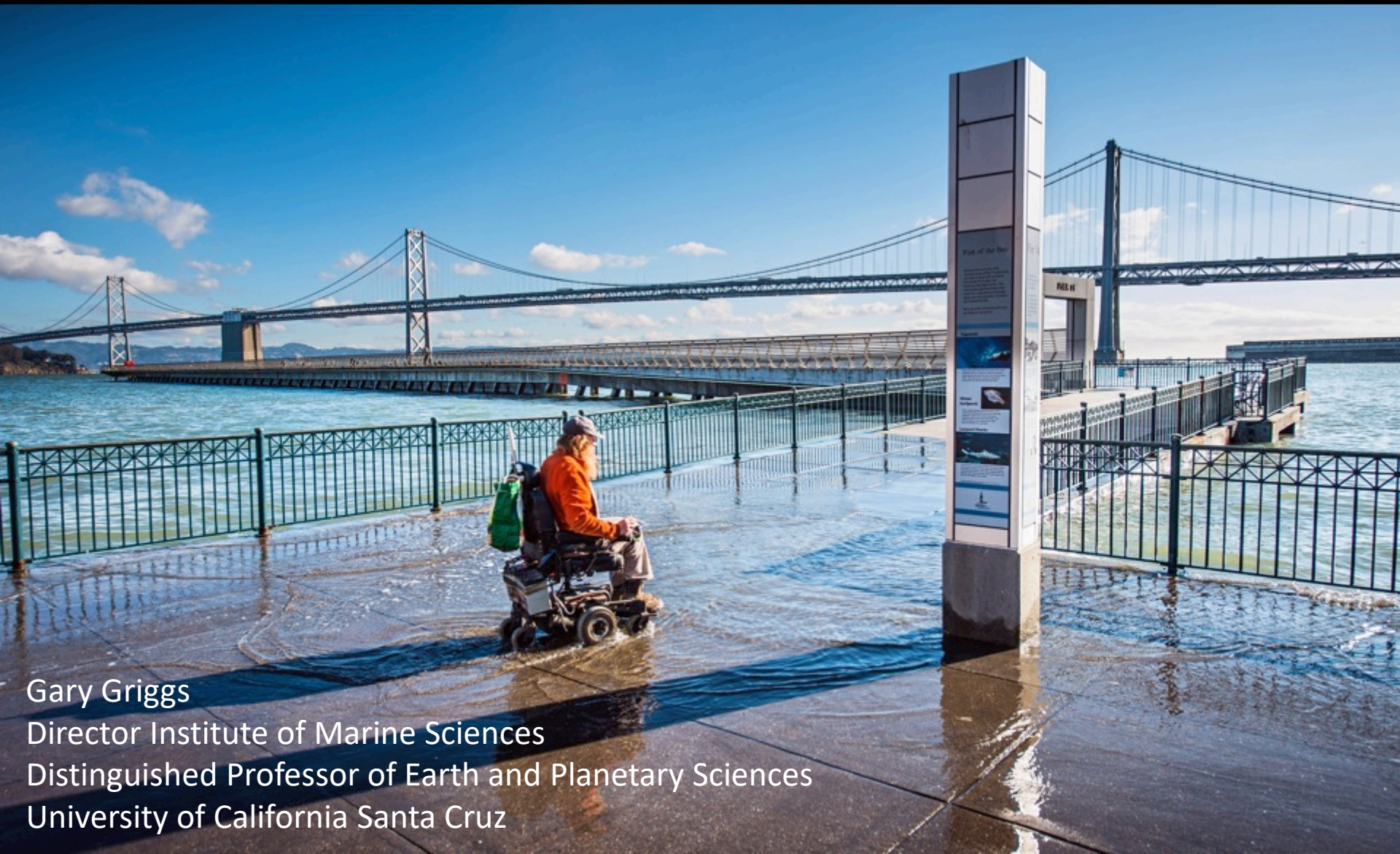
CLIMATE CHANGE and SEA-LEVEL RISE



Gary Griggs
Director Institute of Marine Sciences
Distinguished Professor of Earth and Planetary Sciences
University of California Santa Cruz

The world's 7.3 billion people, and California's 39 million people, are struggling to solve a high-stakes, three-fold problem:

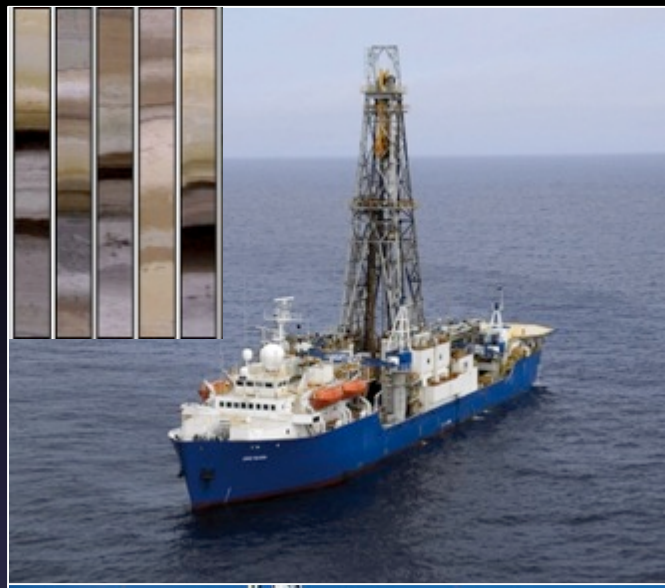
1. Satisfy a growing appetite for food, water and energy

2. Preserve a livable natural environment

3. Build resilience to natural extremes & climate change

Climate changes have been recorded in:

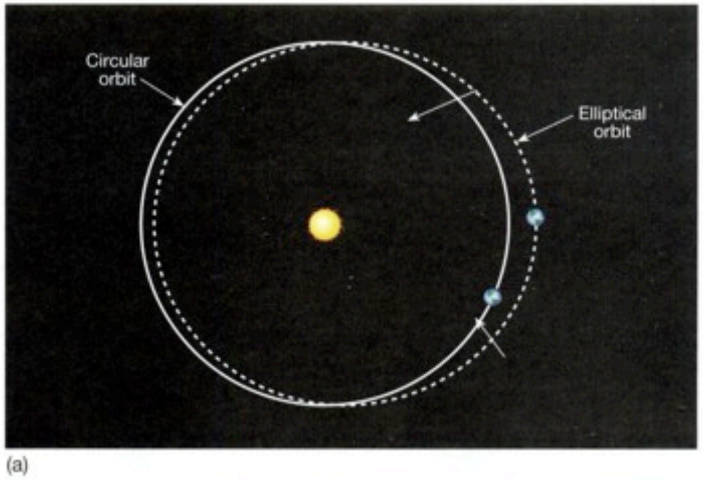
- Deep-sea sediment cores
- Ice cores from Greenland and Antarctica
- Corals from tropical oceans
- Tree rings- dendrochronology
- Pollen records in lake sediments



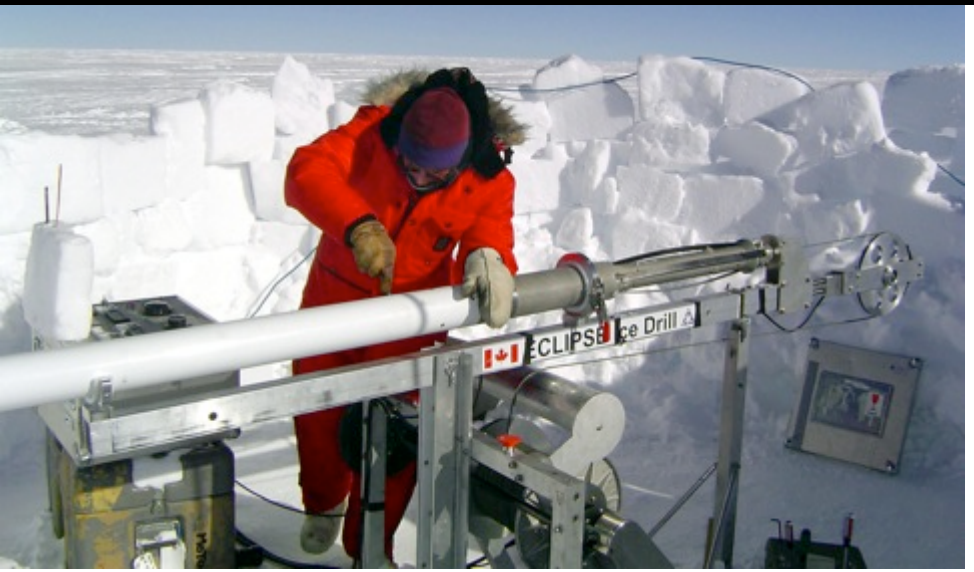
Variations in the Earth's orbit around the Sun played a major role in causing past climate change and Ice Ages

Three Orbital Cycles & Periods

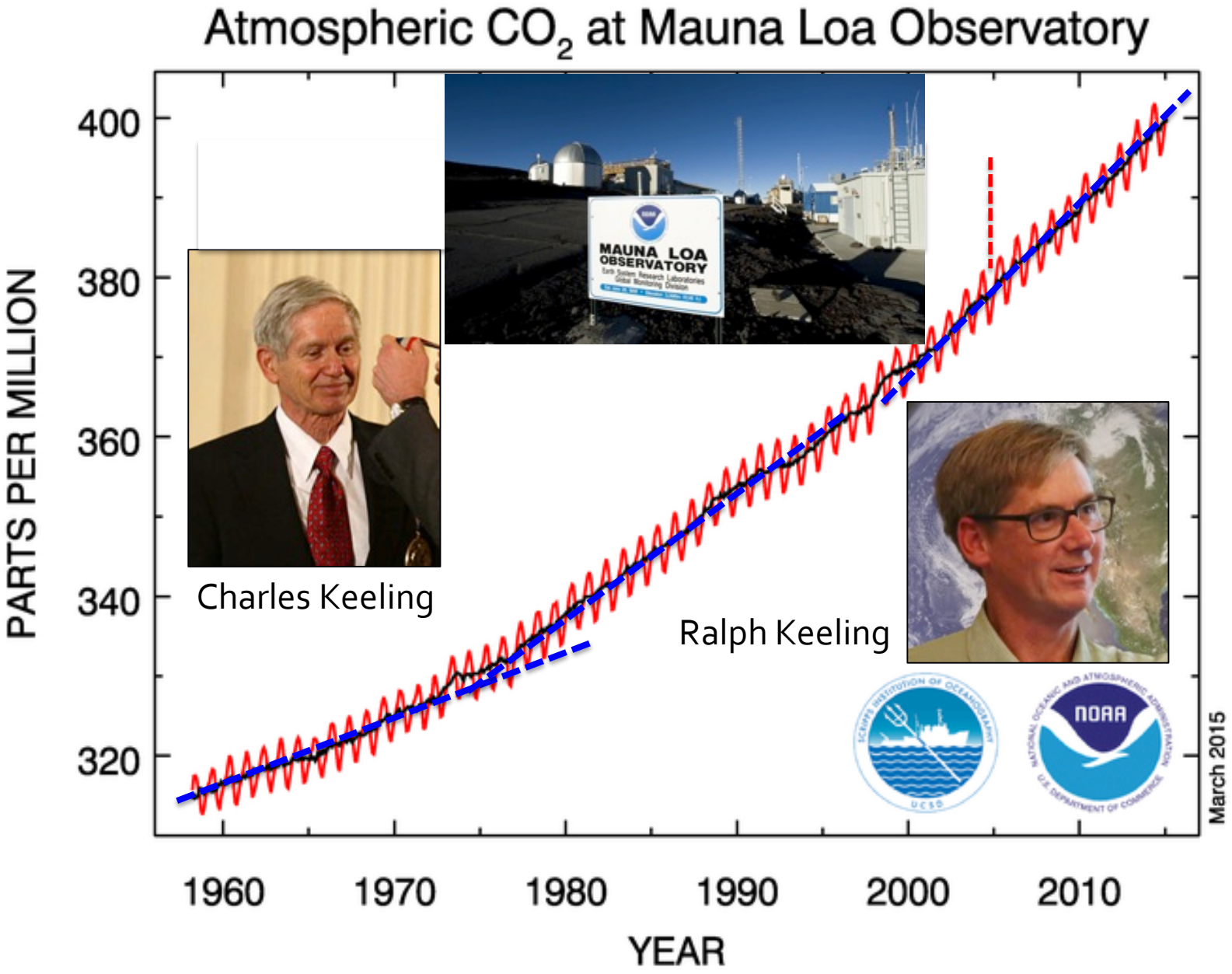
1. Shape of orbit-100,000 years
2. Tilt of axis of rotation ~41,000 years
3. Wobble of Earth's axis- ~26,000 years



Antarctic ice cores 11,500 feet deep extend back 850,000 years and contain air bubbles, which record atmospheric carbon dioxide content.



