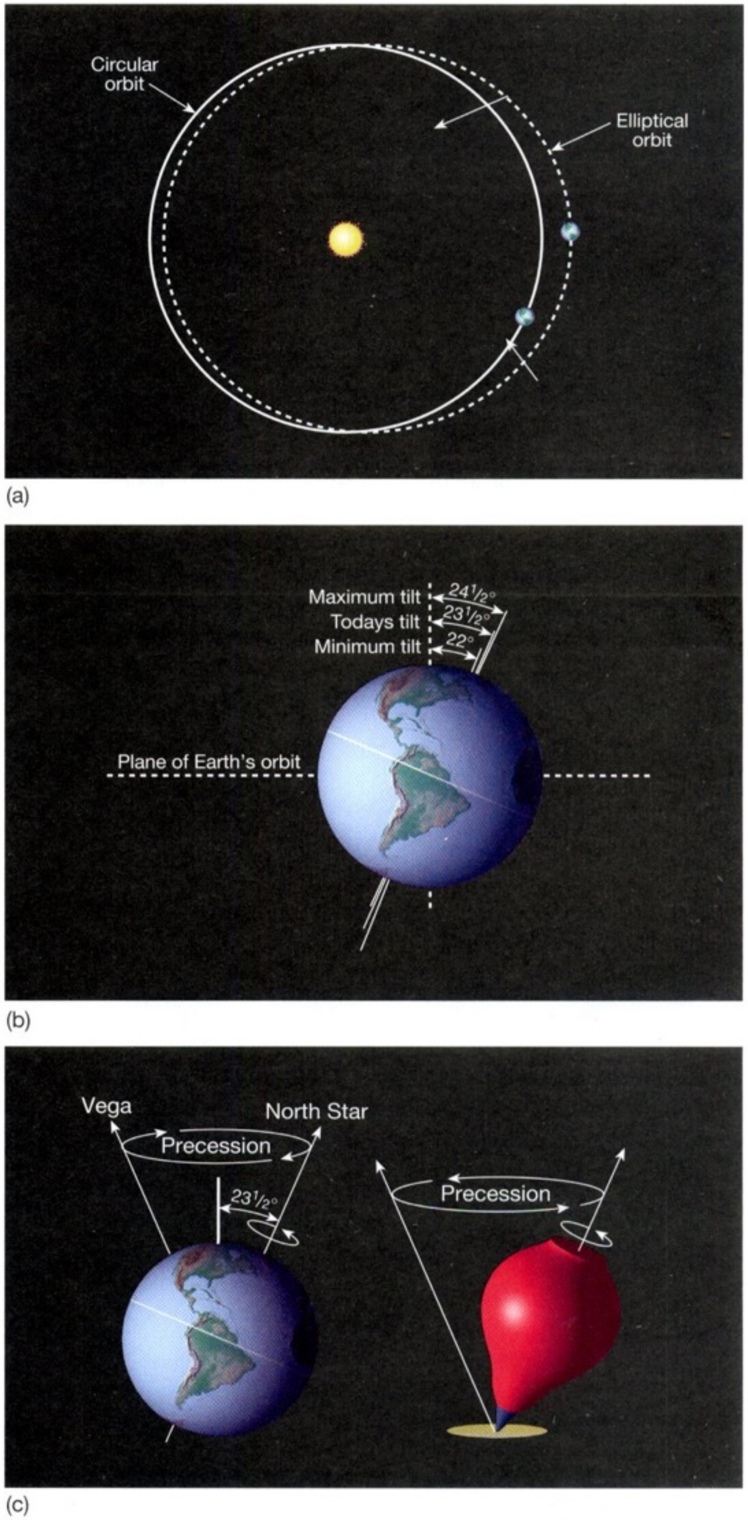
CLIMATE CHANGE, SEA-LEVEL RISE AND CALIFORNIA'S SHORELINE

Variations in the Earth's orbit around the Sun play a major role in causing climate changes, Ice Ages and sea level fluctuations.

Three Orbital Cycles & Periods

1. Shape of orbit-100,000 years
2. Tilt of axis of rotation ~41,000 years
3. Wobble of Earth's axis- ~26,000 years



Temporal Differences in Sea Level

SHORT-TERM:HIGH RATE OF CHANGE

- Astronomical Tides: 5-10 feet over hours; King tides: up to 2 feet
- Storm Surges: up to 3 feet over hours
- El Niño: 1-2 feet over months
- Wave run-up and wave set-up: 4-5 feet over minutes

LONG-TERM:LOW RATE OF CHANGE

- Ice melt and thermal expansion of ocean: hundreds of feet over thousands of years, but only mm/year

Geographic Differences in Sea Level

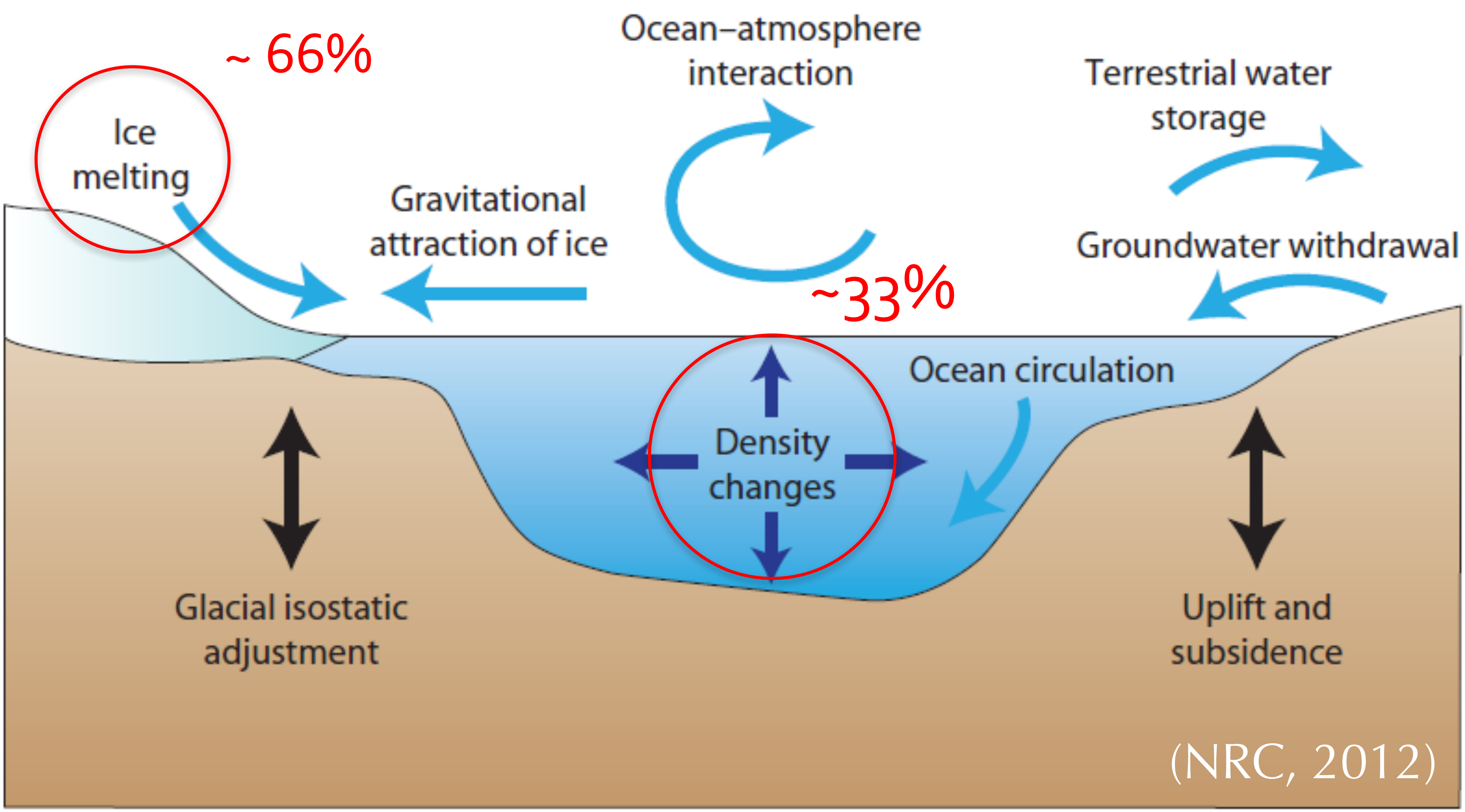
GLOBAL OR ABSOLUTE SEA LEVEL

- Driven primarily by global temperature which affects:
  - Volume of ice sheets and glaciers
  - Ocean temperature, and therefore sea water density and volume

REGIONAL OR RELATIVE SEA LEVEL

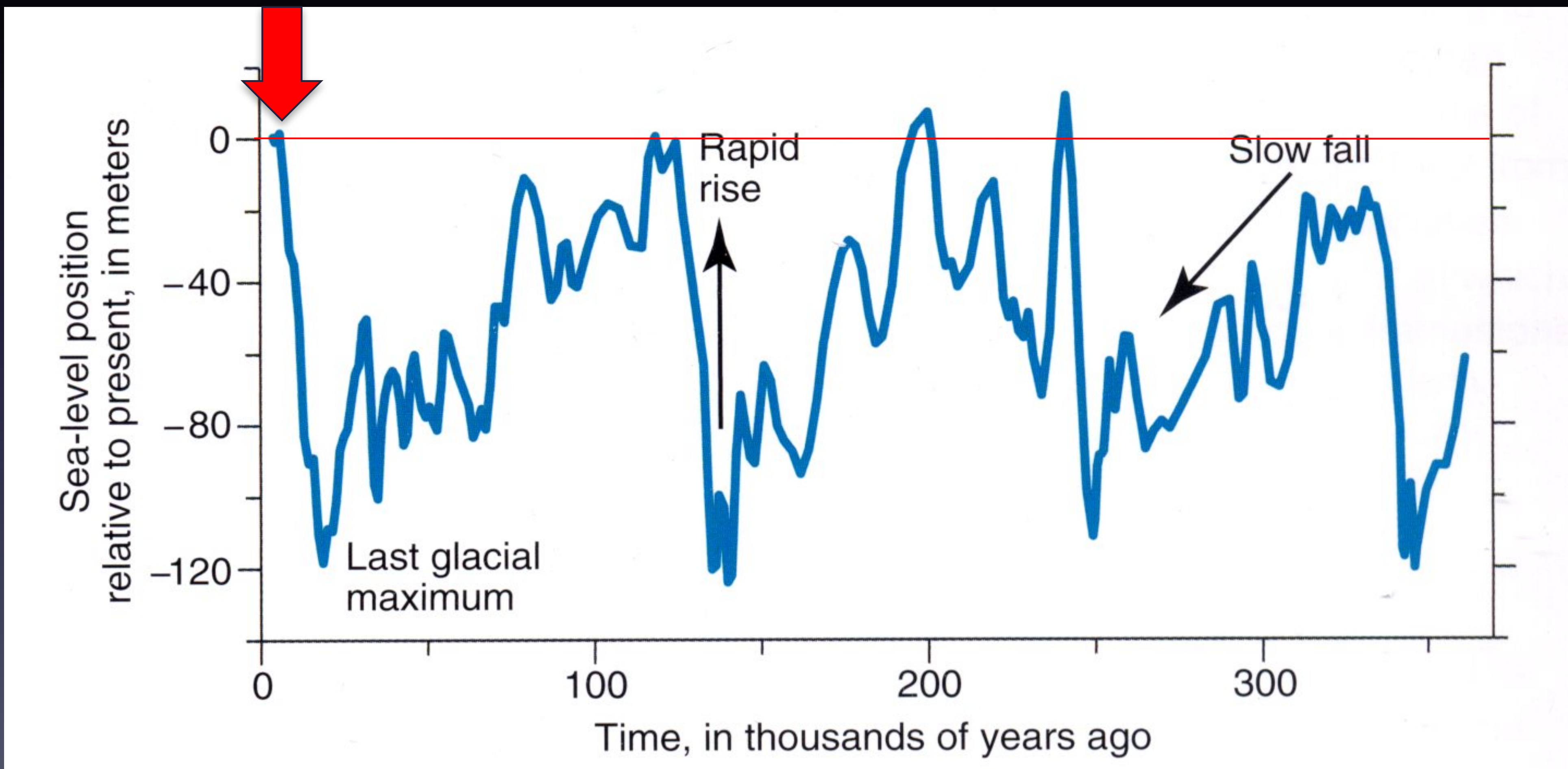
- Tectonics- affects coastal uplift or subsidence
- Land subsidence from fluid withdrawal (petroleum or water)
- Atmosphere-ocean circulation patterns in the Pacific (e.g., El Niño) and storm surge affect ocean levels over days to months
- Gravitational effects

