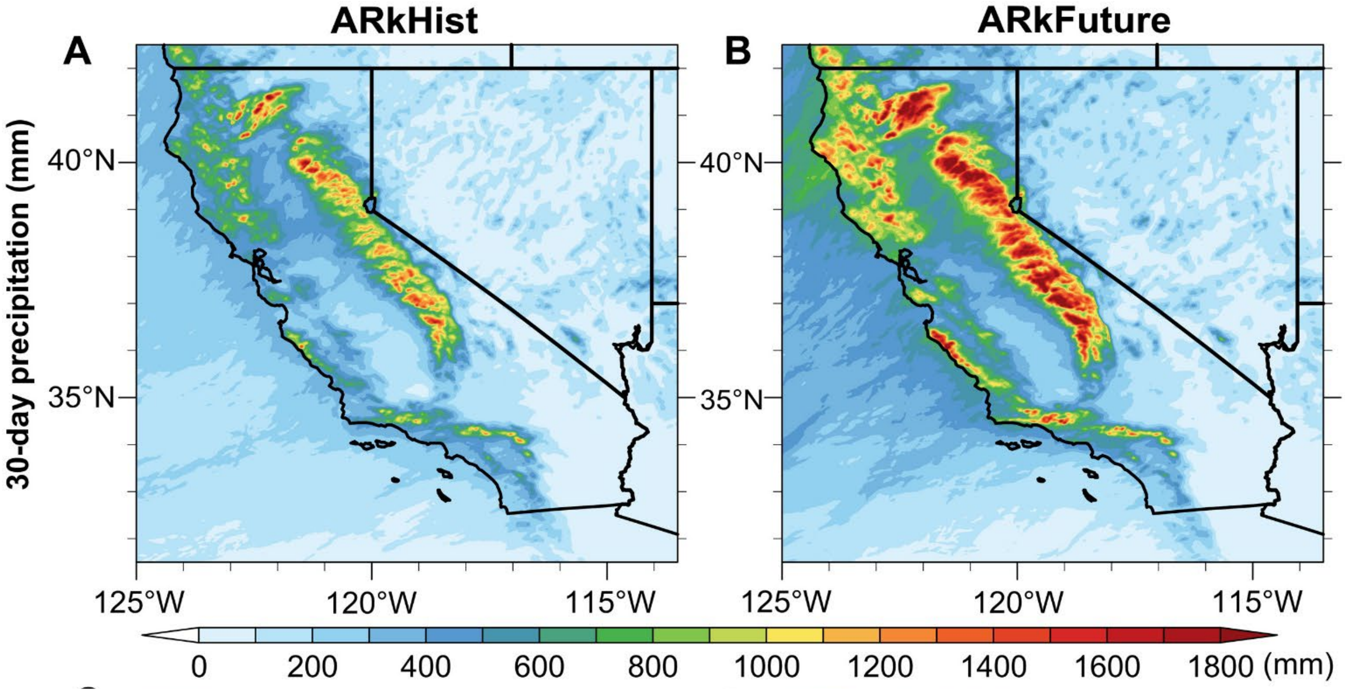




Also….



Predictions of future Cumulative Precipitation



Huang & Swain, 2022

- Future cumulative precipitation over a 30d period may be 35-60% larger in Northern/Central California in a climate future (2170s) than 1996-2005 decade
  - Based on "Arkstorm" scenario (multiple atmospheric rivers in a month, loosely based on 1862)

Paleoflood research suggests much larger floods have occurred historically, possibly compounding future climate shifts

Water year	Annual peak streamflow (ft^3/s)	Water year	Annual peak streamflow (ft^3/s)	Water year	Annual peak streamflow (ft^3/s)
650	>600,000	1933	16,500	1961	8,000
1437	>400,000	1934	22,600	1962	40,000
1574	>400,000	1935	60,900	1963	240,000
1711	>400,000	1936	58,300	1964	24,000
1862	>262,000	1937	33,000	1965	260,000
1905	24,200	1938	114,000	1966	6,500
1906	59,700	1939	10,900	1967	46,000
1907	156,000	1940	89,200	1968	30,000
1908	10,300	1941	38,800	1969	120,000
1909	119,000	1942	83,200	1970	122,000
1911	81,300	1943	152,000	1971	48,000
1914	74,100	1944	20,100	1972	12,000
1915	47,900	1945	94,400	1973	69,000
1916	40,700	1946	42,200	1974	55,000
1917	42,300	1947	27,900	1975	46,000
1919	67,500	1948	21,000	1976	15,000
1920	20,100	1949	37,500	1978	40,000
1921	39,200	1950	34,400	1979	33,000
1922	31,600	1951	180,000	1980	175,000
1923	39,000	1952	37,200	1981	20,000
1924	14,000	1953	49,700	1982	152,000
1925	99,500	1954	42,600	1983	93,000
1926	27,400	1955	10,800	1984	88,000
1927	67,700	1956	219,000	1985	17,000
1928	163,000	1957	42,000	1986	259,000
1930	24,400	1958	54,000	1997	298,000
1931	9,900	1959	20,000	--	--
1932	21,100	1960	75,000	--	--