THE KEELING CURVE



Where humanity's CO2 comes from

91% 33.4 billion metric tonnes

Fossil Fuels & Cement 2010

9% 3.3 billion metric tonnes

Land Use Change 2010

Where humanity's CO2 goes

50% 18.4 billion metric tonnes

Atmosphere 2010

26% 9.5 billion metric tonnes

Land 2010

24% 8.8 billion metric tonnes

Oceans 2010

Global Carbon Project

2010 data updated from:
Le Quéré et al. 2009, Nature Geoscience
Canadell et al. 2007, PNAS

CO2Now.org

In the next hour the world will use about 150 million gallons of oil, 15 billion cubic feet of natural gas, and a million tons of coal, which all produce carbon dioxide.

We're not running out of fossil fuels,
we're running out of atmosphere.

Likely local climate change effects based on historic patterns and climate models

1] higher temperatures

2] summer water shortages and longer droughts

3] increase in wild land fires

4] more concentrated winter rainfall and more flooding

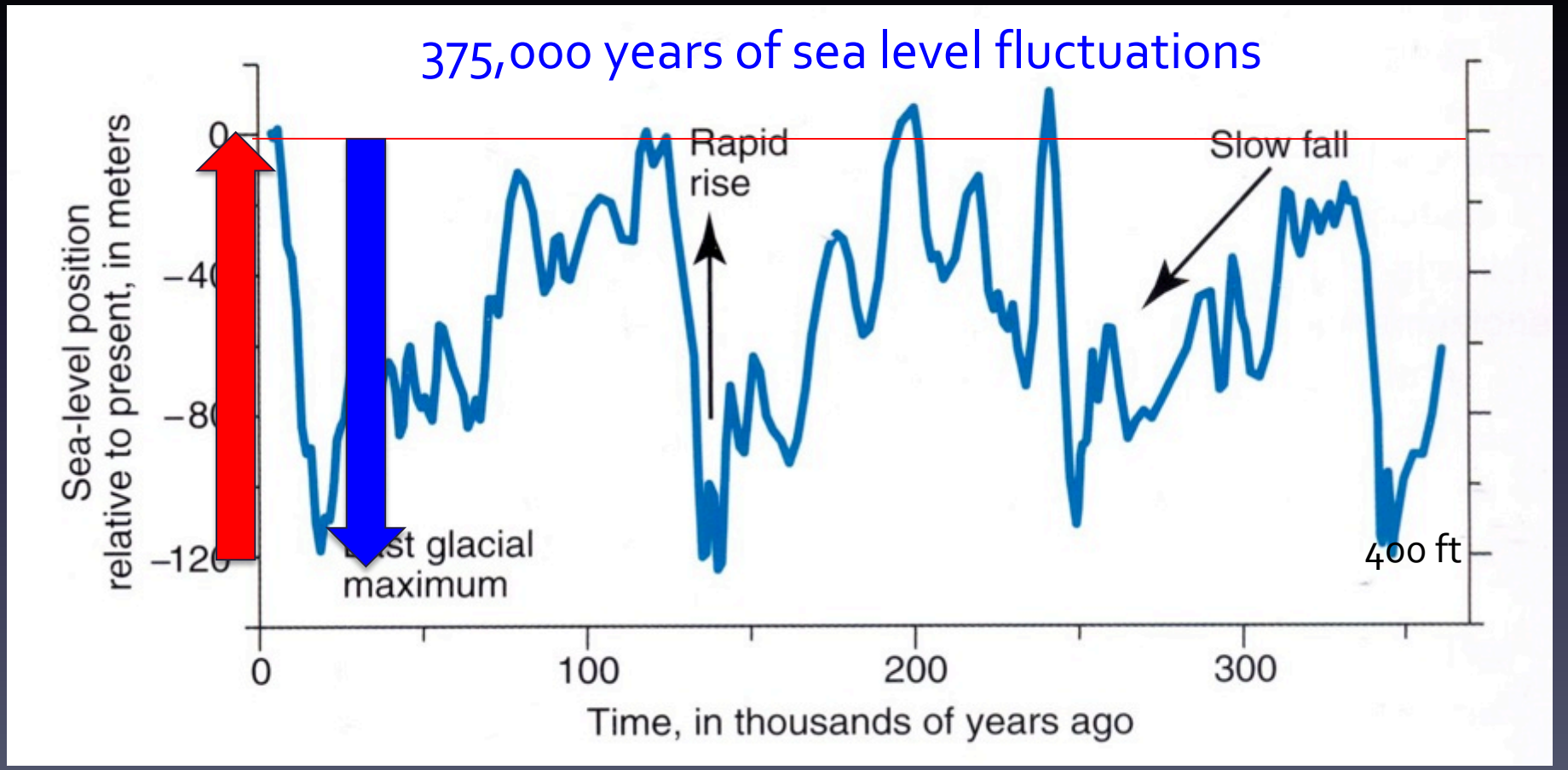
5] sea-level rise with increased rates of coastal inundation and shoreline retreat

These will not be new events, but will likely occur more frequently and be more intense than in the past.

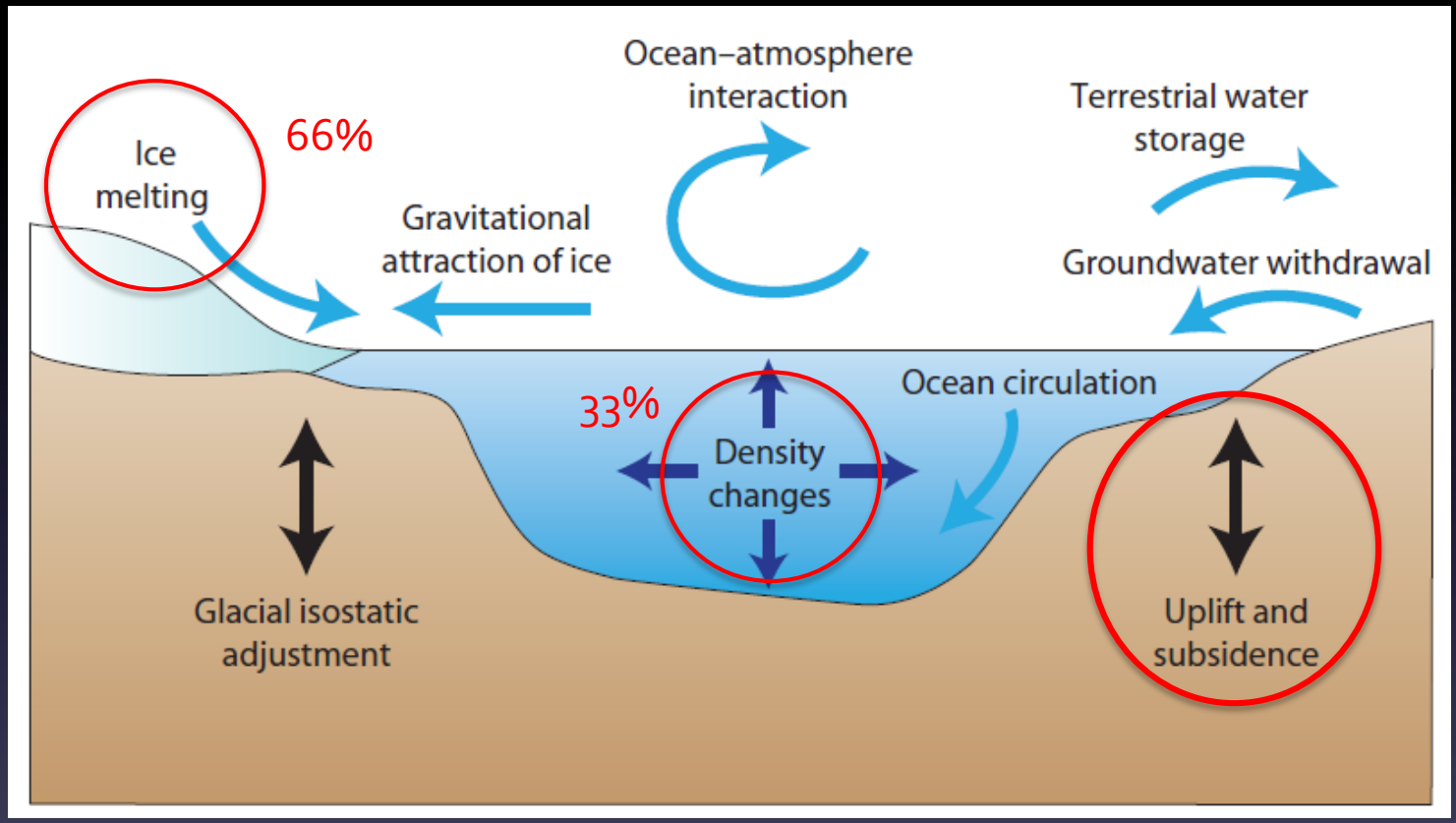
New FEMA maps show more of East Palo Alto at risk of flooding

By Peninsula Press on December 12, 2015 at 6:27 AM

Changes in sea level are driven primarily by global temperature. As the Earth has warmed and cooled, sea level has risen and fallen, in response to 1) melting or expansion of glaciers and ice sheets, and 2) expansion and contraction of sea water.