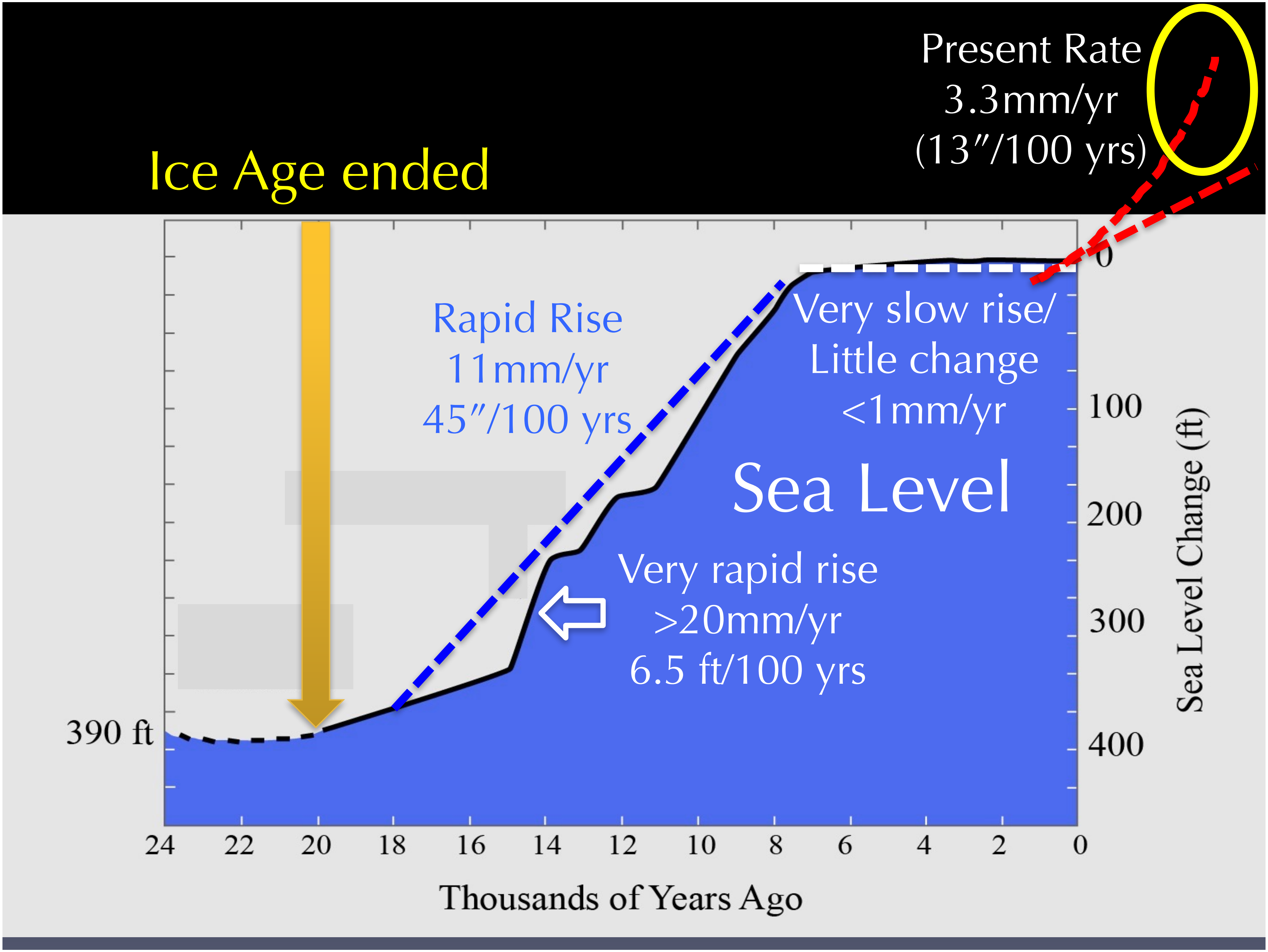
Components of Global and Regional Sea-Level Rise

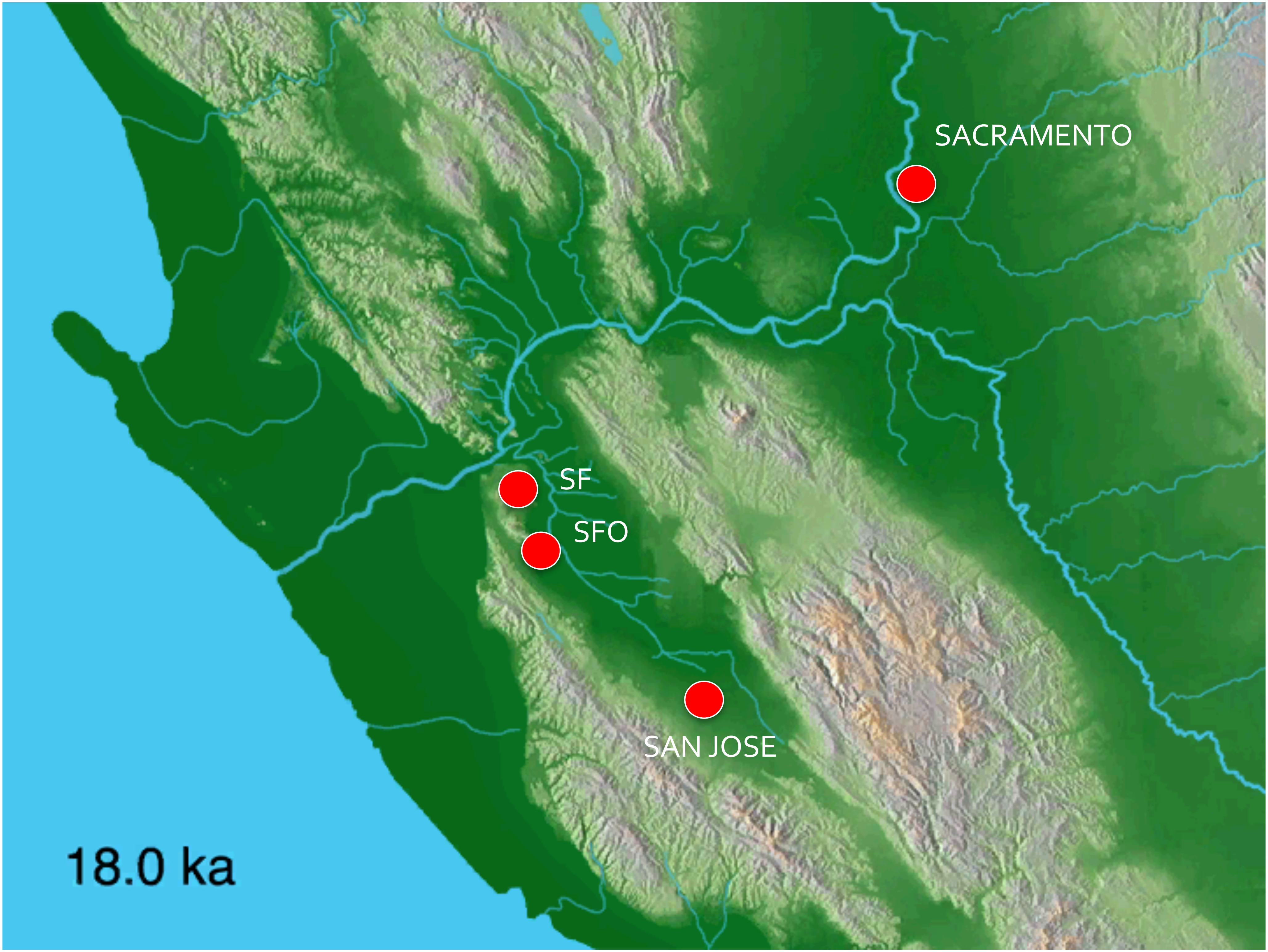


As Earth has cooled and warmed, glaciers and ice caps have advanced and retreated, and sea level has risen and fallen.

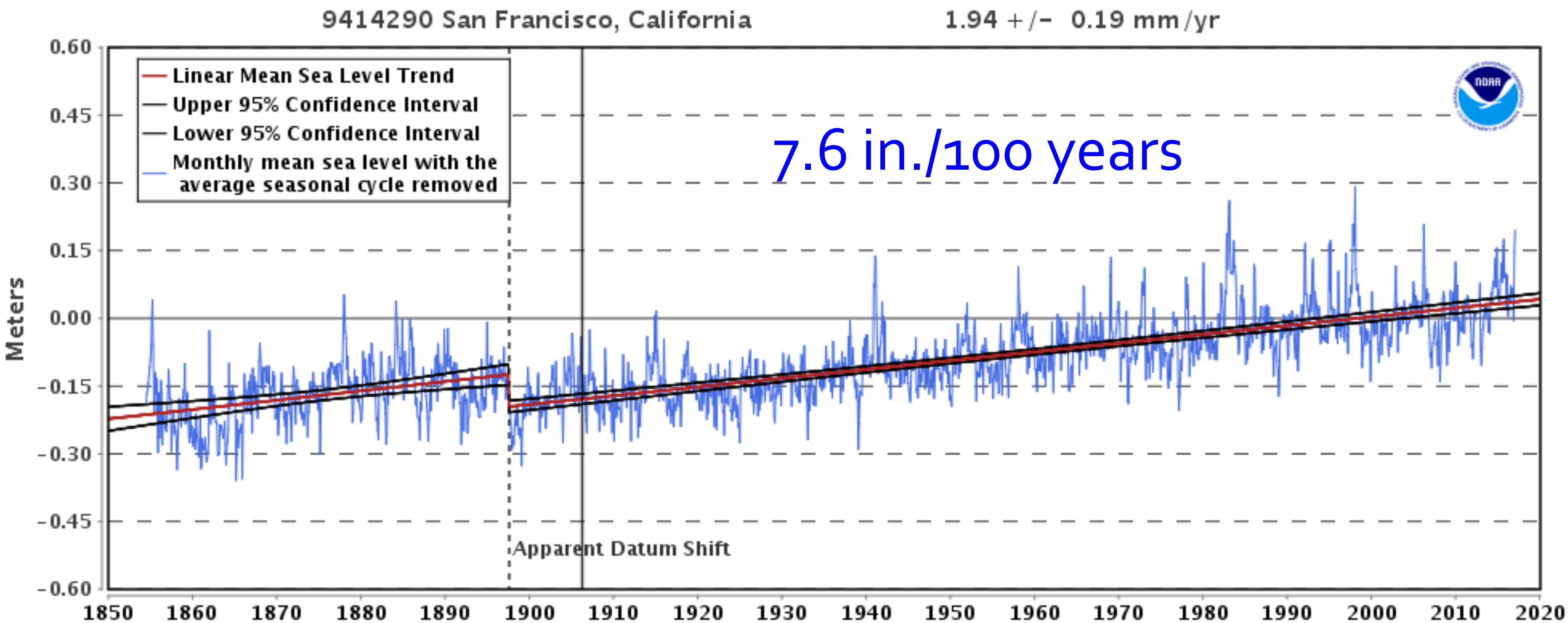
At the peak of the last Ice Age, about 3% of the ocean's water, 10 million mi^3 removed from the ocean and converted to ice and snow. Sea level dropped about 125 m (400 feet) below the present.