Some truly astonishing floods on American River in last 2000 years, according to USGS Bulletin 17c

Water year 650: > 600,000 cfs
1437: > 400,000 cfs
1574: > 400,000 cfs
1711: > 400,000 cfs

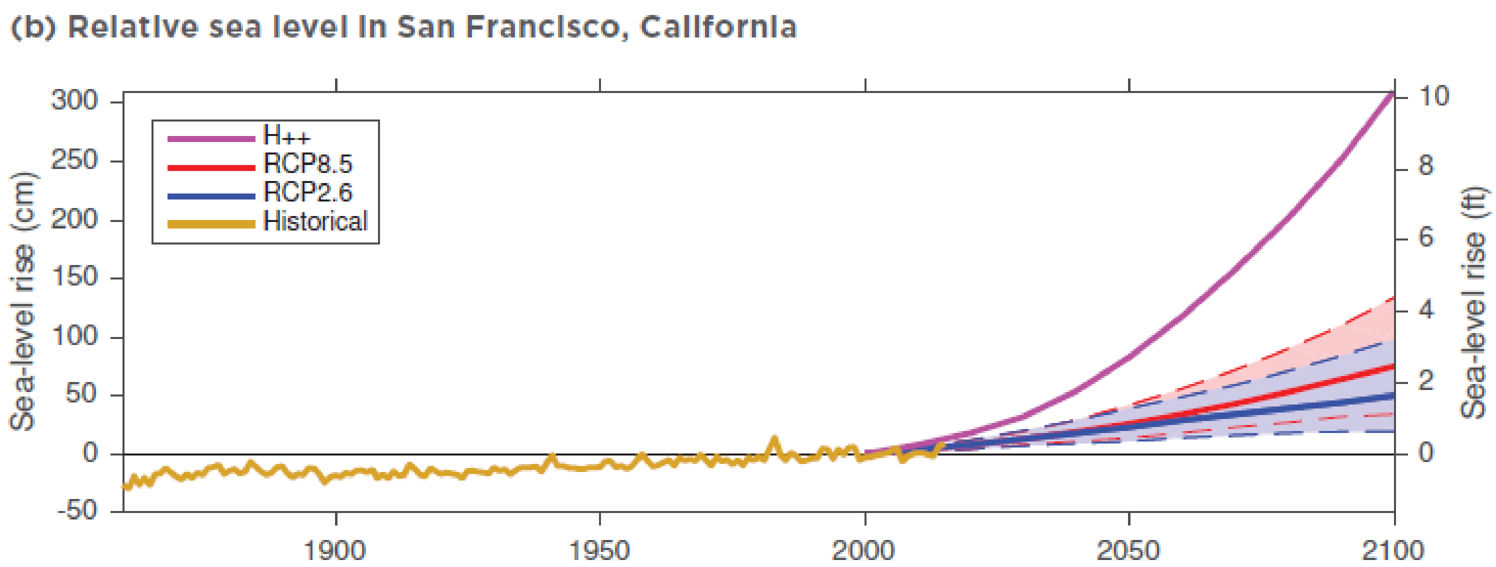
1862: 262,000-325,000 cfs

1986: 134,000 cfs (reservoir affected)
1997: 117,000 cfs (reservoir affected)

Natural Flow Estimates
1986: 259,000 cfs
1997: 298,000 cfs

England et al., 2017, USGS Bulletin 17c

Sea Level Rise Projections



San Francisco: 10-300 cm by 2100, depending on scenario and uncertainty in response

Delta: ~0-375 cm by 2100, due to differences in vertical land motion from SF

Conclusions

- Delta is at risk from sea-level rise *and* future extreme floods
- Subsidence is compounding risk
- “Lost and forgotten” records can help us better assess trends and make better, localized projections and risk assessment