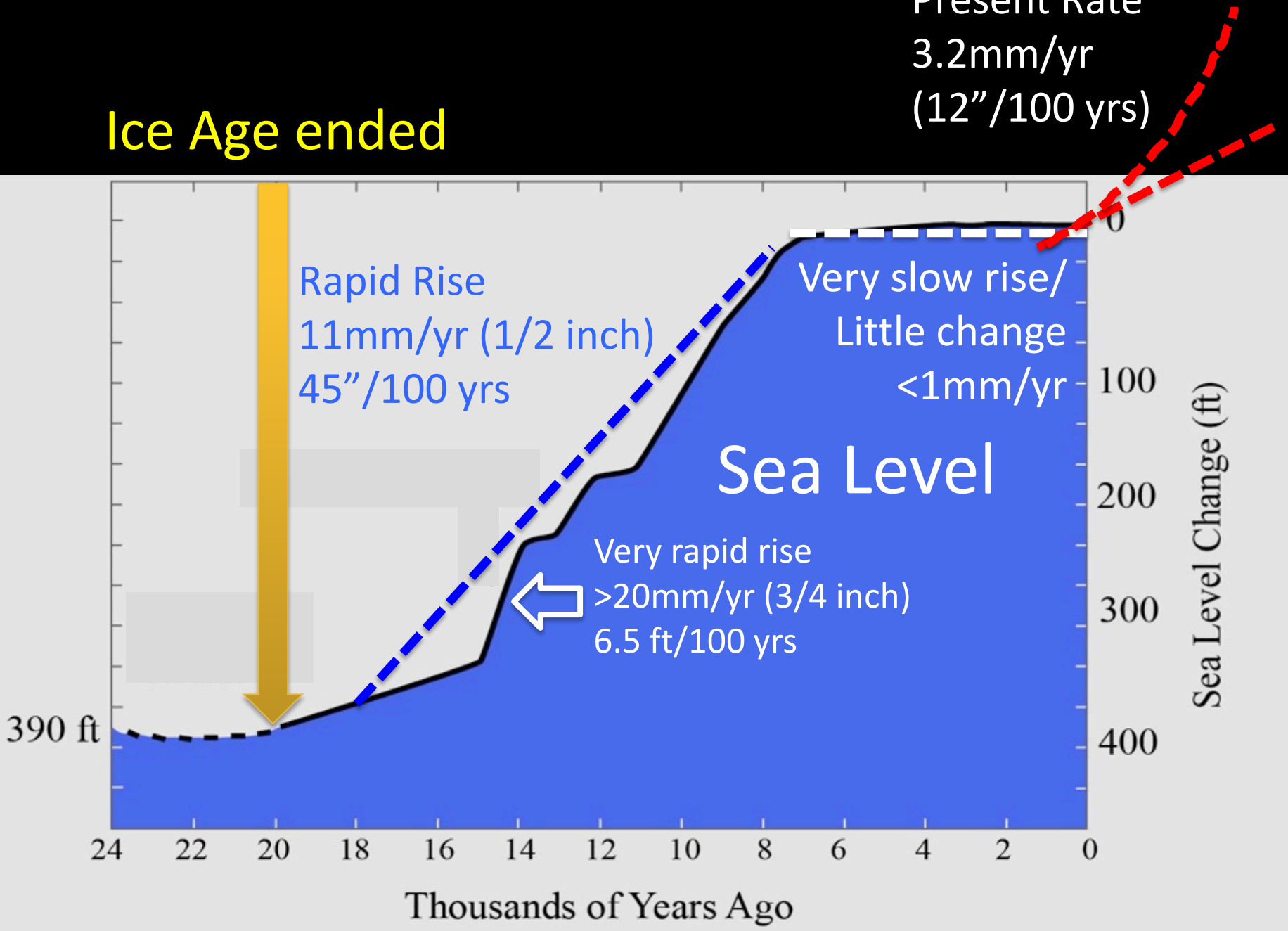


Components of Global and Regional Sea-Level Rise

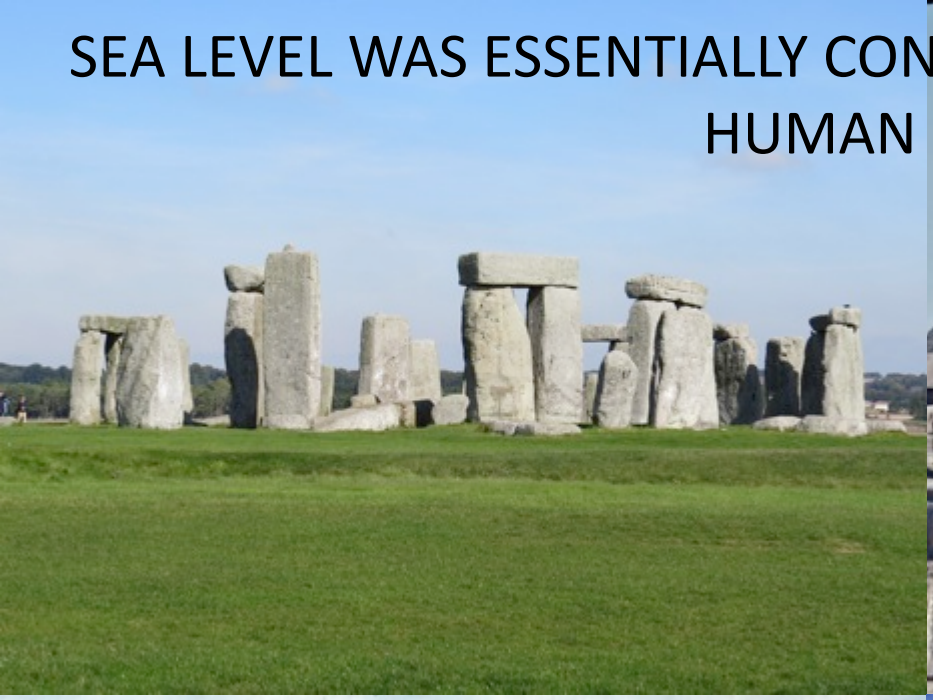


Sea-level rise at a particular place can be higher or lower than the global mean due to regional effects

Ice Age ended



SEA LEVEL WAS ESSENTIALLY CONSTANT OVER THE ENTIRE HISTORY OF HUMAN CIVILIZATION



And they are still being built

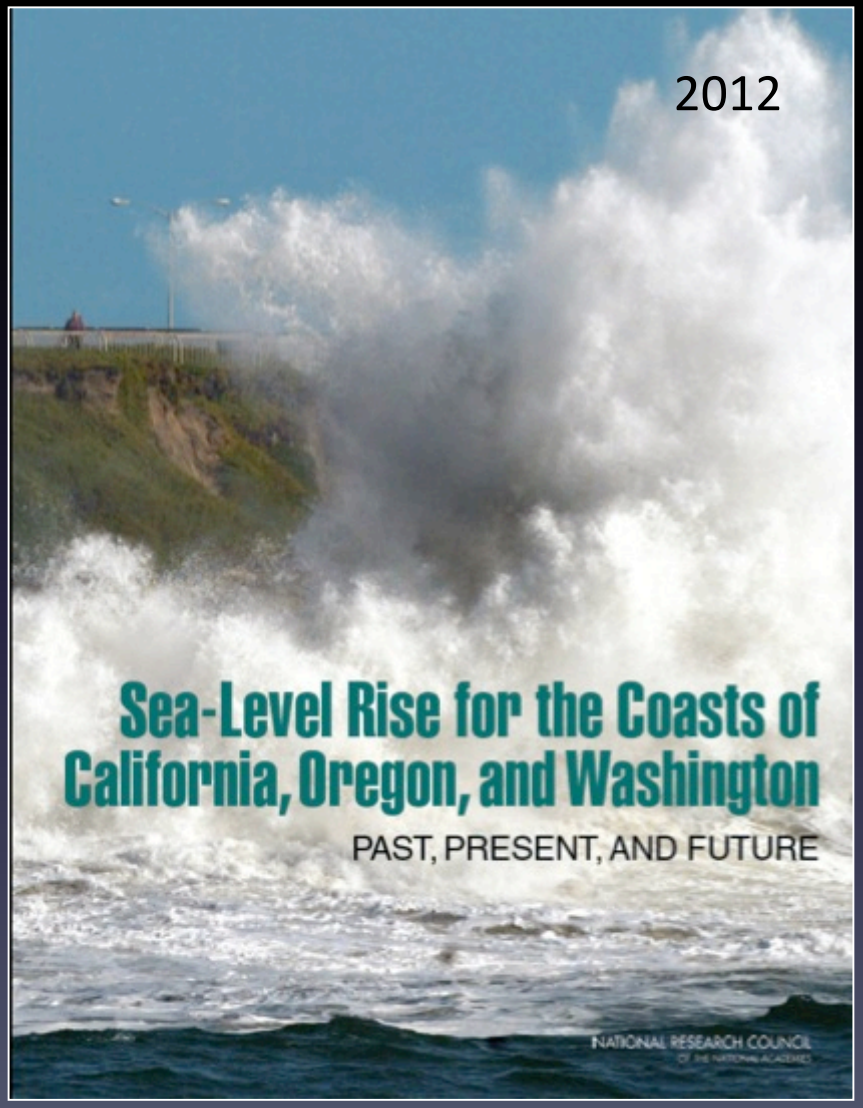
Rising waters

108 million people in just 20 cities

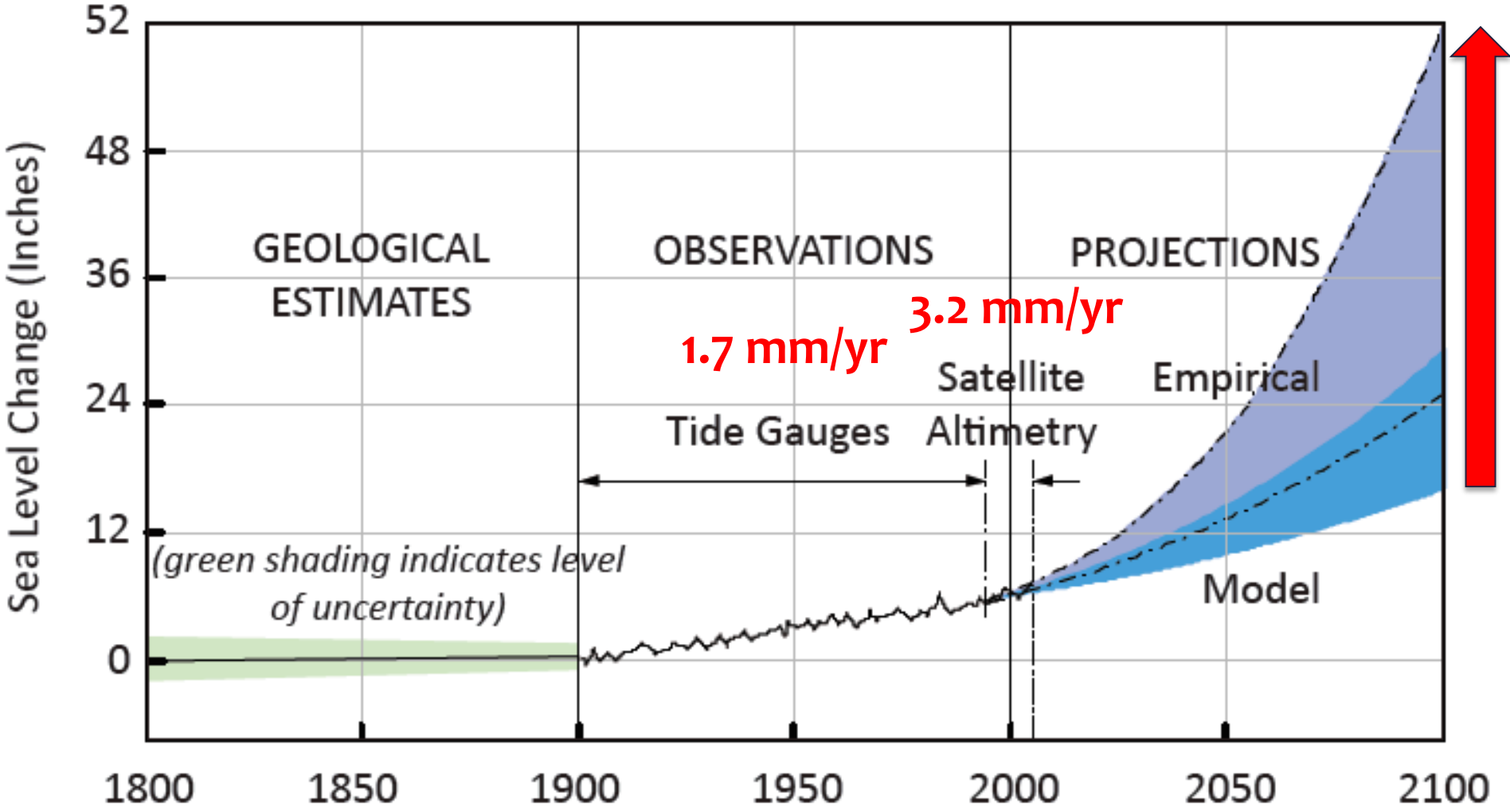
Sea levels going up 60 percent faster than previous UN climate panel forecasts, scientists report Wednesday


Sacramento
San Francisco
SFO
Farallons
Palo Alto
18.0 ka

Sea-Level Rise for the Coast of California: Past, Present, and Future



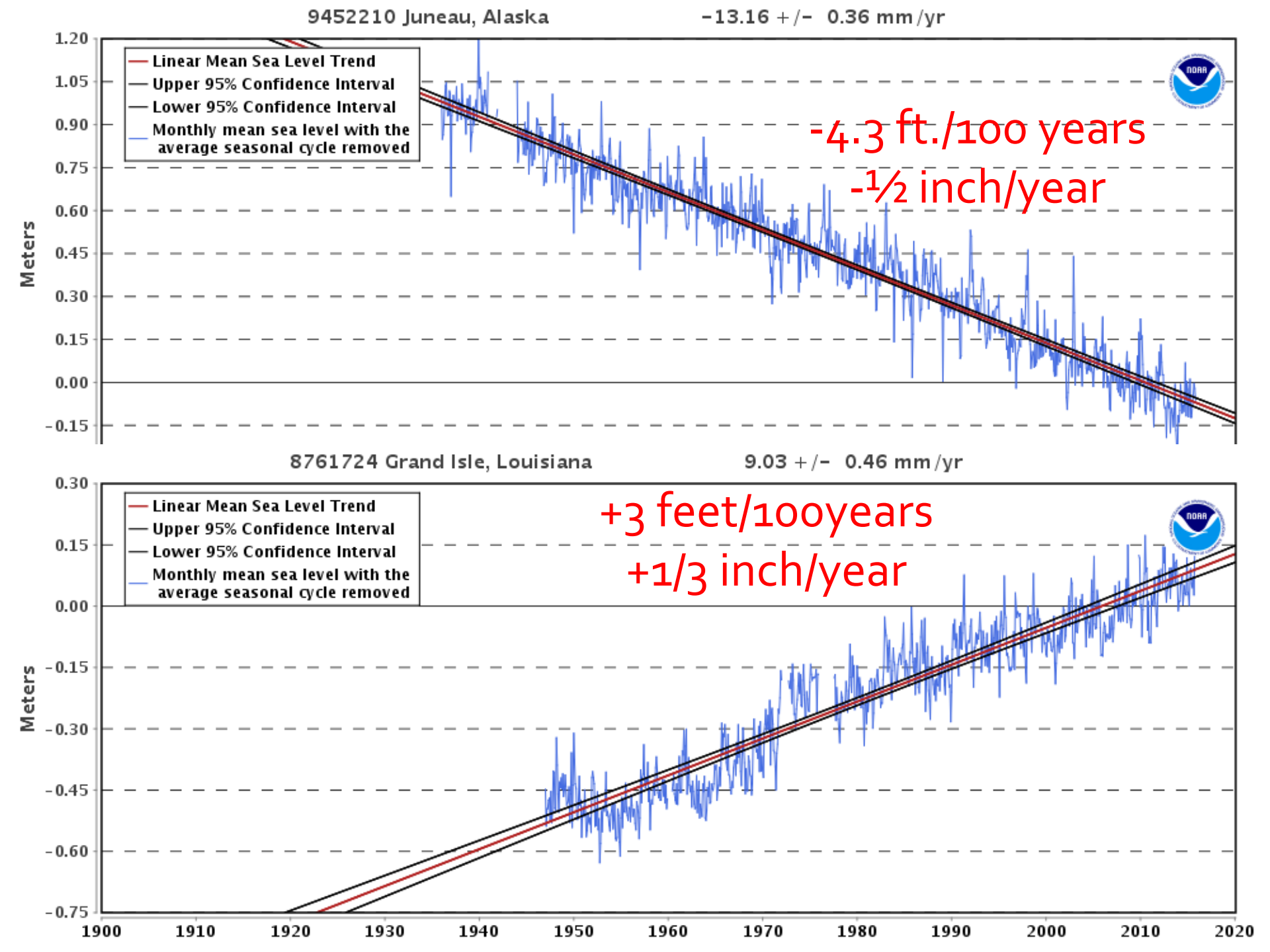
The rate of global sea-level rise was measured from tide gages historically and satellites since 1993.