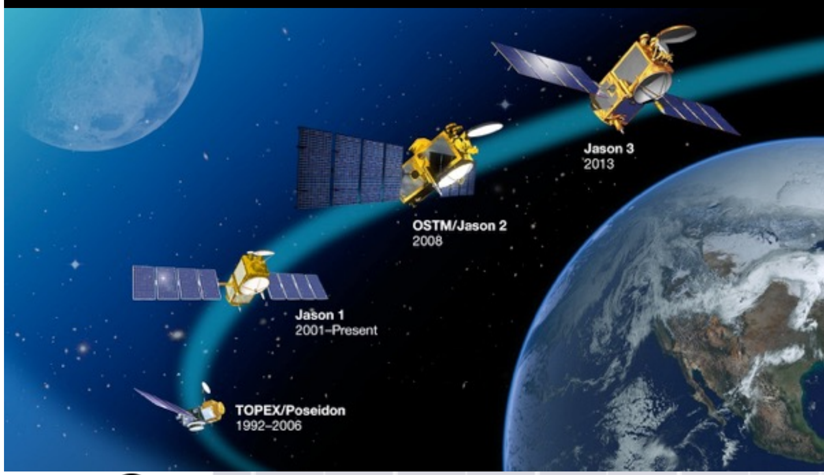

Ice Age ended
Present Rate
3.3mm/yr
(13″/100 yrs)
Rapid Rise
11mm/yr
45″/100 yrs
Very slow rise/
Little change
<1mm/yr
Sea Level
Very rapid rise
>20mm/yr
6.5 ft/100 yrs
390 ft
0
100
200
300
400
Sea Level Change (ft)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago

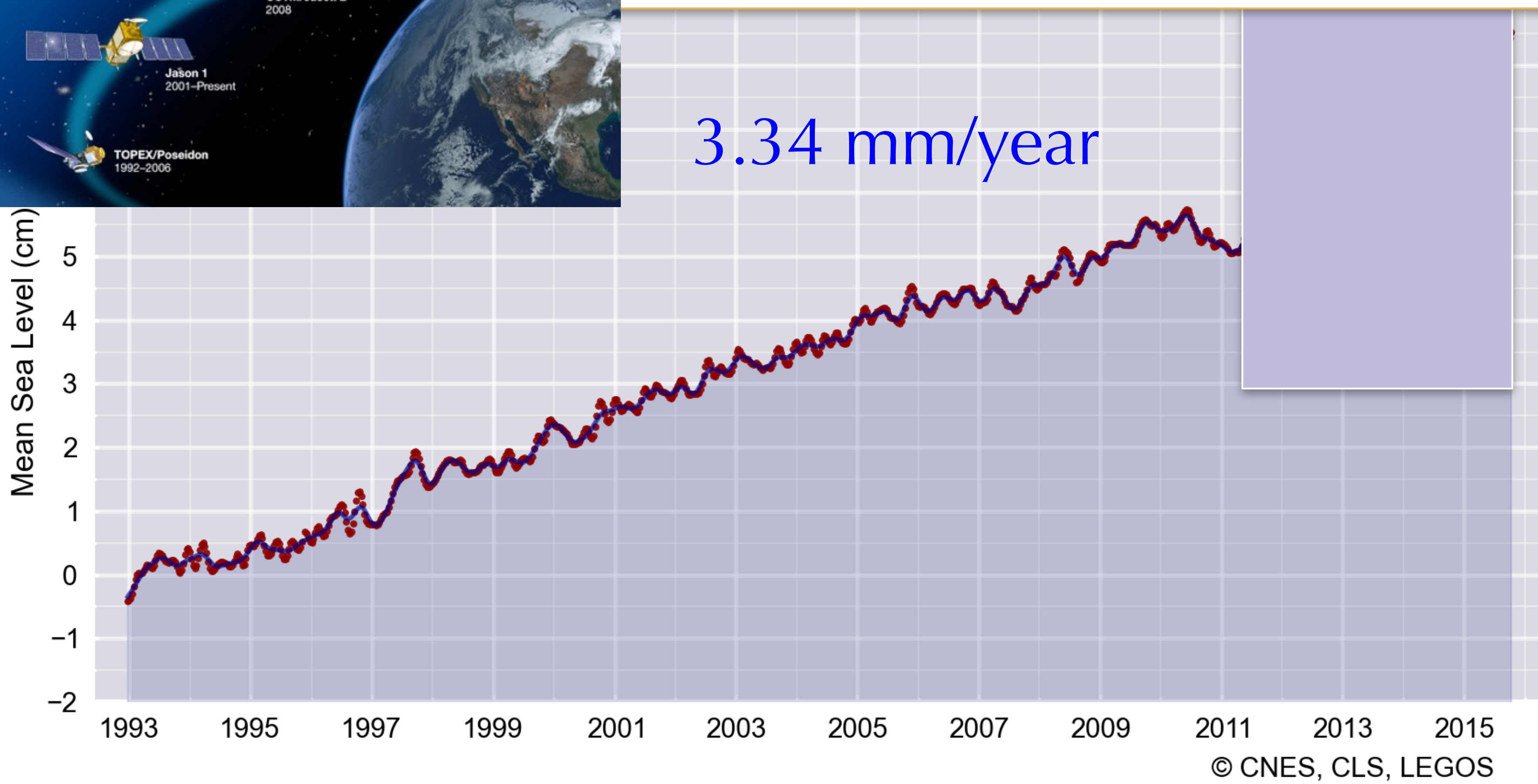

SACRAMENTO
SF
SFO
SAN JOSE
18.0 ka

NOAA TIDE GAUGE FOR SAN FRANCISCO
Oldest in North America



GLOBAL SEA-LEVEL RISE NOW MEASURED PRECISELY FROM SATELLITES

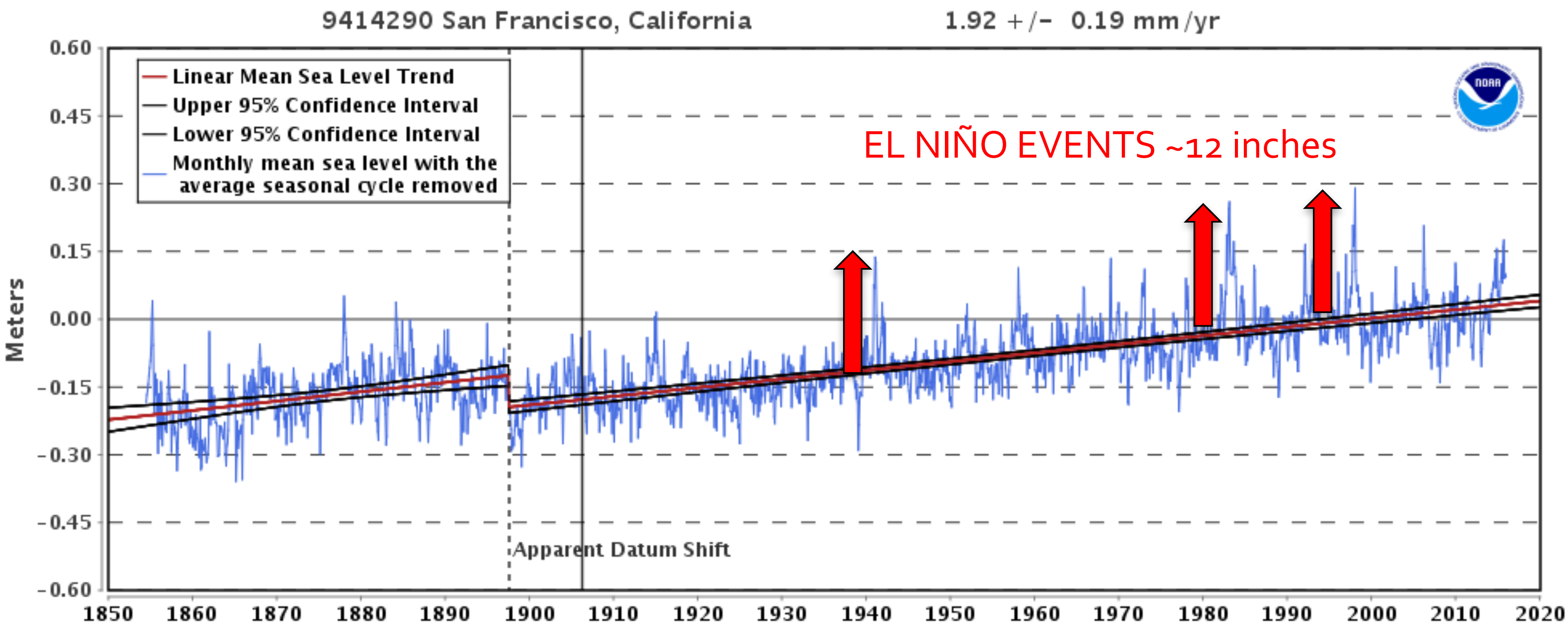




Approximately 216 feet of sea-level rise contained in ice.

California Recent Sea-Level Rise
Importance of short-term events

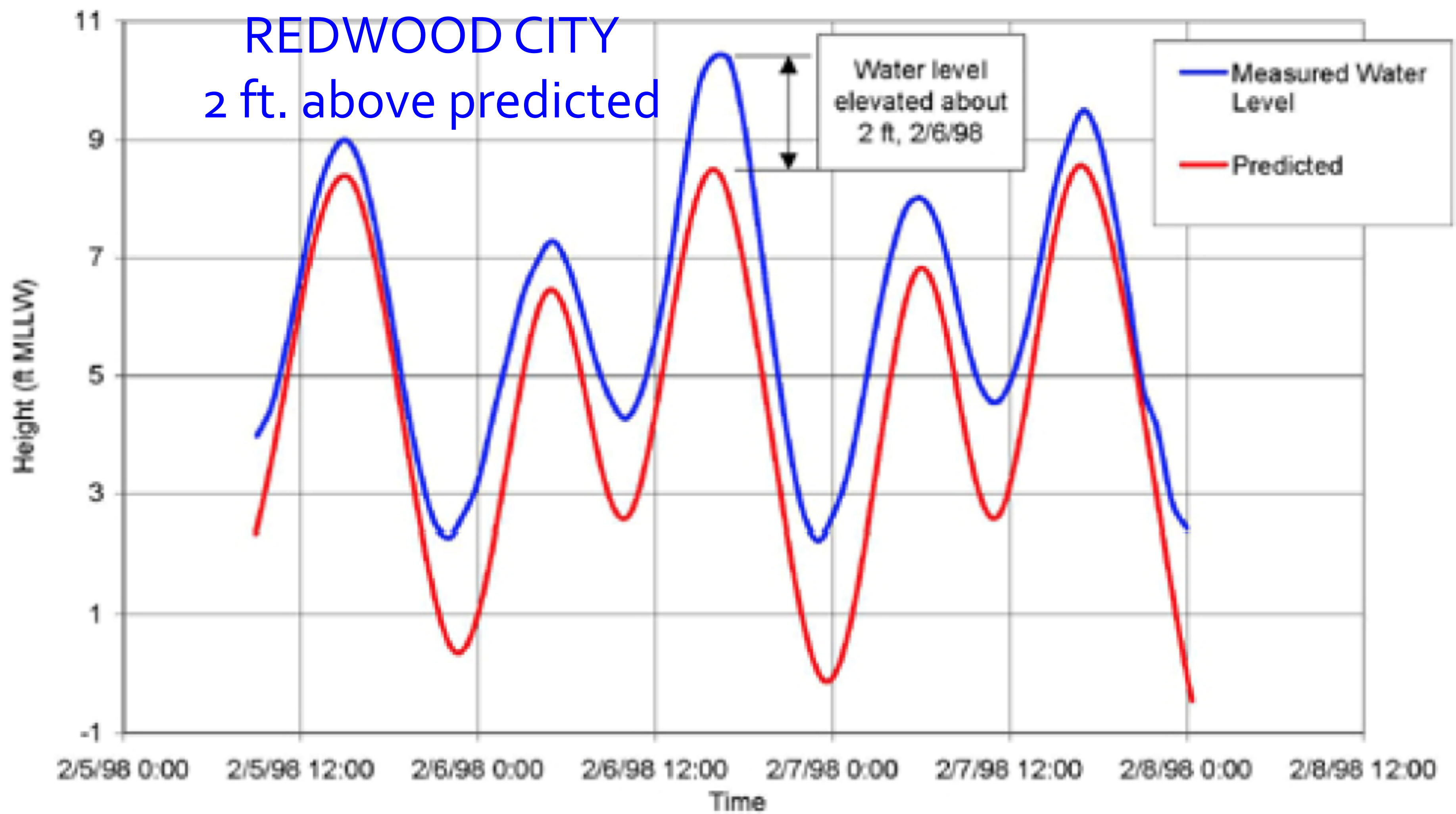
SAN FRANCISCO: 1.9 mm/yr. (7.6"/100 years)



Jan. 27, 1983 El Niño High Tides

STATION	PREDICTED TIDE (FT. MLLW)	RECORDED TIDE (FT. MLLW)	DIFFERENCE (FEET)
SAN DIEGO	7.40	8.35	0.95
LOS ANGELES	6.9	7.96	1.06
SAN FRANCISCO	7.1	8.87	1.77