Uncertainty

- *Natural variations in climate*
- *Future greenhouse gas emissions*
- *Release of carbon from thawing of permafrost*
- *Rate of melting of Greenland ice cap*
- *Acceleration of flow rate of Antarctic glaciers into ocean*

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


9452210 Juneau, Alaska
-13.16 +/- 0.36 mm/yr
Linear Mean Sea Level Trend
Upper 95% Confidence Interval
Lower 95% Confidence Interval
Monthly mean sea level with the average seasonal cycle removed
-4.3 ft./100 years
-½ inch/year
Meters
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
-0.15
8761724 Grand Isle, Louisiana
9.03 +/- 0.46 mm/yr
+3 feet/100years
+1/3 inch/year
0.30
0.15
0.00
-0.15
-0.30
-0.45
-0.60
-0.75
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

"HOW ON EARTH DO WE TURN IT OFF?"

2030

Height in Inches

72

60

48

36

24

12

0

2050

Height in Inches

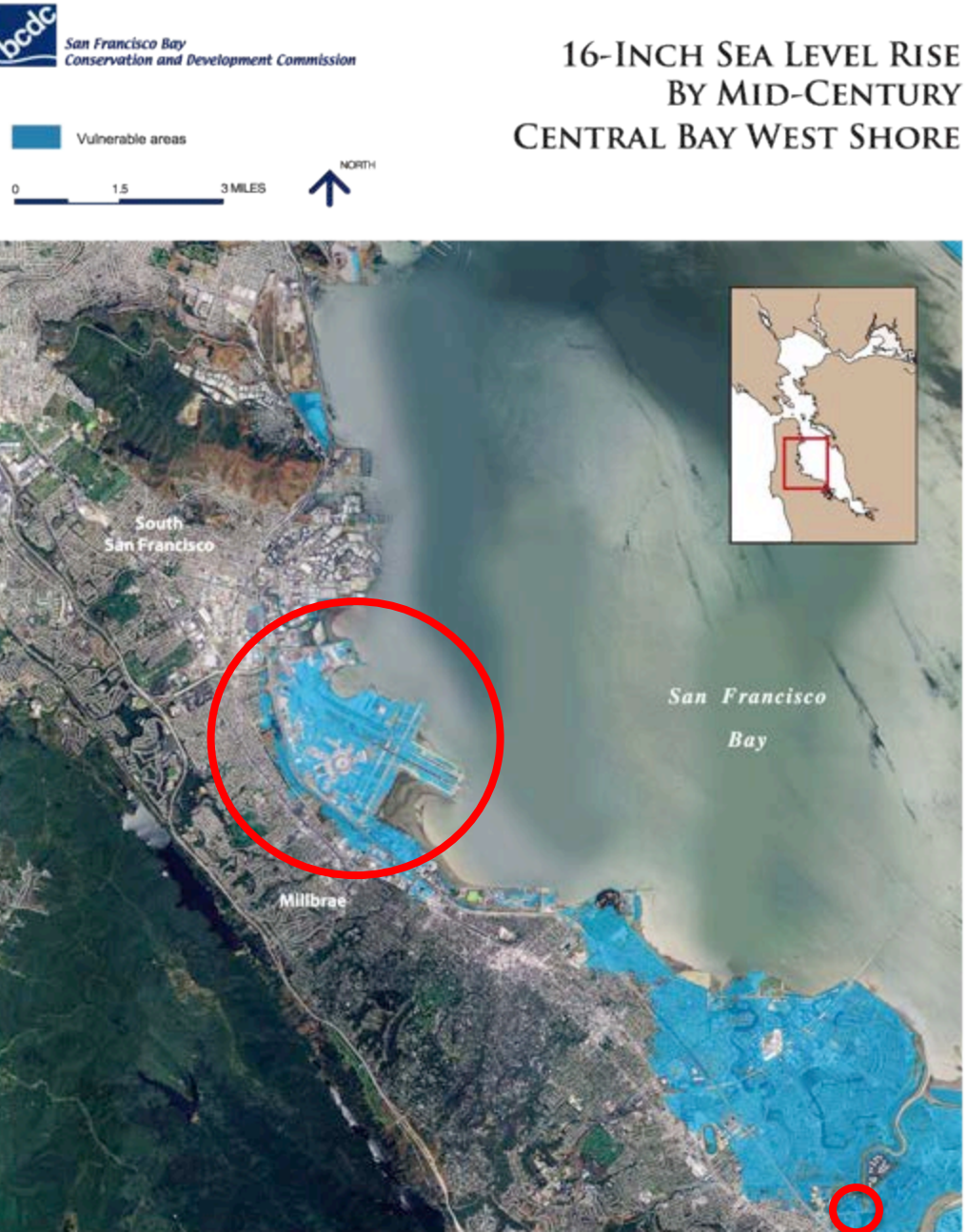
72
60
48
36
24
12
0

2100

Height in Inches

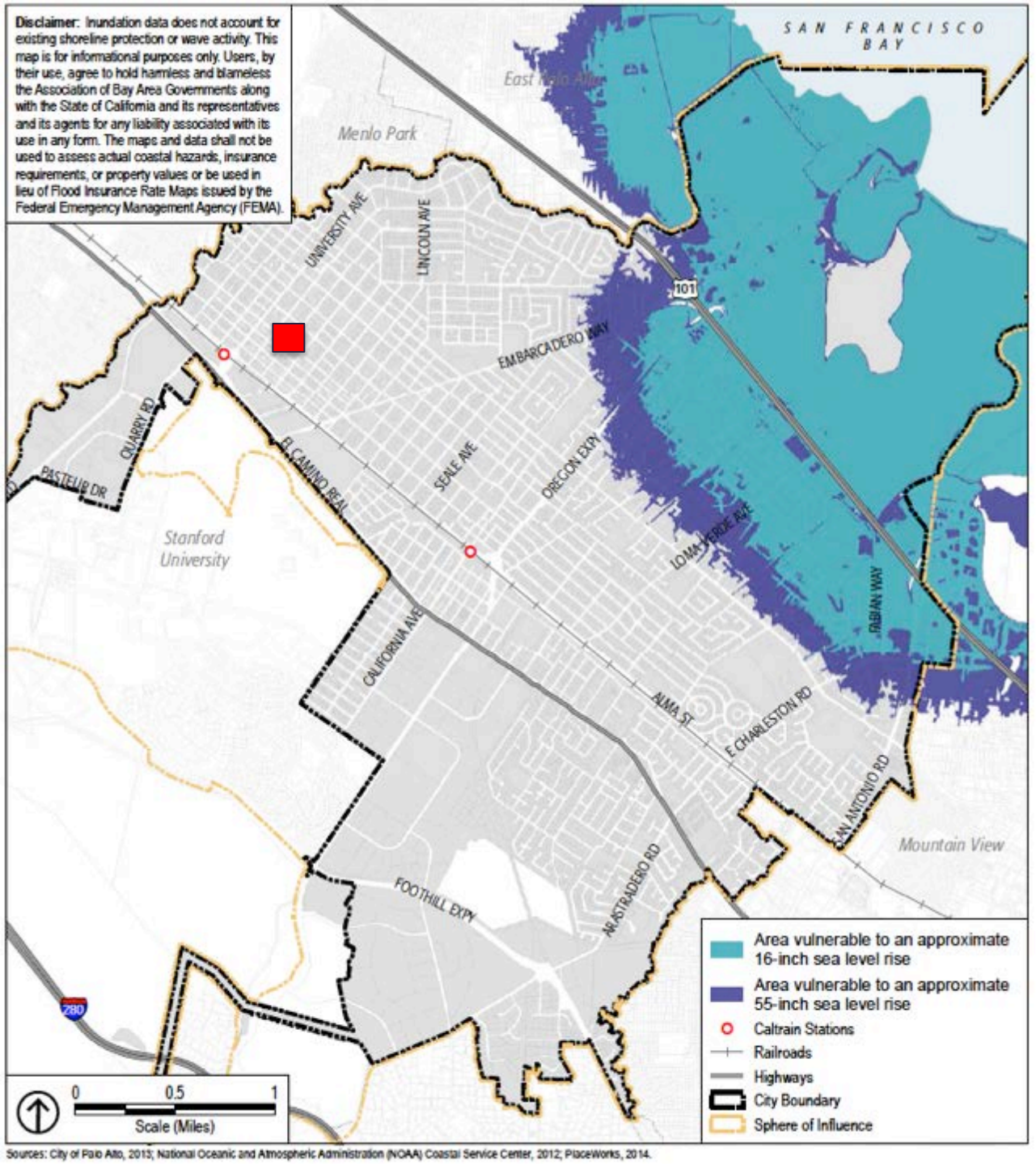
72
60
48
36
24
12
0

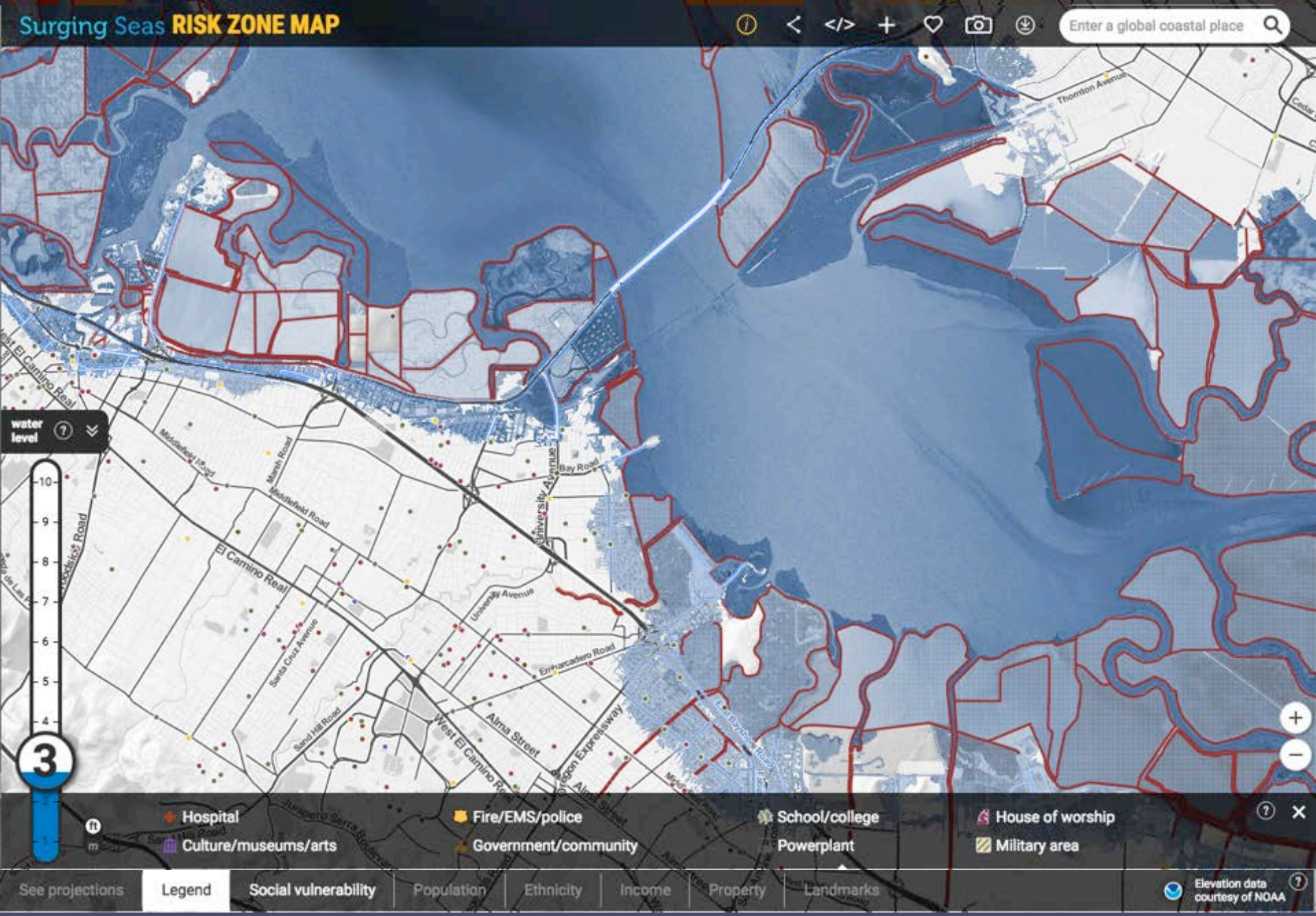
San Francisco International Airport and Oracle with a 16-inch rise in sea level.