El Niño 1997-98-Elevated Water Levels



Source: CO-OPS Verified Hourly Height Water Level

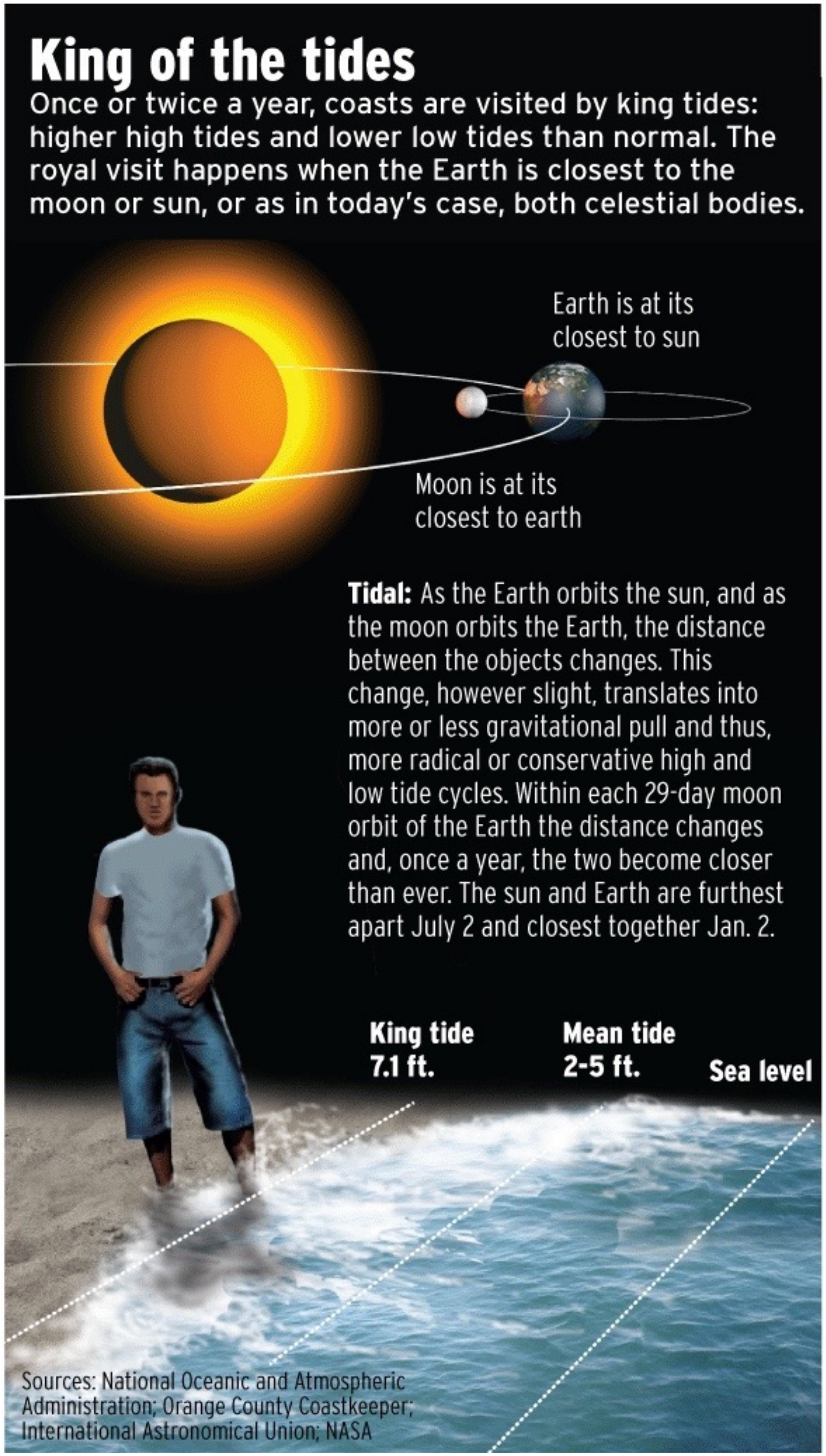
figure 3

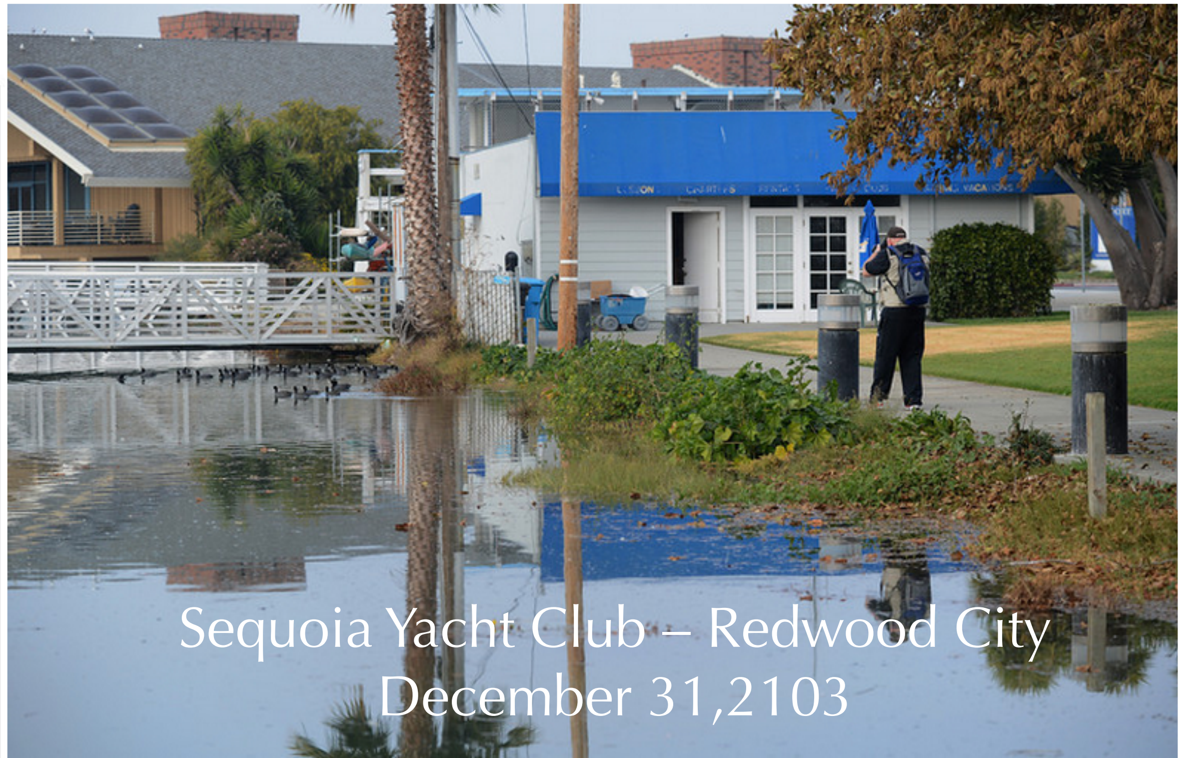
South Bay Salt Ponds Restoration Project