Not an acceptable long-term solution

BCDC sea-level rise inundation map for city of Palo Alto




Surging Seas RISK ZONE MAP
Enter a global coastal place
water level
3
ft
m
Hospital
Fire/EMS/police
School/college
House of worship
Culture/museums/arts
Government/community
Powerplant
Military area
See projections
Legend
Social vulnerability
Population
Ethnicity
Income
Property
Landmarks
Elevation data courtesy of NOAA
El Camino Real
University Avenue
Bay Road
Middlefield Road
Marsh Road
Embarcadero Road
Alma Street
Sand Hill Road
Santa Cruz Avenue
Oregon Expressway
Thornton Avenue

Temporal Differences in Sea Level Change

LONG-TERM:LOW RATE OF CHANGE

- Ice melt and thermal expansion of ocean: mm/year but hundreds of feet over thousands of years
- Plate tectonics and changing volume of ocean basins: hundreds of feet over millions of years

SHORT-TERM:HIGH RATE OF CHANGE (California)

- Tsunamis: up to 20 feet or more over minutes
- Storm Surges: up to 3 feet over hours
- El Niño: 1-2 feet over months
- Tides: 8-12 feet over hours, including King Tides

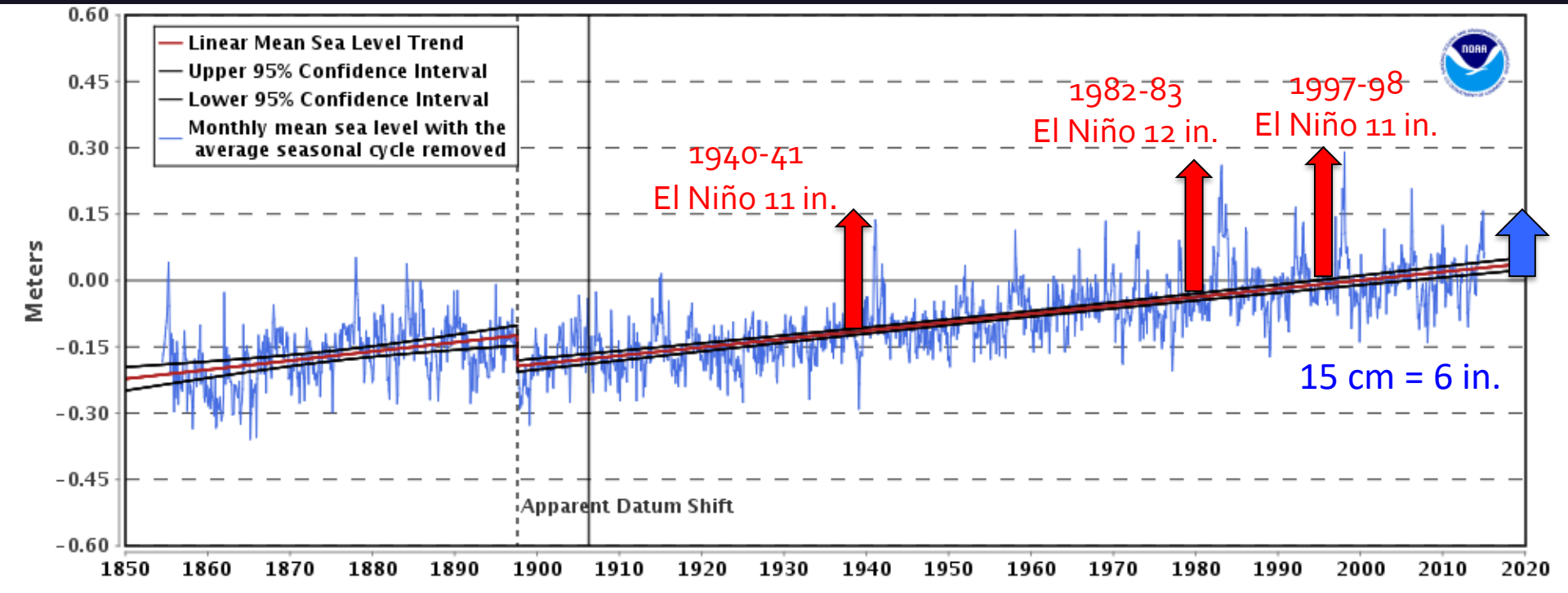
Sea level is rising and the bathtub is slowly overflowing, but….

The extreme events are going to be of greater concern in the near term

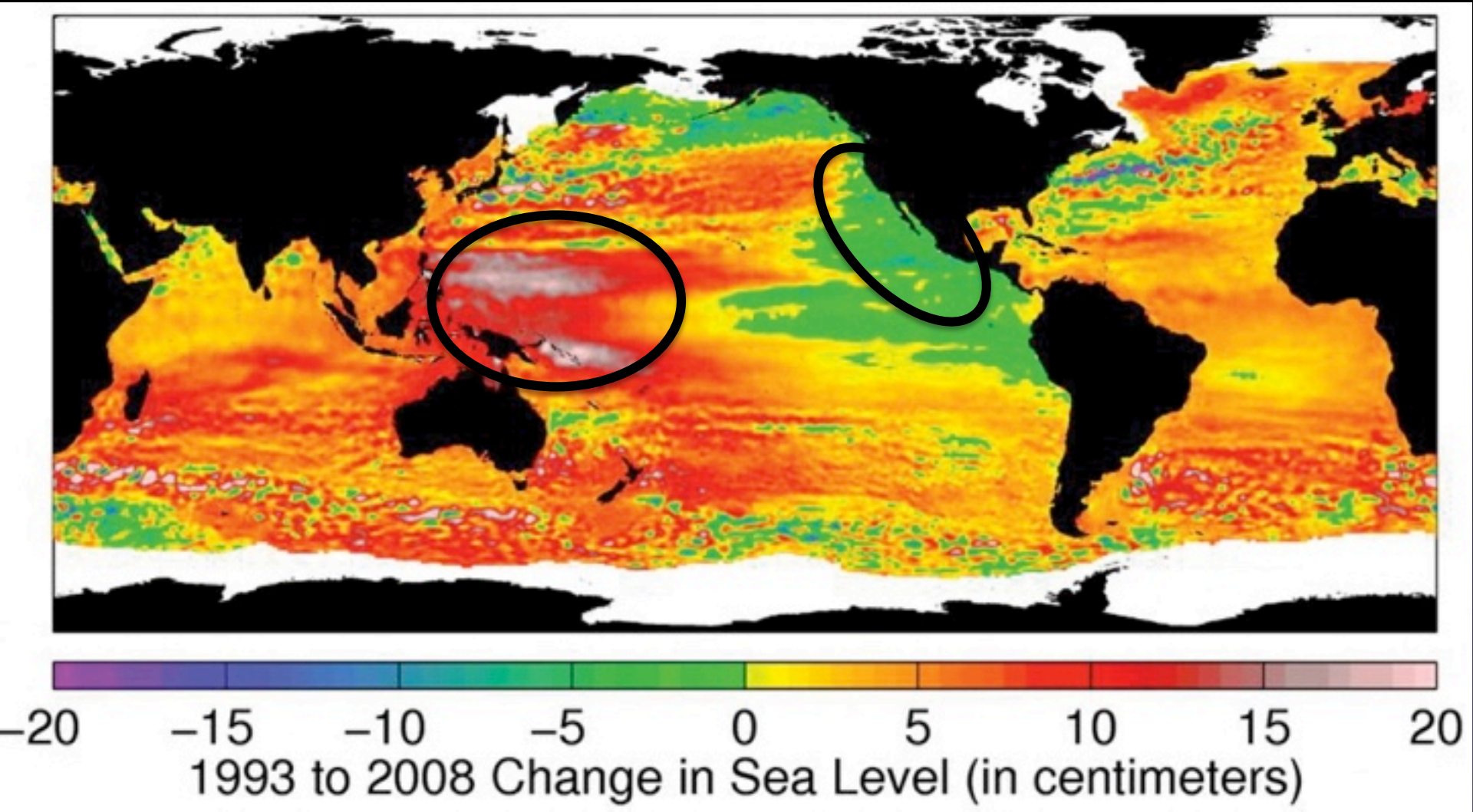
California Recent Sea-Level Rise

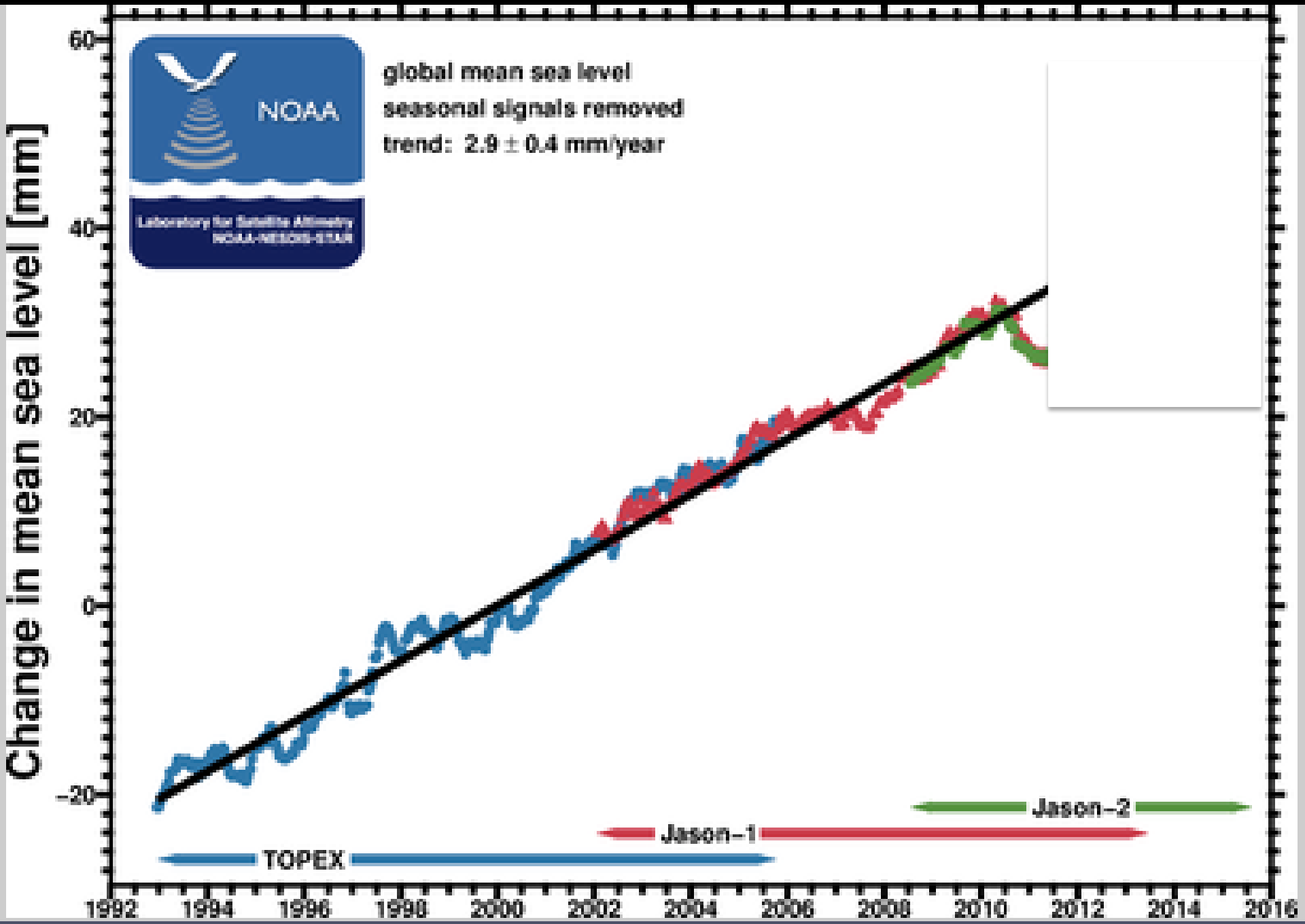
Short-term events have had greater impacts than sea-level rise over the past century, and this will likely continue until at least 2050, except perhaps in very low lying areas.

SAN FRANCISCO: 1.9 mm/yr. (7.4”/100 years)



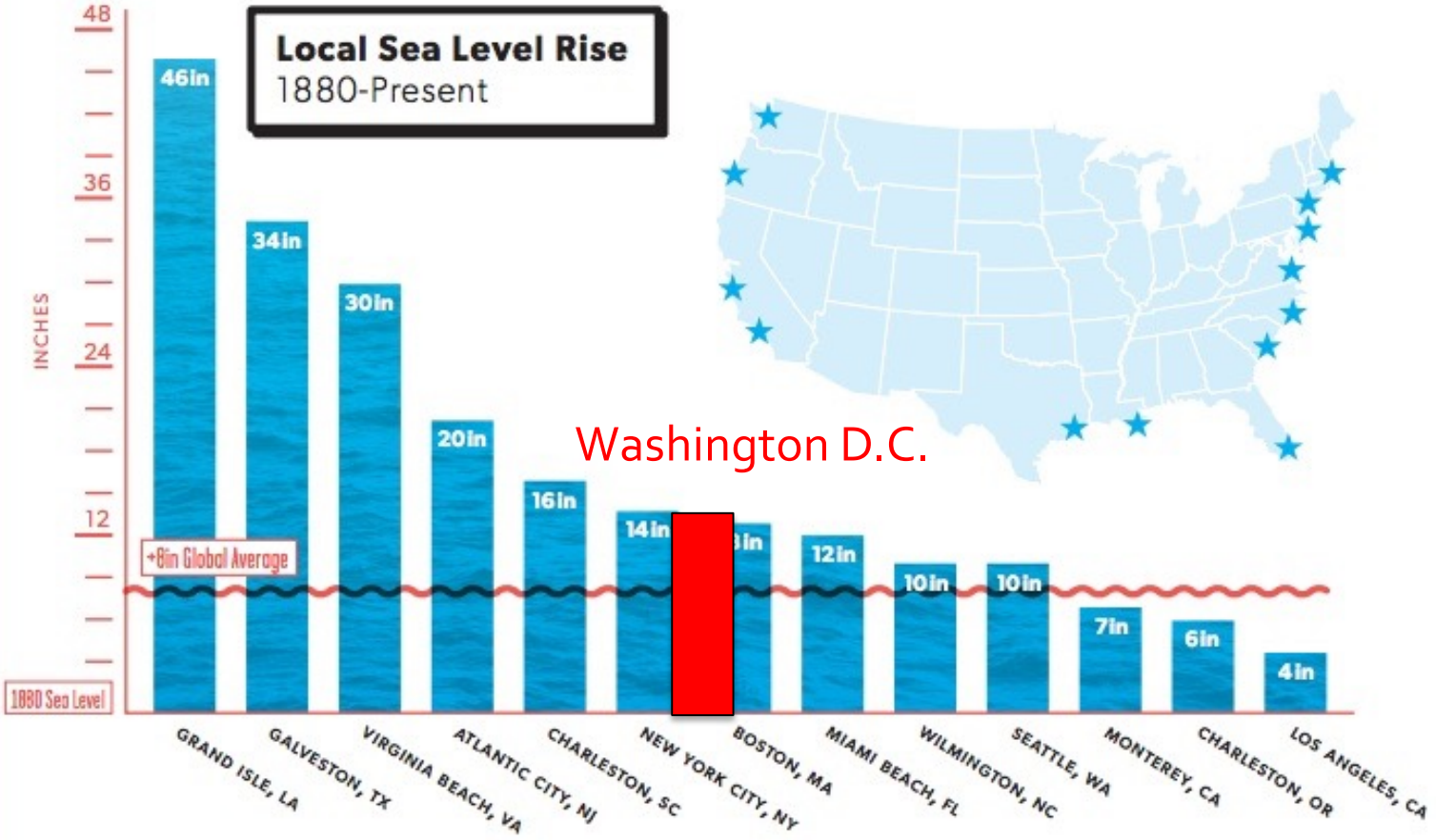
A nearly 20 year hiatus in sea-level rise along the west coast…




NOAA
Laboratory for Satellite Altimetry
NOAA-NESDIS-STAR
global mean sea level
seasonal signals removed
trend: 2.9 ± 0.4 mm/year
Change in mean sea level [mm]
60
40
20
0
-20
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
TOPEX
Jason-1
Jason-2

FACT 1

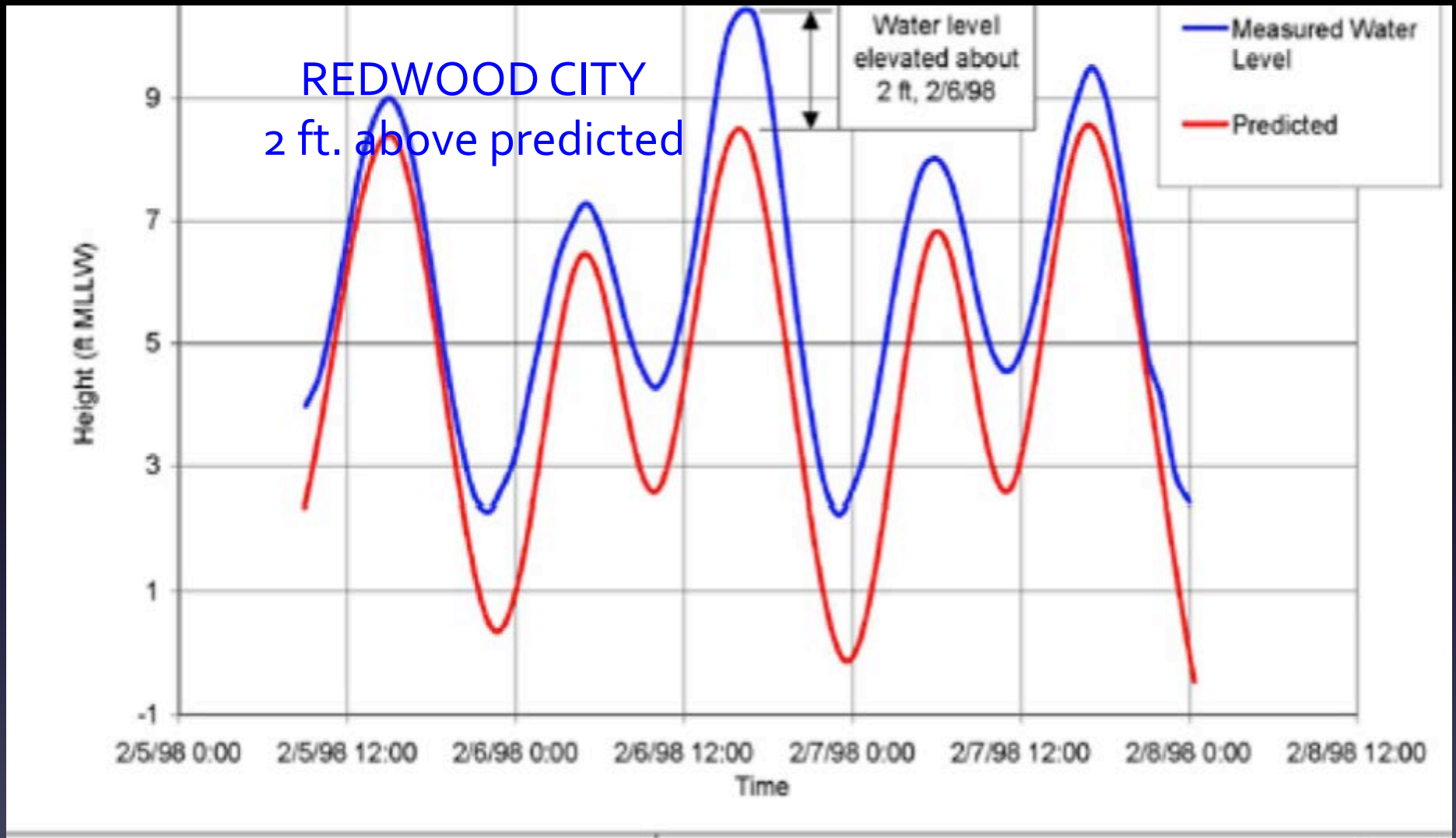
Global average sea level has increased 8 inches since 1880. Sea levels along the U.S. East Coast and Gulf of Mexico are rising much faster.



The rate of local sea level rise varies depending on both global and local factors, including currents, ocean floor topography, variations in ocean density, and land uplift or subsidence due to geological reasons or human activities.

Short-Term Impacts of High Tides and Large Storm Waves
Mission Beach, San Diego- 1988

El Niño 1997-98-Elevated Water Levels



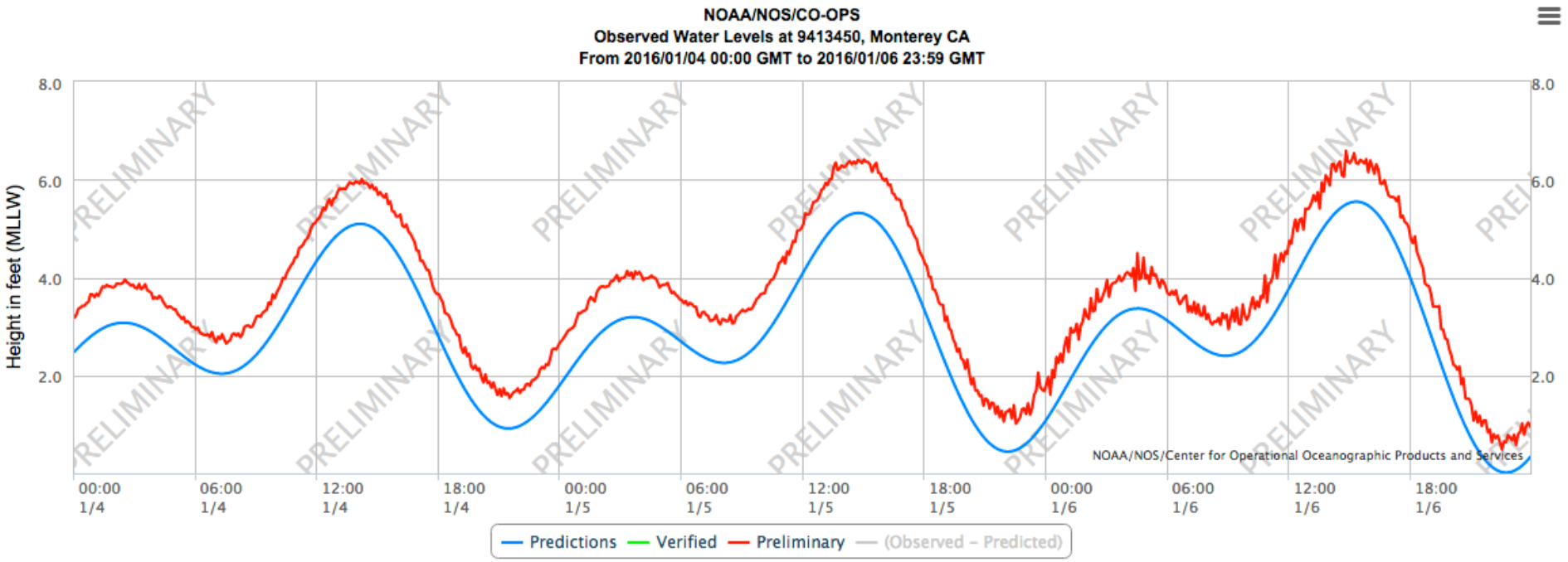
Source: CO-OPS Verified Hourly Height Water Level