Predicted and Measured Tidal Elevations at Redwood City, CA

PWA Ref 1750.04

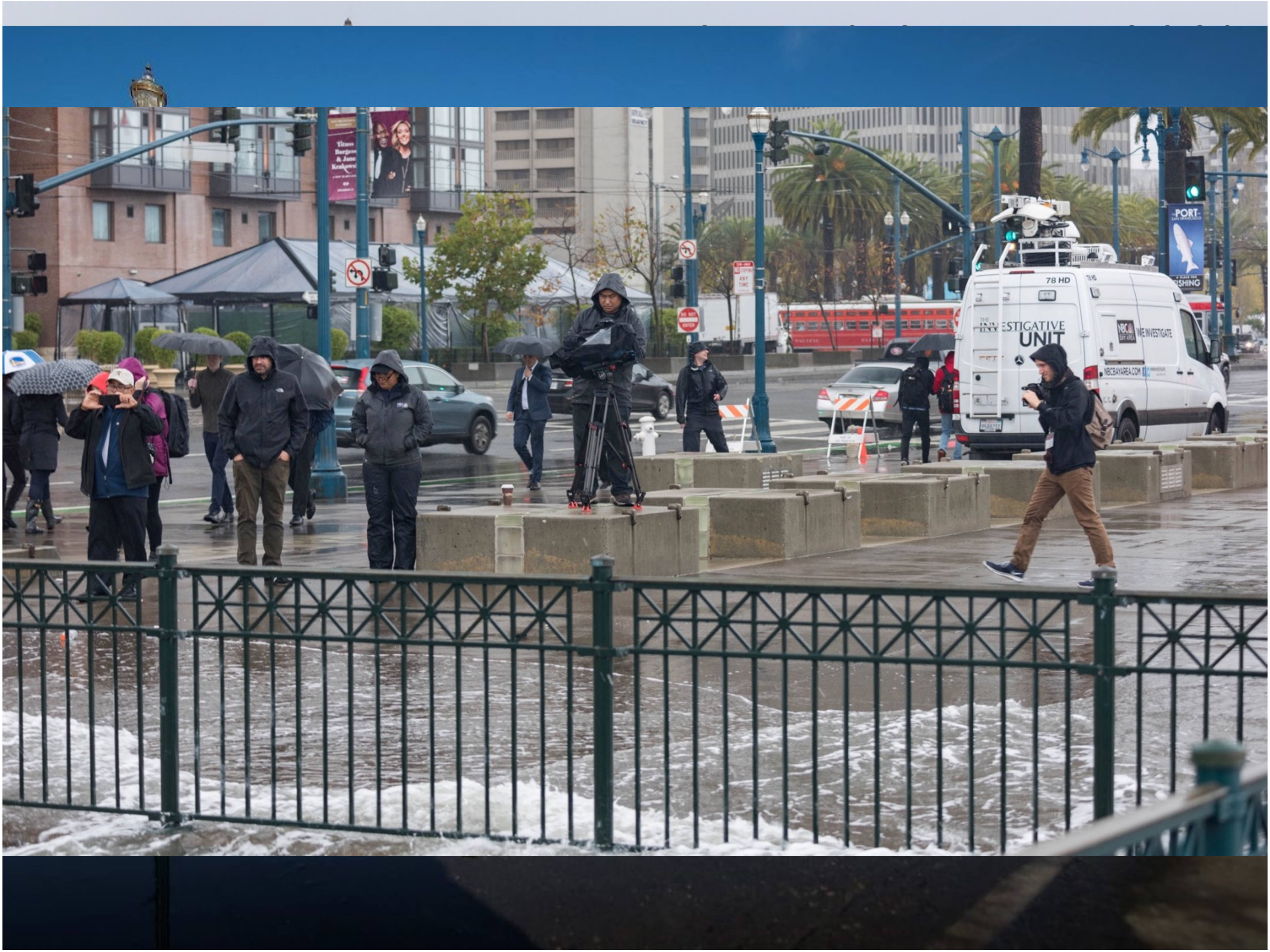
PWA





Sequoia Yacht Club – Redwood City
December 31,2103

Mill Valley Off Ramp, Highway 101
December 12, 2012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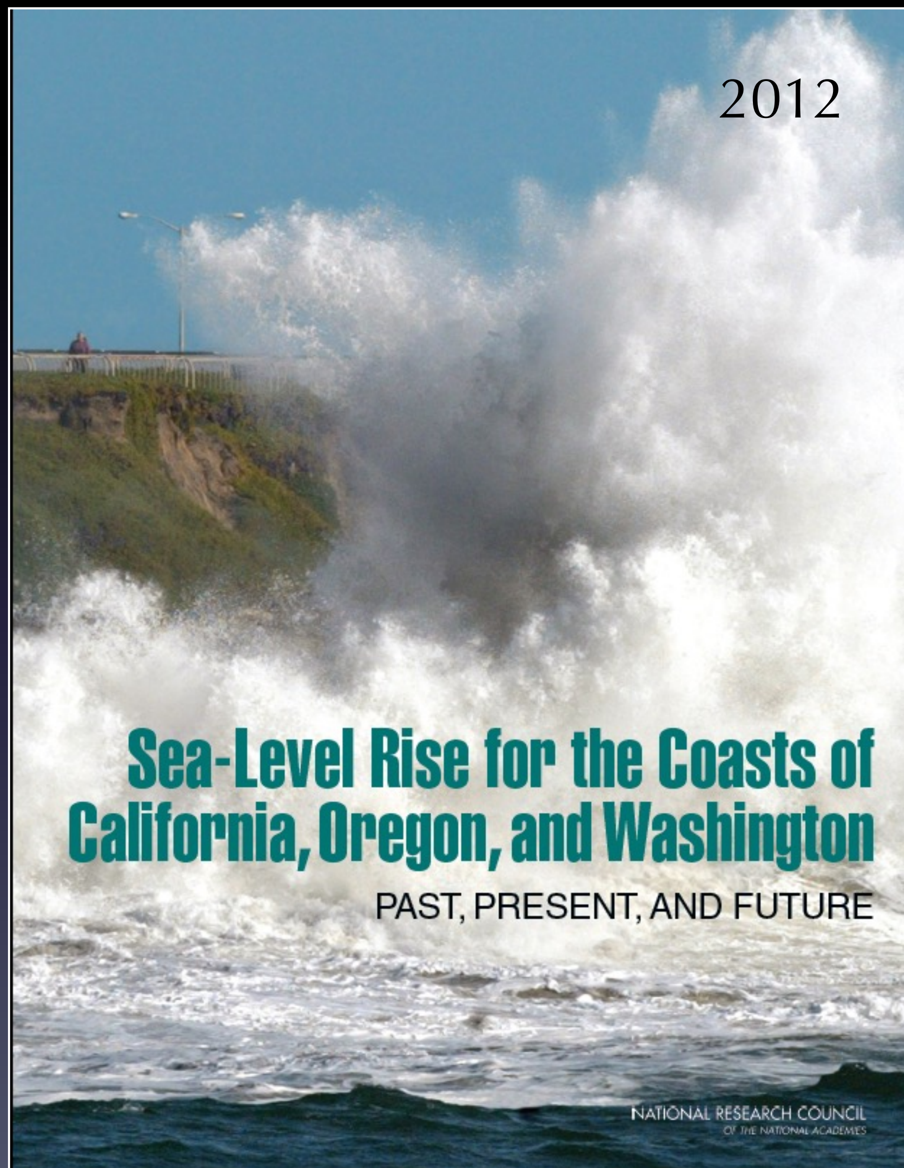
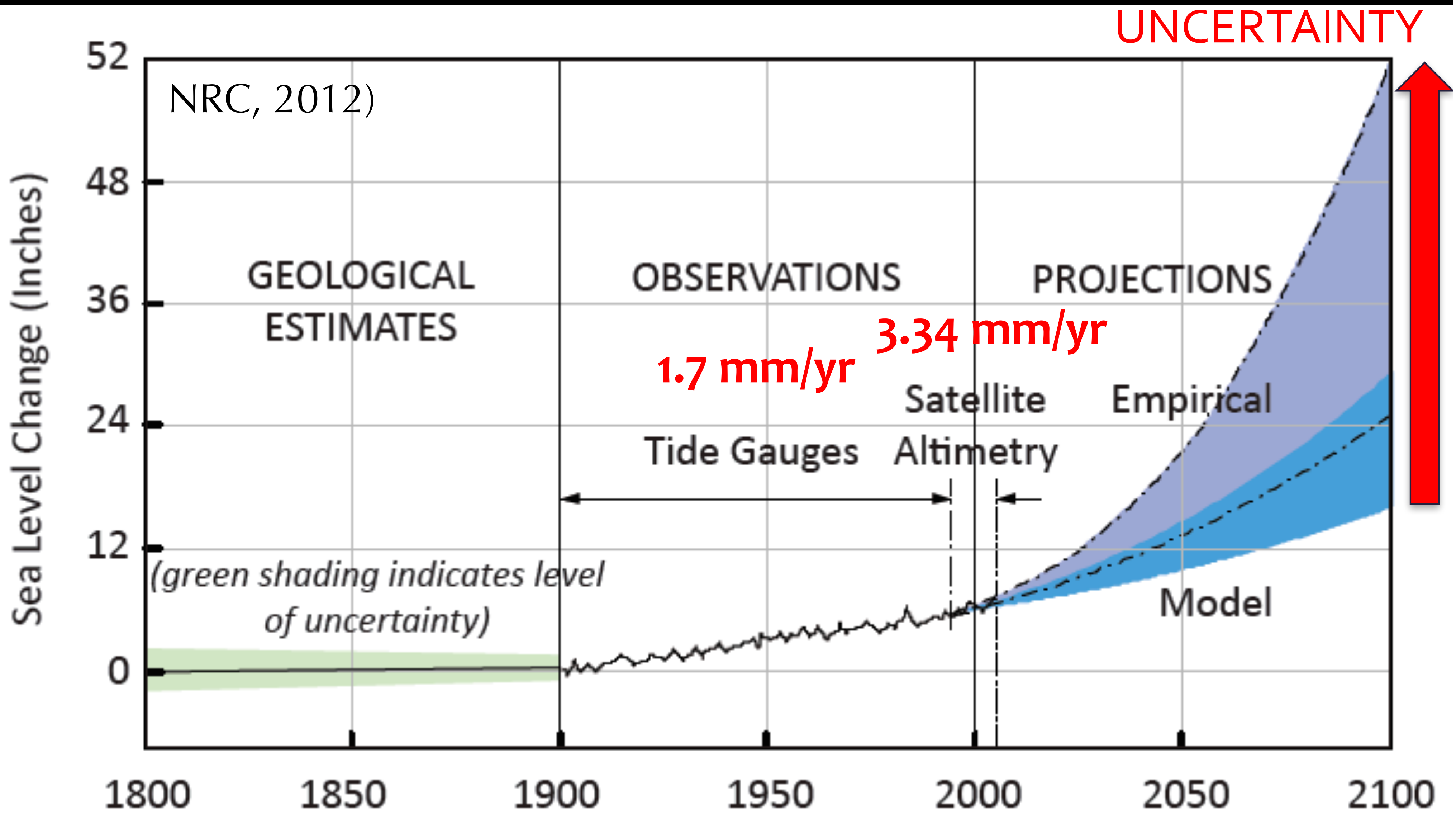
Sea-Level Rise for the Coast of California: Past, Present, and Future



Global sea-level rise was measured from tide gauges historically and satellites since 1993.



nature International weekly journal of science

NATURE | ARTICLE

日本語要約

Contribution of Antarctica to past and future sea-level rise

Robert M. DeConto & David Pollard

Affiliations | Contributions | Corresponding author

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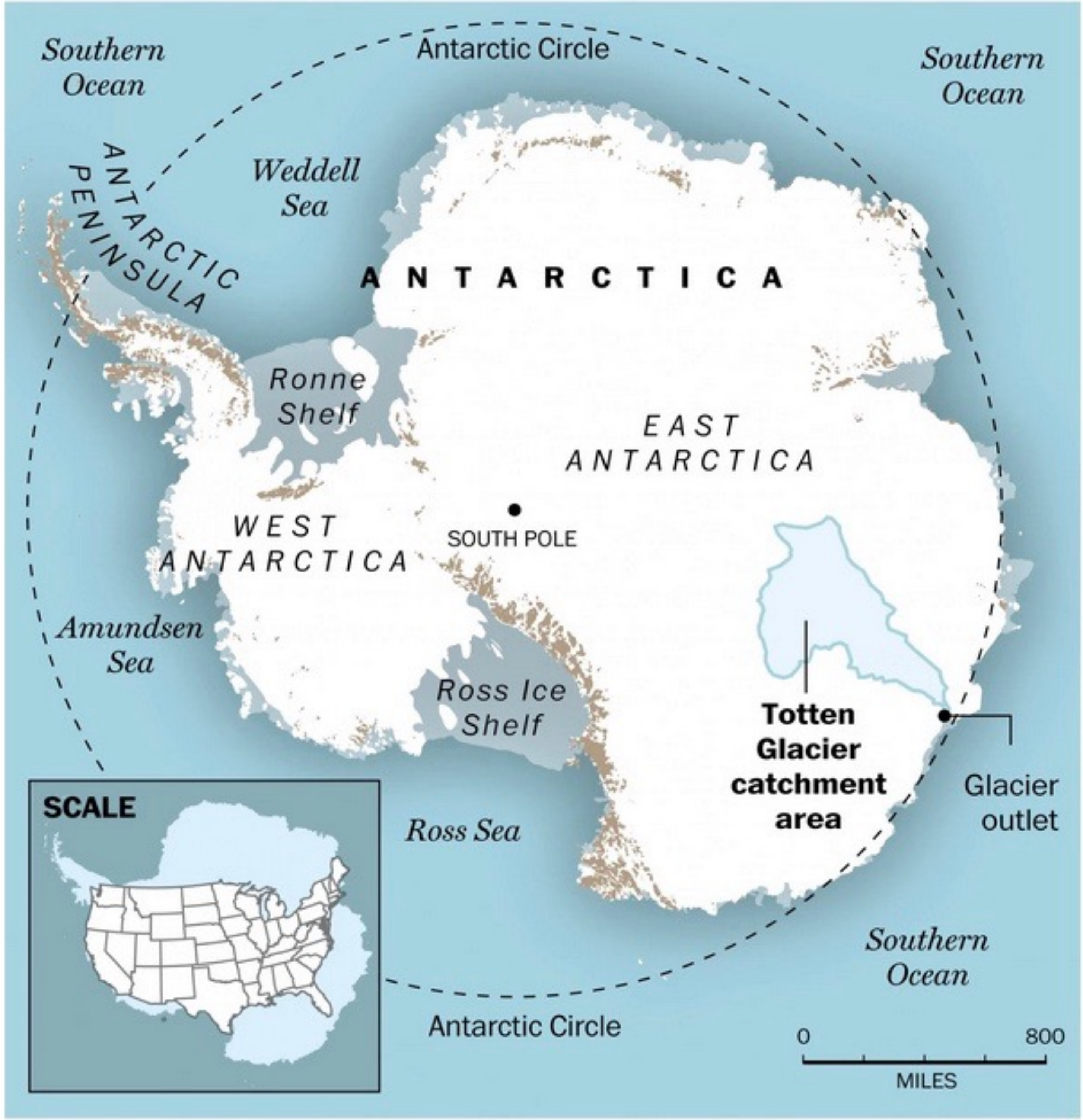
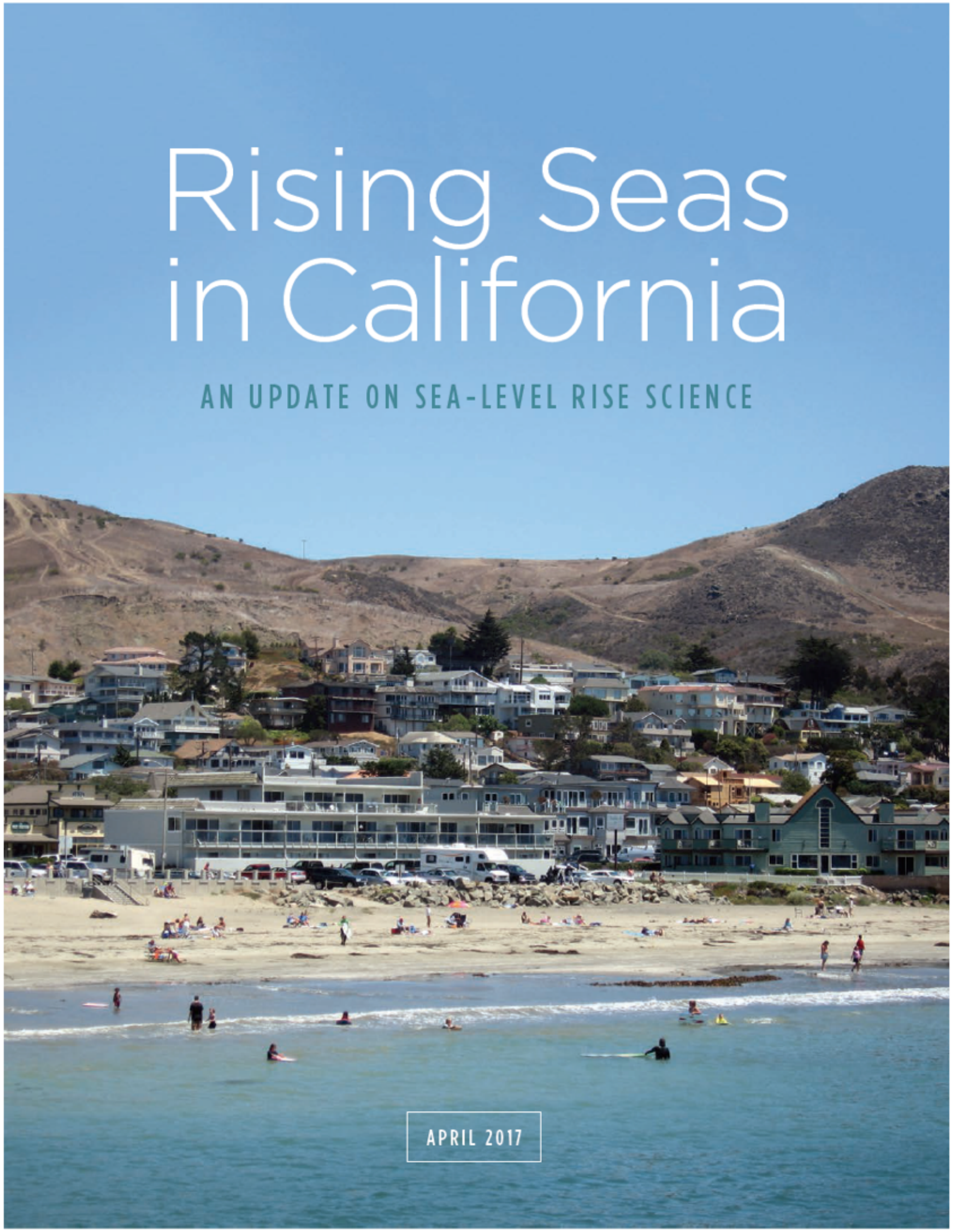
Abstract