figure 3

South Bay Salt Ponds Restoration Projec

Predicted and Measured Tidal Elevations at Redwood City, CA

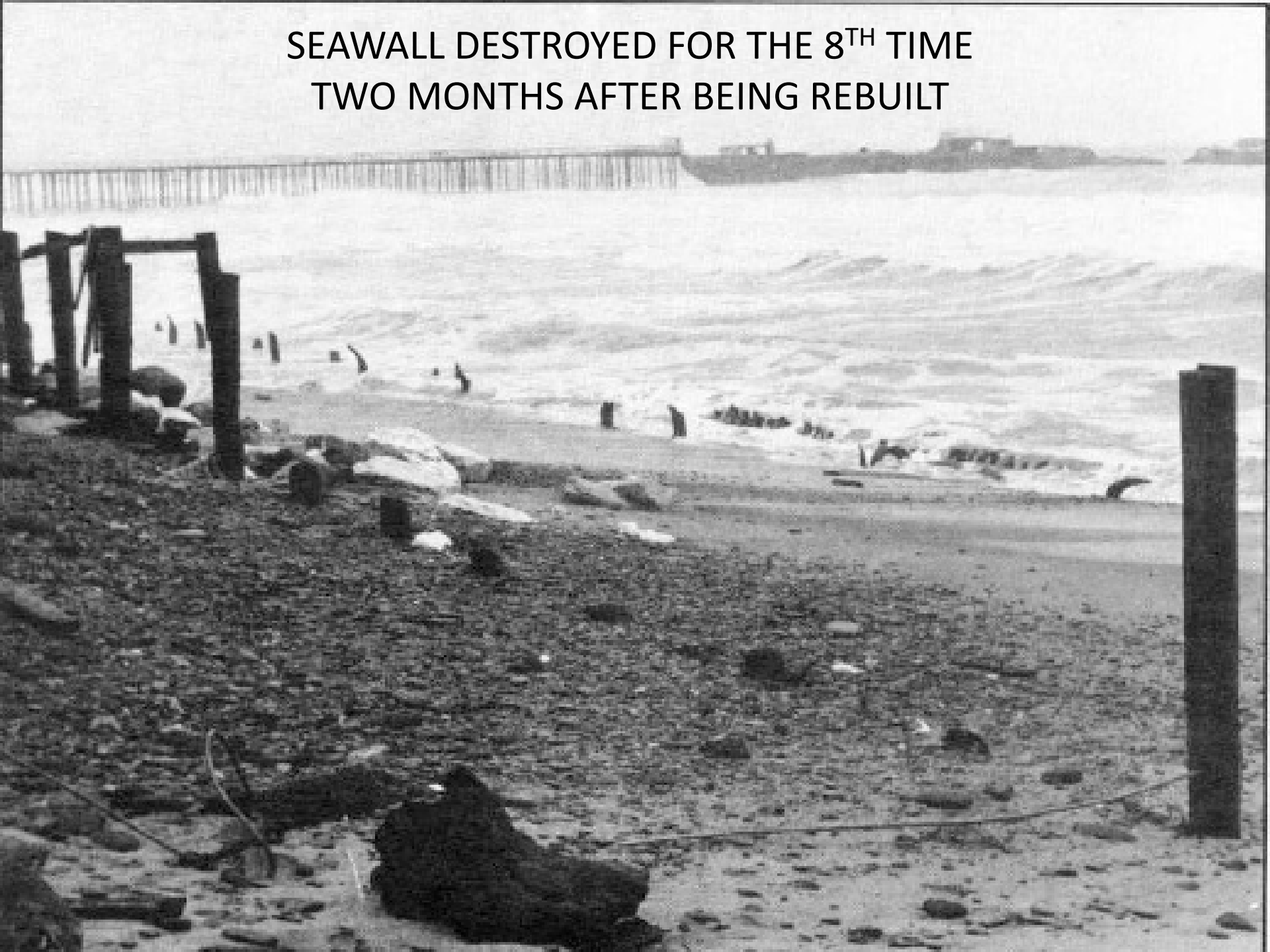
MONTEREY
JANUARY 4-6, 2016



Seacliff State Beach- Santa Cruz County

Seacliff State Beach- El Niño Winter 1983

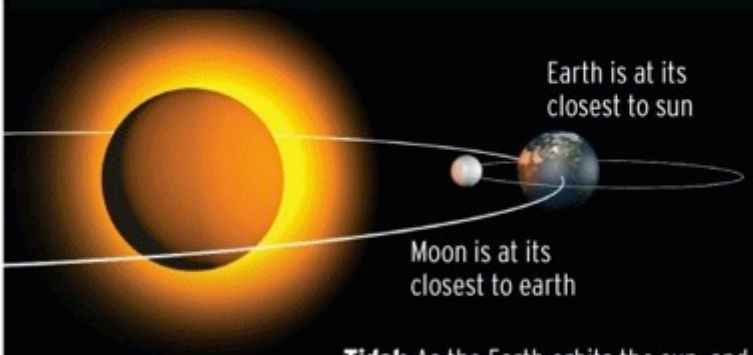
SEAWALL DESTROYED FOR THE 8TH TIME
TWO MONTHS AFTER BEING REBUILT



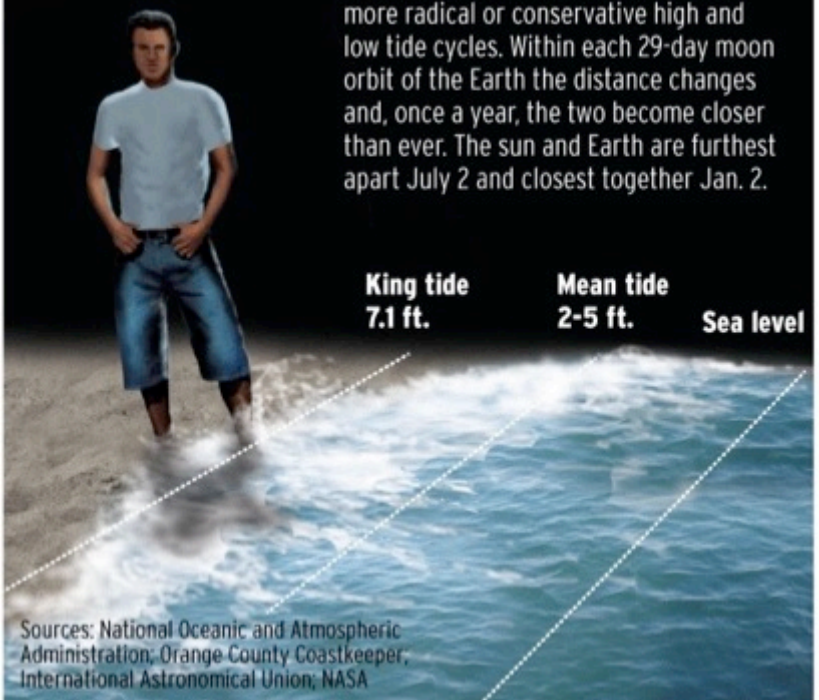
TIDES

King of the tides

Once or twice a year, coasts are visited by king tides: higher high tides and lower low tides than normal. The royal visit happens when the Earth is closest to the moon or sun, or as in today's case, both celestial bodies.



Tidal: As the Earth orbits the sun, and as the moon orbits the Earth, the distance between the objects changes. This change, however slight, translates into more or less gravitational pull and thus, more radical or conservative high and low tide cycles. Within each 29-day moon orbit of the Earth the distance changes and, once a year, the two become closer than ever. The sun and Earth are furthest apart July 2 and closest together Jan. 2.



Sources: National Oceanic and Atmospheric Administration, Orange County Coastkeeper, International Astronomical Union, NASA

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

Sequoia Yacht Club- Redwood City December 31, 2013

King Tide 2012
The Embarcadero
San Francisco

Mill Valley, Marin County King Tide December 12, 2012

IMPACTS OF SHORT (AND LONG) TERM SEA-LEVEL RISE


Twin Lakes-Flooded Roadways


Capitola-Flooded park facilities


Aptos Seascape-
Damaged oceanfront homes


Pacifica-Cliff retreat

Cor tions

wave run-up

wave set-up

storm surge

seasonal effects

tide difference

sea level rise

in height towards
ne (shoaling)

MSL (datum)

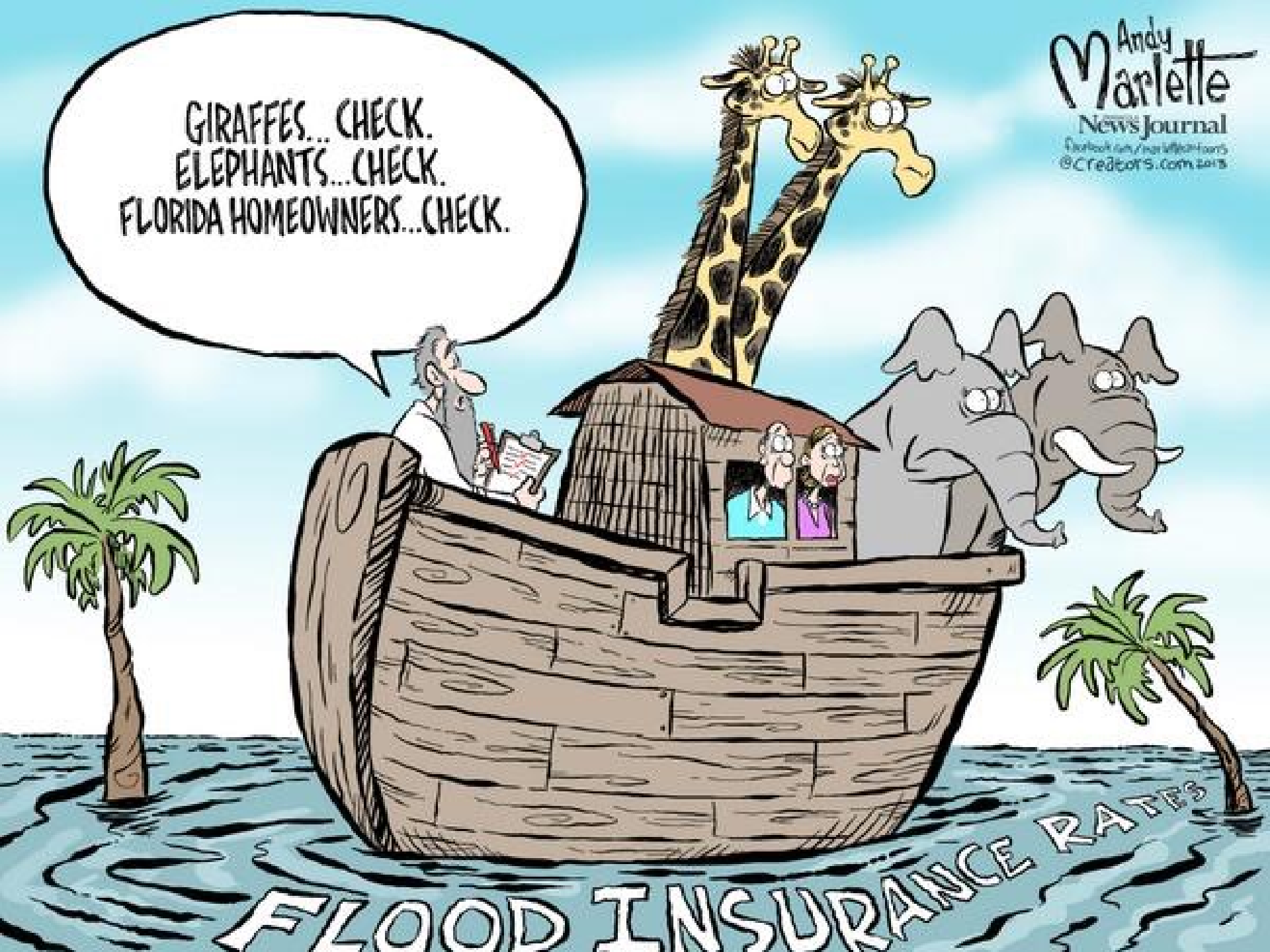
beach slope $\tan\beta$

storm

USGS

VENICE HAS BEEN DEALING WITH HIGH WATER FOR YEARS

MIAMI DURING HURRICANES HAS HIGH WATER


GIRAFFES... CHECK.
ELEPHANTS...CHECK.
FLORIDA HOMEOWNERS...CHECK.
Andy Marlette
News Journal
@Creators.com 2013
FLOOD INSURANCE RATES

NEW ORLEANS AND KATRINA

NEW YORK AND NEW JERSEY AND SUPERSTORM SANDY

What Next? Options for the future

ADAPTATION OR RESPONSES TO SEA-LEVEL RISE AND EXTREME EVENTS

1. IGNORE SEA-LEVEL RISE
2. BUILD FLOATING CITIES
3. BUILD BARRIERS: SEAWALLS
4. PLAN FOR MANAGED RETREAT

We need to inventory those coastal areas that are subject to short and long-term sea-level rise, assess vulnerabilities and risks, and develop responses.

Which of these future projections should we be using?

What is the sea-level rise rate from closest tide gauge?

What is the cost or value of the proposed project or infrastructure?

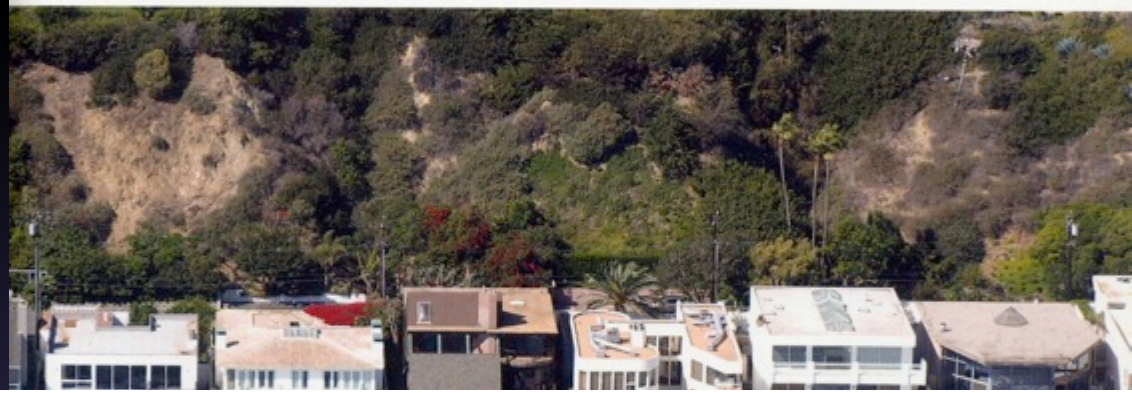
What is the lifespan of the proposed project or infrastructure?

What is the impact of damage to or loss of facility or infrastructure?

RESPONDING/ADAPTING TO SEA-LEVEL RISE

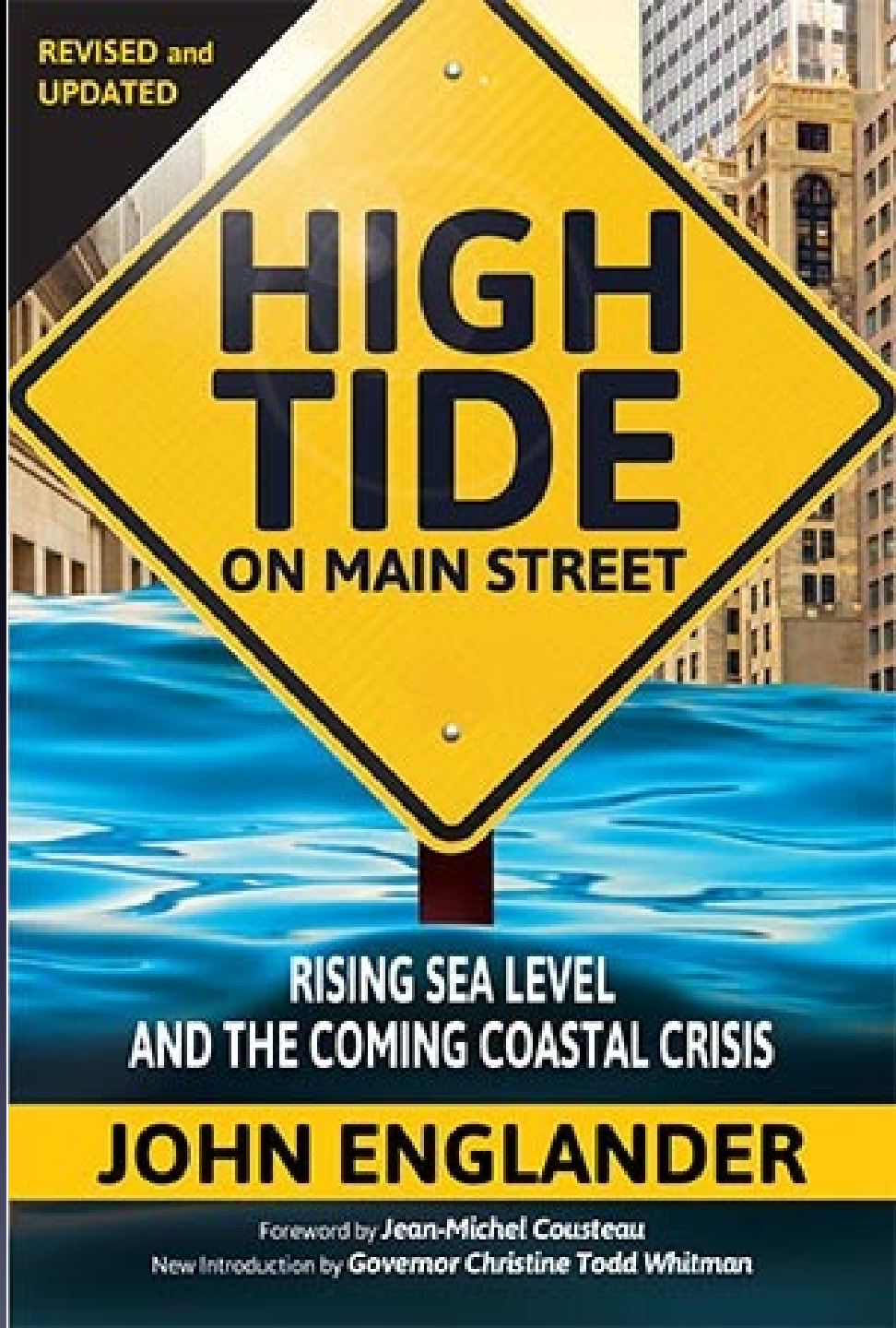
Adapting to Sea Level Rise:
A Guide for California's Coastal Communities

Nicole Russell
Gary Griggs
University of California Santa Cruz

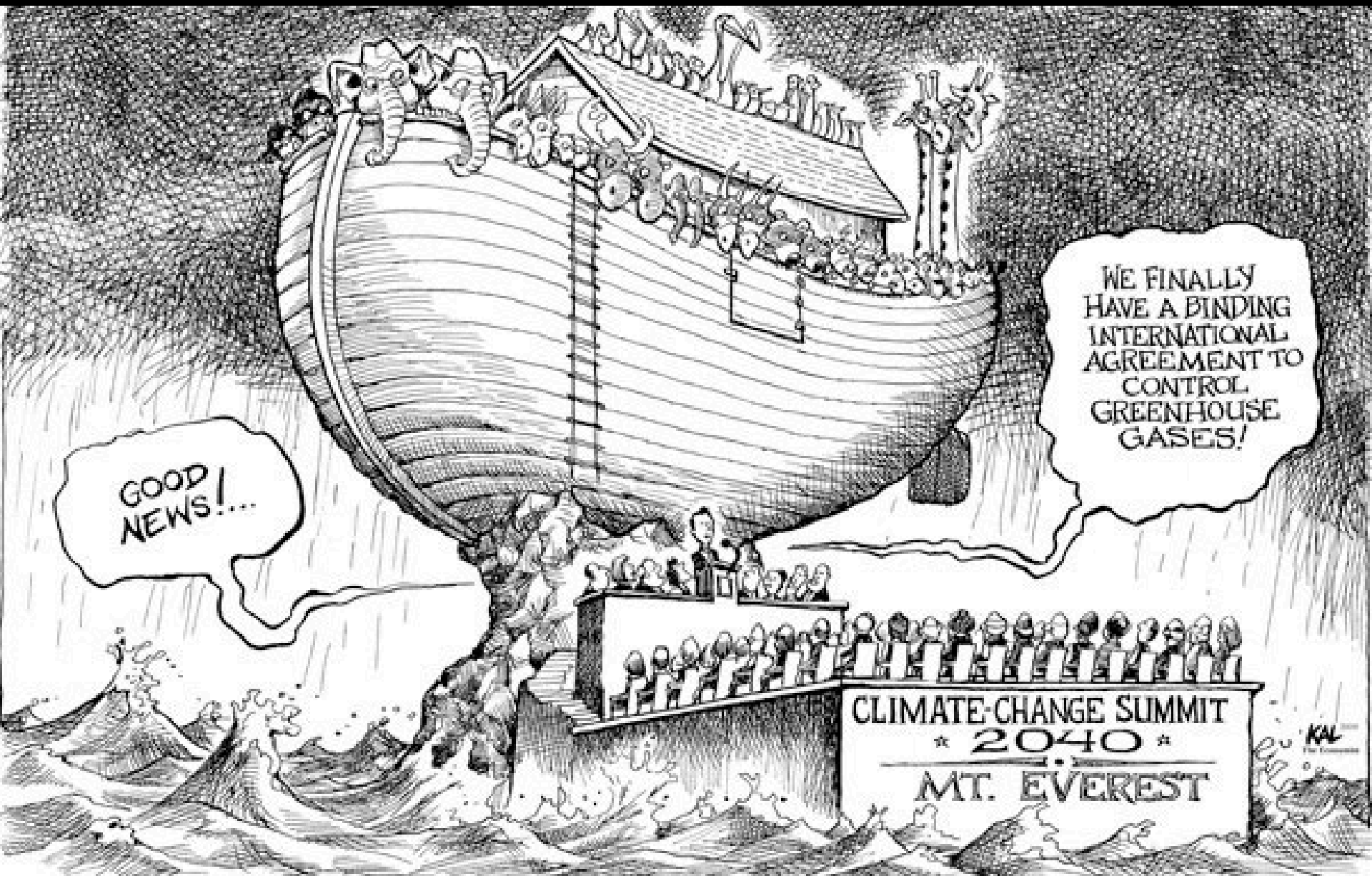


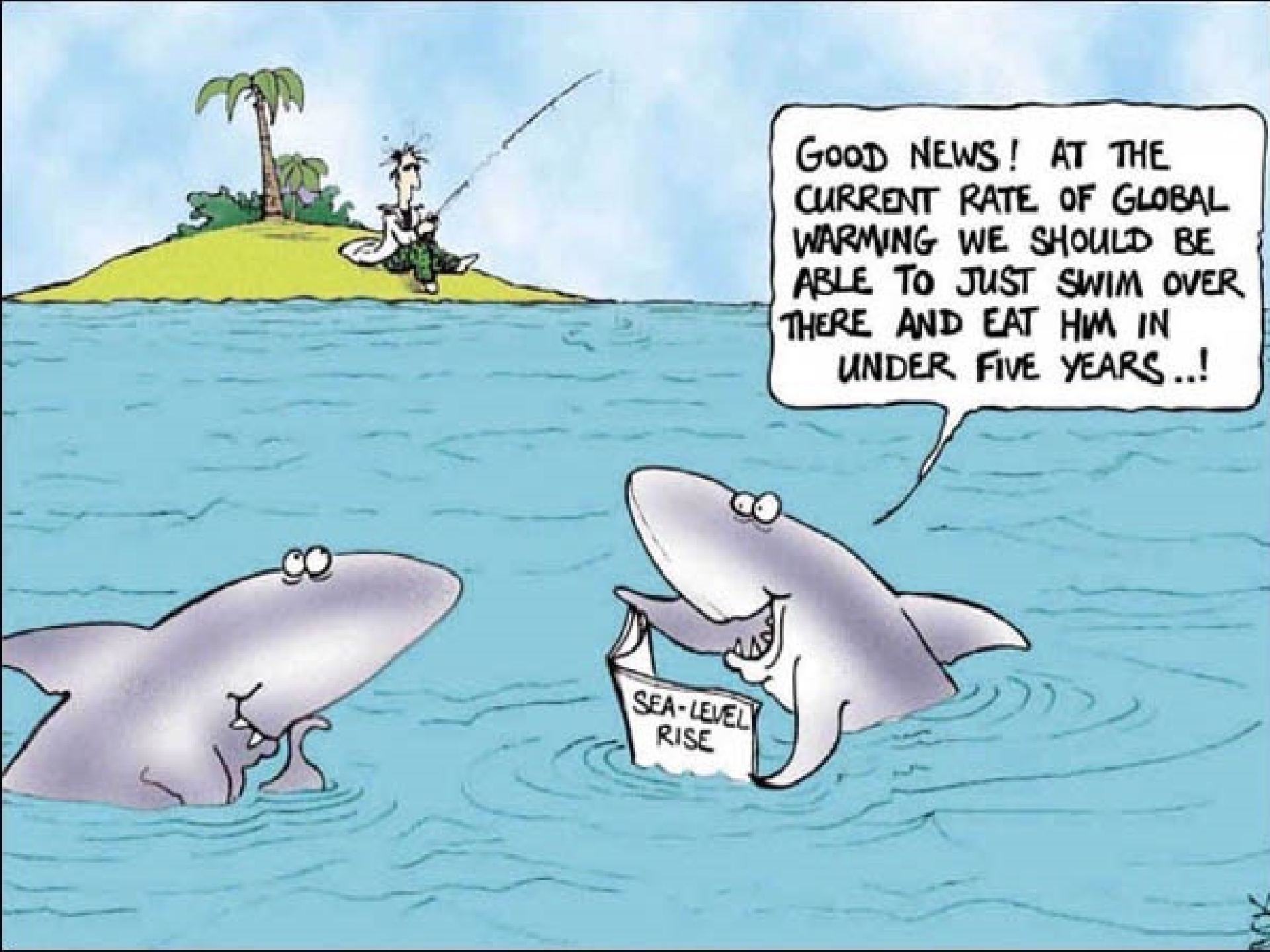
We have exactly enough time if we start now.

It's real.
It's us.
It's bad.
Scientists agree.
There's hope.



POST-PARIS CLIMATE CHANGE SUMMIT




GOOD NEWS! AT THE CURRENT RATE OF GLOBAL WARMING WE SHOULD BE ABLE TO JUST SWIM OVER THERE AND EAT HIM IN UNDER FIVE YEARS..!
SEA-LEVEL RISE