Polar temperatures over the last several million years have, at times, been slightly warmer than today, yet global mean sea level has been 6–9 metres higher as recently as the Last Interglacial (130,000 to 115,000 years ago) and possibly higher during the Pliocene epoch (about three million years ago). In both cases the Antarctic ice sheet has been implicated as the primary contributor, hinting at its future vulnerability. Here we use a model coupling ice sheet and climate dynamics—including previously underappreciated processes linking atmospheric warming with hydrofracturing of buttressing ice shelves and structural collapse of marine-terminating ice cliffs—that is calibrated against Pliocene and Last Interglacial sea-level estimates and applied to future greenhouse gas emission scenarios. Antarctica has the potential to contribute more than a metre of sea-level rise by 2100 and more than 15 metres by 2500, if emissions continue unabated. In this case atmospheric warming will soon become the dominant driver of ice loss, but prolonged ocean warming will delay its recovery for thousands of years.

Antarctica holds 61% of Earth's fresh water: 6,400,000 cubic miles of ice.





CALIFORNIA OCEAN SCIENCE TRUST

California Ocean Protection Council
OPC-SAT
Science Advisory Team

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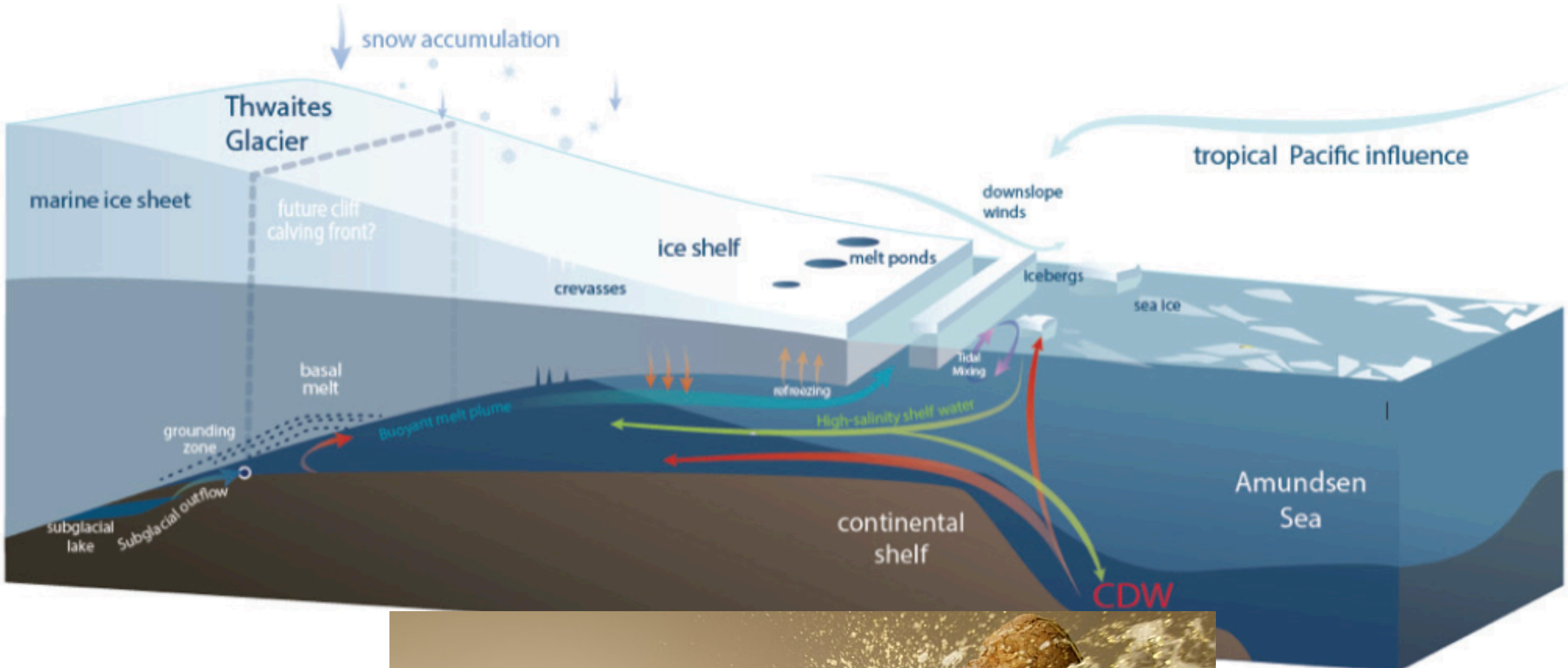
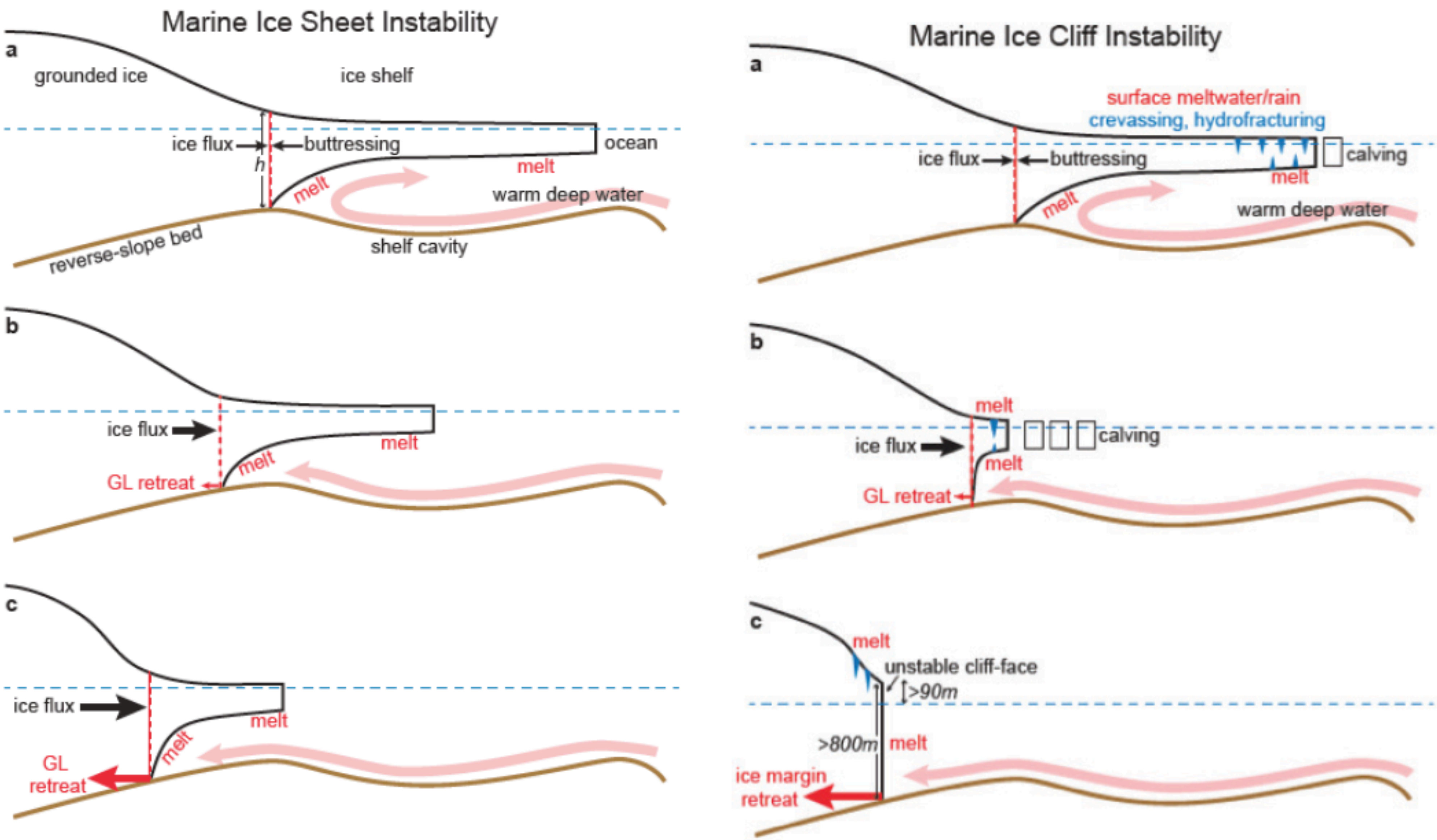
KEY FINDINGS - 2017

- Scientific understanding of sea-level rise advancing at rapid pace.
- Direction of sea-level rise is clear
- Rate of ice loss from Greenland and Antarctic Ice Sheets is increasing
- New evidence has highlighted the potential for extreme sea-level rise
- Probabilities of specific sea-level increases can inform decisions
- Current policy decisions are shaping our coastal future
- Waiting for scientific certainty is neither a safe nor a prudent option

ANTARCTIC ICE SHEET/GLACIAL DYNAMICS

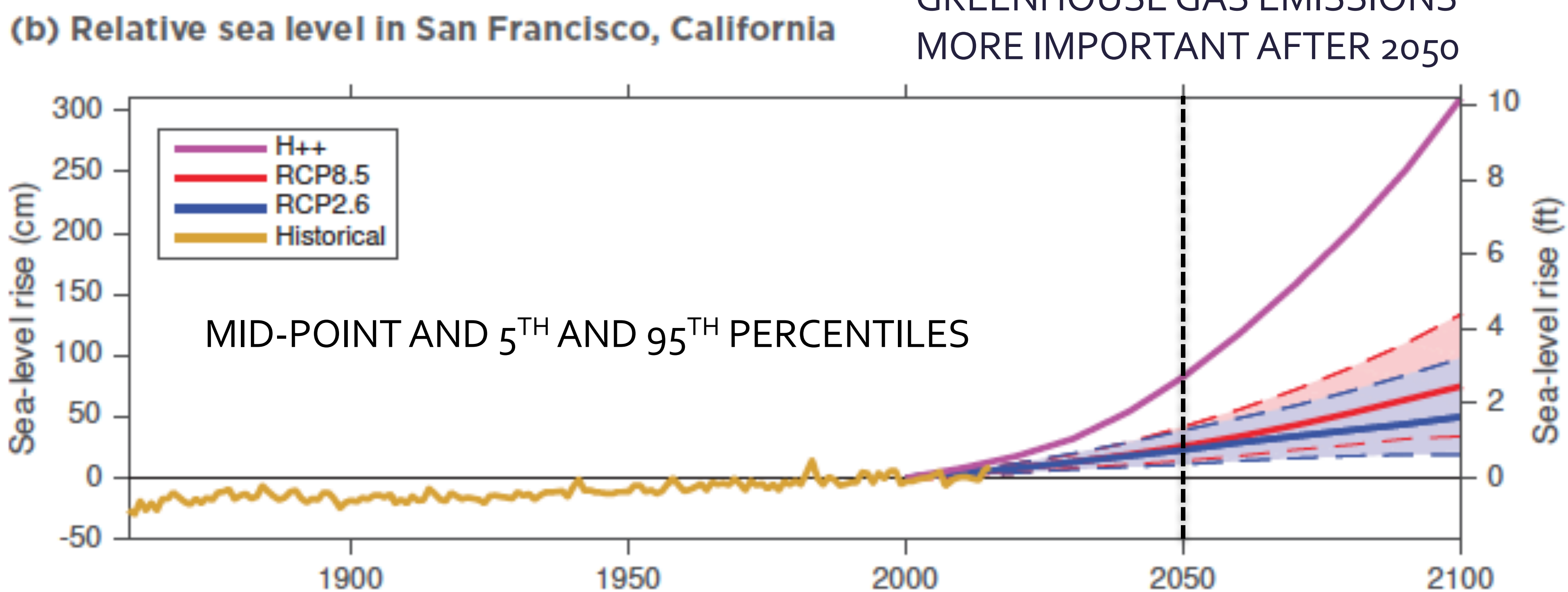


ANTARCTIC ICE SHEET/CLIFF INSTABILITY



PROJECTIONS OF FUTURE SEA-LEVEL RISE FOR SAN FRANCISCO

GREENHOUSE GAS EMISSIONS MORE IMPORTANT AFTER 2050



FUTURE SEA-LEVEL RISE PROJECTIONS

(b) San Francisco, Golden Gate

Feet above 1991-2009 mean	MEDIAN	NRC	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE
Year / Percentile	*50% probability SLR meets or exceeds...*		*67% probability SLR is between...*	*5% probability SLR meets or exceeds...*	*0.5% probability SLR meets or exceeds...*
2030	0.4	0.5	0.3 — 0.5	0.6	0.8
2050	0.9	1.0	0.6 — 1.1	1.4	1.9
2100 (RCP 2.6)	1.6		1.0 — 2.4	3.2	5.7
2100 (RCP 4.5)	1.9		1.2 — 2.7	3.5	5.9
2100 (RCP 8.5)	2.5	3.0	1.6 — 3.4	4.4	6.9
2100 (H++)	10				
2150 (RCP 2.6)	2.4		1.3 — 3.8	5.5	11.0
2150 (RCP 4.5)	3.0		1.7 — 4.6	6.4	11.7
2150 (RCP 8.5)	4.1		2.8 — 5.8	7.7	13.0
2150 (H++)	22				

SAN FRANCISCO

PROBABILITIES OF PARTICULAR HEIGHT (IN FEET) BEING REACHED OR EXCEEDED BY SPECIFIC YEAR

Table 4. Probability that sea-level rise at San Francisco, Golden Gate, will meet or exceed a particular height (feet) in a given year under: (a) RCP 8.5, and (b) RCP 2.6.

Estimates are based on Kopp et al., 2014. All heights are with respect to a 1991-2009 baseline; values refer to a 19-year average centered on the specified year. Grey shaded areas have less than a 0.1% probability of occurrence.

(a) RCP 8.5

	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2020										
2030	0.1%									
2040	3.3%									
2050	31%	0.4%								
2060	65%	3%	0.2%	0.1%						
2070	84%	13%	1.2%	0.2%	0.1%					
2080	93%	34%	5%	0.9%	0.3%	0.1%	0.1%			
2090	96%	55%	14%	3%	0.9%	0.3%	0.2%	0.1%	0.1%	
2100	96%	70%	28%	8%	3%	1%	0.5%	0.3%	0.2%	0.1%
2150	100%	96%	79%	52%	28%	15%	8%	4%	3%	2%
2200	100%	97%	91%	80%	65%	50%	36%	25%	18%	13%

(b) RCP 2.6

	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2020										
2030										
2040	3.1%									
2050	19%	0.3%								
2060	43%	1.4%	0.2%							
2070	62%	4%	0.6%	0.2%						
2080	74%	11%	2%	0.4%	0.2%	0.1%				
2090	80%	20%	3%	1.0%	0.4%	0.2%	0.1%	0.1%		
2100	84%	31%	7%	2%	0.8%	0.4%	0.2%	0.1%	0.1%	
2150	93%	62%	31%	14%	7%	4%	2%	2%	1%	1%
2200	93%	68%	42%	22%	12%	7%	5%	3%	2%	1%

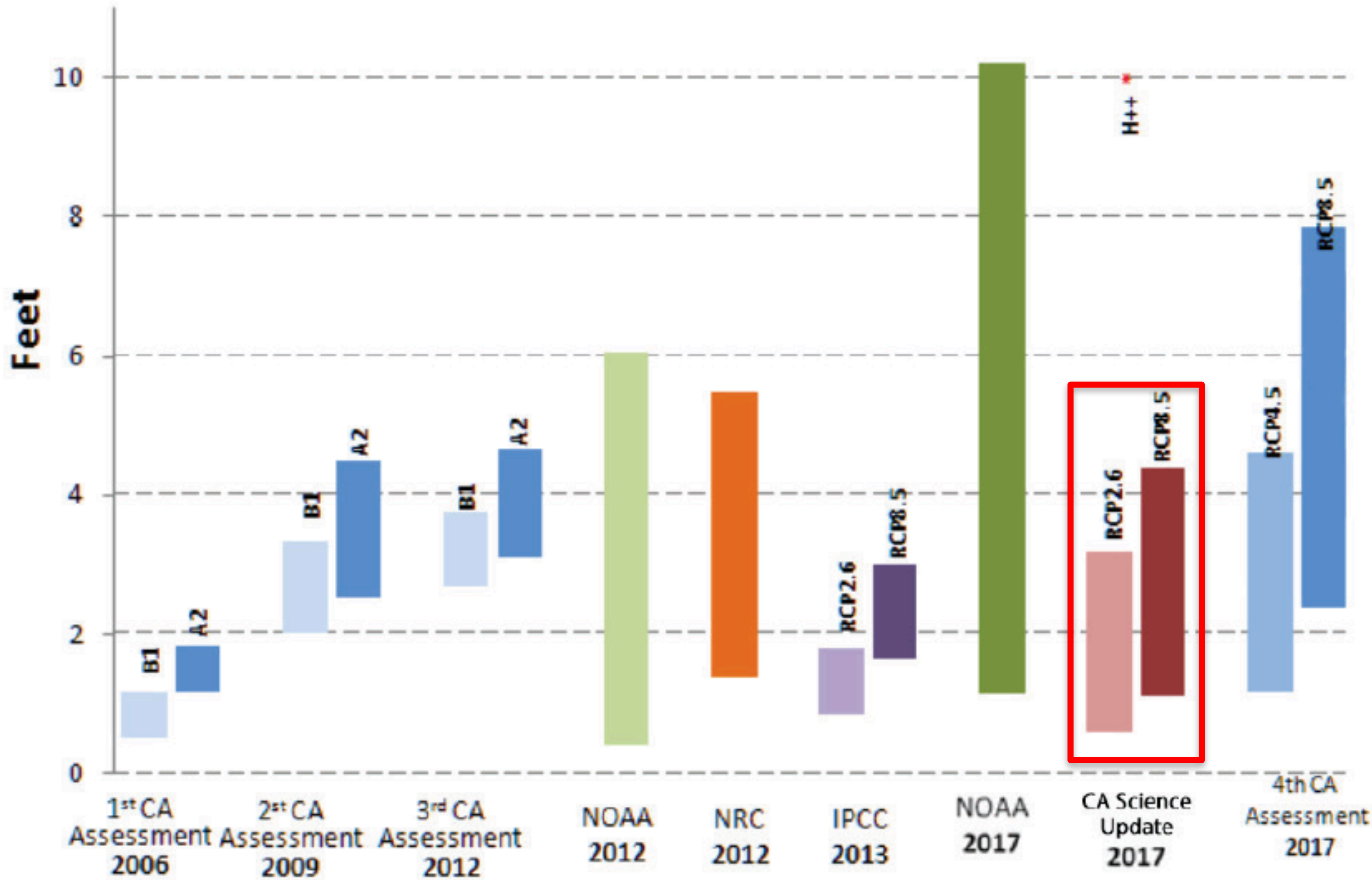
Uncertainty

- Future greenhouse gas emission scenarios
- Model uncertainty
- Natural variations in Earth's climate

1. Rate of melting of Greenland ice cap
2. Acceleration of flow rate of Antarctic glaciers into ocean
3. Release of carbon from thawing of permafrost

"There are the known knowns, there are the known unknowns, and there are the unknown unknowns".

COMPARISONS OF CALIFORNIA AND NATIONAL SEA-LEVEL RISE PROJECTIONS FOR 2100



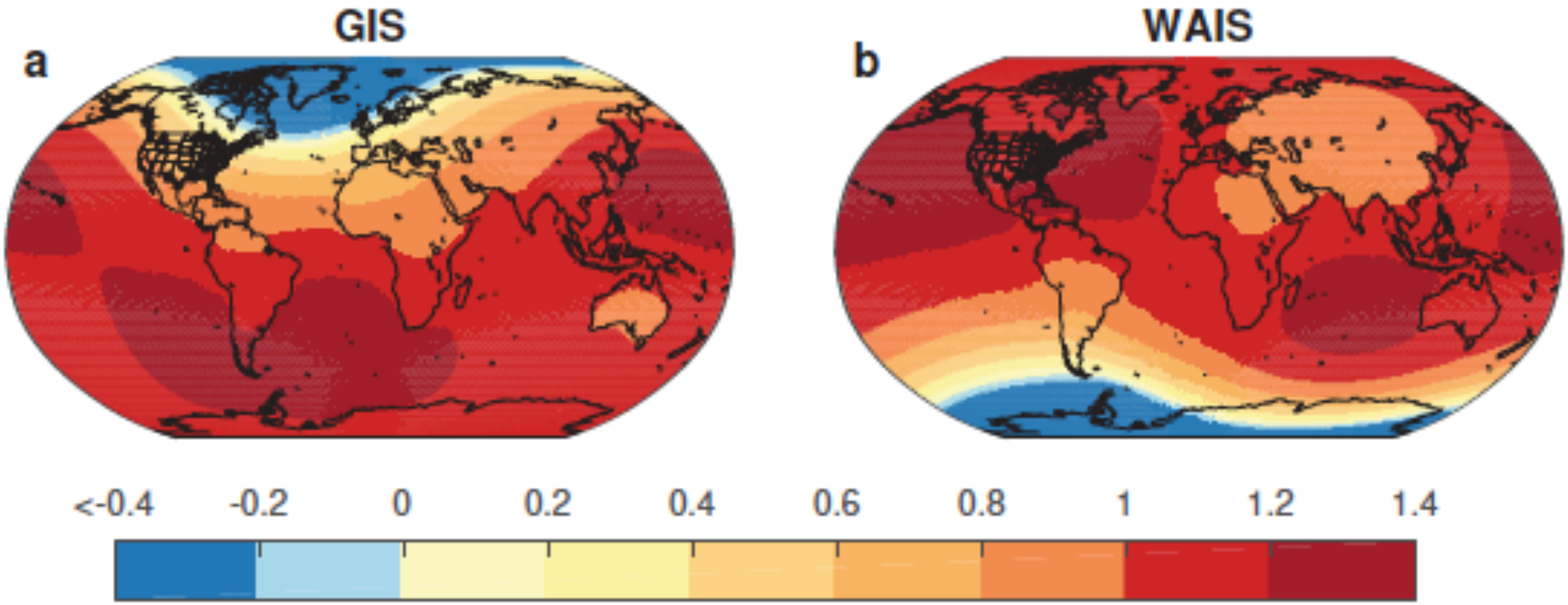


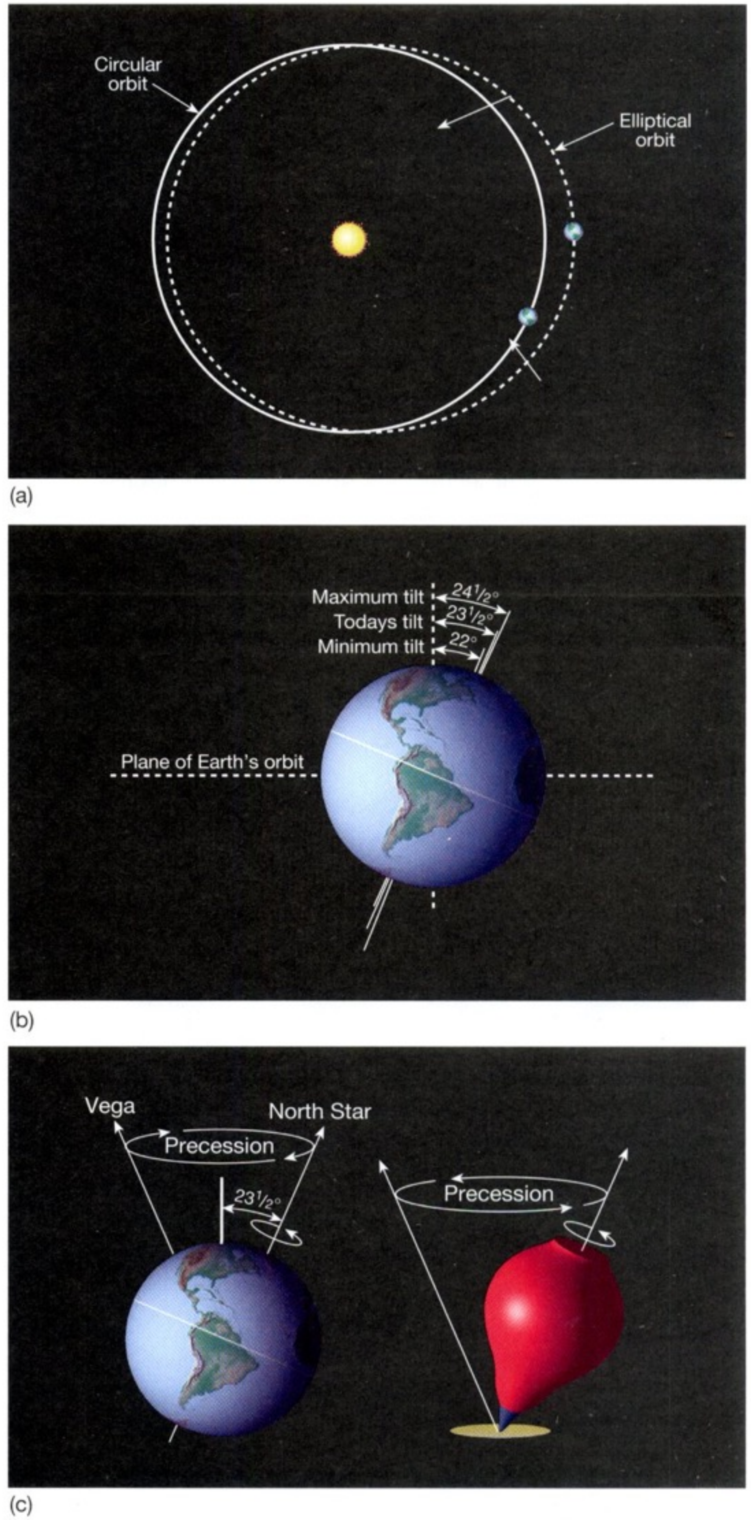
Figure 1. Sea-level 'fingerprints' resulting from the distribution of ice and water around the Earth and ensuing gravitational and rotational effects.

The maps depict the relative response of sea-level to the loss of ice mass from (a) Greenland Ice Sheet (GIS) and (b) West Antarctic Ice Sheet (WAIS). The color bar represents the fractional departure of relative sea level rise from that expected given the ice contribution to global mean sea level. For example, when ice is lost from the Greenland Ice Sheet the relative effect on the US West Coast is 75% of the sea-level rise expected from the water volume added to the ocean. By comparison, when ice is lost from the West Antarctic Ice Sheet the US West Coast experiences 125% of sea-level rise from that expected from the water volume added.

Variations in the Earth's orbit around the Sun play a major role in causing climate changes, ice ages and sea level fluctuations.

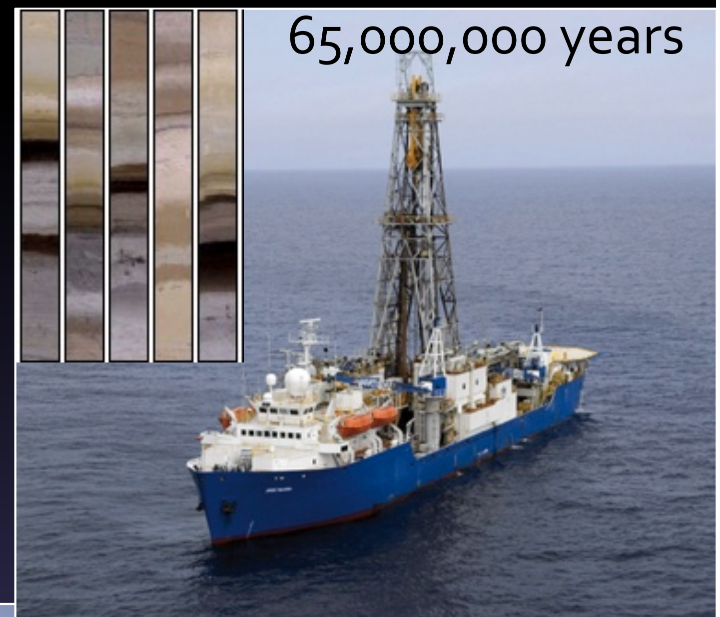
Three Orbital Cycles & Periods

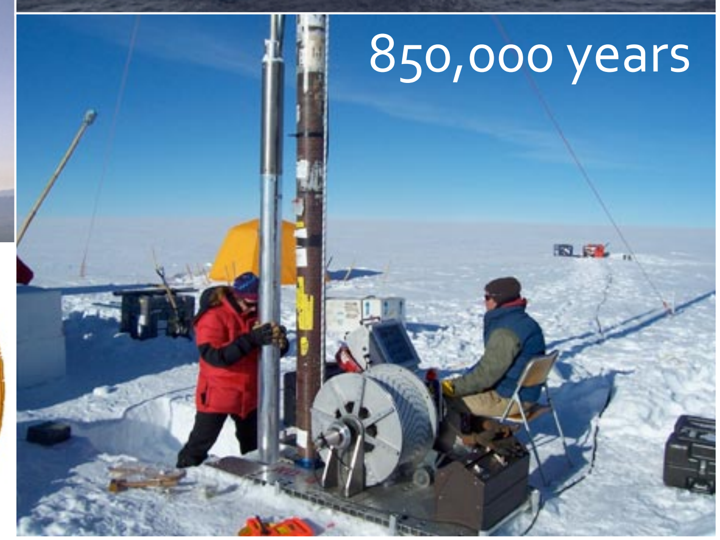
1. Shape of orbit-100,000 years
2. Tilt of axis of rotation ~41,000 years
3. Wobble of Earth's axis- ~26,000 years



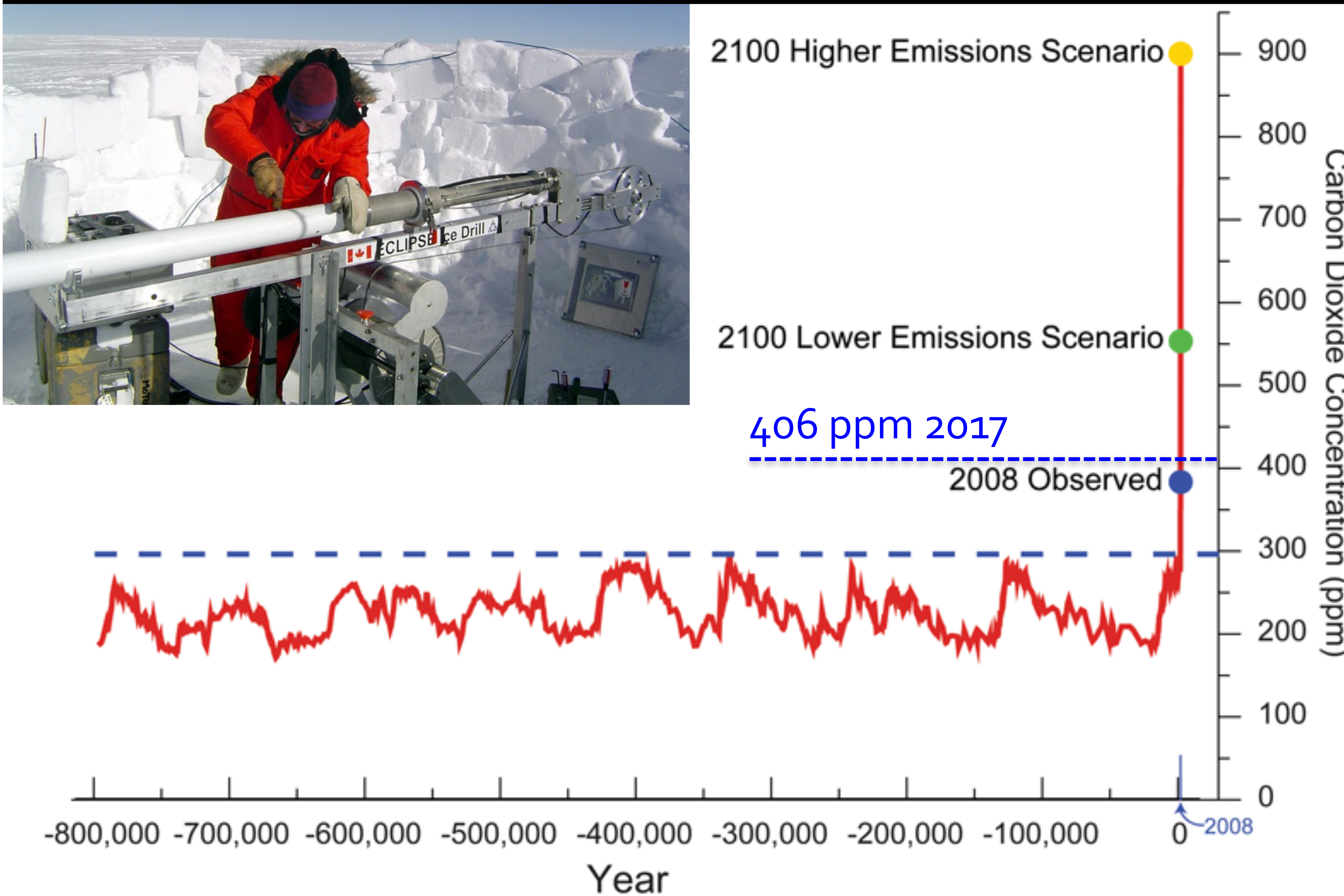
Climate changes have been recorded in:

- Deep-sea sediment cores
- Ice cores from Greenland and Antarctica
- Tree rings
- Deep-sea corals





Ice cores from Antarctica extend down 11,500 feet, extend back 850,000 years, and contain a continuous record of atmospheric carbon dioxide content.



King tides rolling into the Bay Area

Here is a look at the high tides forecast for the Bay Area on Thursday and Friday. Tides will be highest in the cul-de-sac of the South Bay, where water "piles up" in the tight confines.

High tides around the Bay Area

1 Mare Island
Thursday: **7.0 ft.**, 12:00 a.m.
Friday: **6.9 ft.**, 12:50 p.m.

2 Port Chicago
Thursday: **5.9 ft.**, 12:53 p.m.
Friday: **5.8 ft.**, 1:44 p.m.

3 Richmond
Thursday: **7.5 ft.**, 10:50 a.m.
Friday: **7.4 ft.**, 11:41 a.m.

4 San Francisco
Thursday: **7.2 ft.**, 10:34 a.m.
Friday: **7.0 ft.**, 11:24 a.m.

5 Rincon Point
Thursday: **7.56 ft.**, 10:52 a.m.
Friday: **7.44 ft.**, 11:42 a.m.

6 Alameda
Thursday: **7.9 ft.**, 11:03 a.m.
Friday: **7.8 ft.**, 11:54 a.m.

7 Hunter's Point
Thursday: **8.1 ft.**, 11.01 a.m.
Friday: **8.0 ft.**, 11:53 a.m.

8 San Leandro Marina
Thursday: **8.9 ft.**, 11:28 a.m.
Friday: **8.7 ft.**, 12:19 p.m.

9 San Mateo Bridge
Thursday: **9.1 ft.**, 11:25 a.m.
Friday: **9.0 ft.**, 12:16 p.m.

10 Princeton, Half Moon Bay
Thursday: **6.9 ft.**, 9:28 a.m.
Friday: **6.7 ft.**, 10:18 p.m.

11 Redwood City
Thursday: **9.6 ft.**, 10:44 a.m.
Friday: **9.5 ft.**, 12:27 p.m.

12 Dumbarton Bridge
Thursday: **10.1 ft.**, 11:44 a.m.
Friday: **10.0 ft.**, 12:36 p.m.

13 Coyote Creek
Thursday: **10.5 ft.**, 11:50 a.m.
Friday: **10.3 ft.**, 12:41 p.m.

14 Santa Cruz
Thursday: **6.7 ft.**, 9:12 a.m.
Friday: **6.5 ft.**, 10:01 a.m.

Source: California King Tides Initiative

BAY AREA NEWS GROUP