Climate Change, Sea-Level Rise, and the California Coast

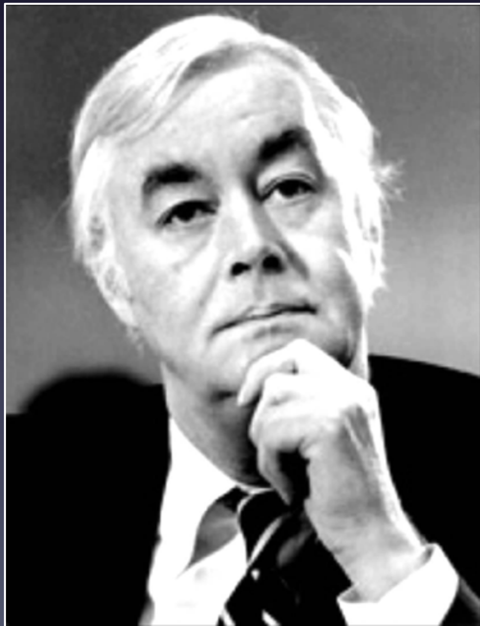
Gary Griggs
Distinguished Professor of Earth and Planetary Sciences
University of California Santa Cruz

“The good think about science is that it’s true, whether or not you believe it”.

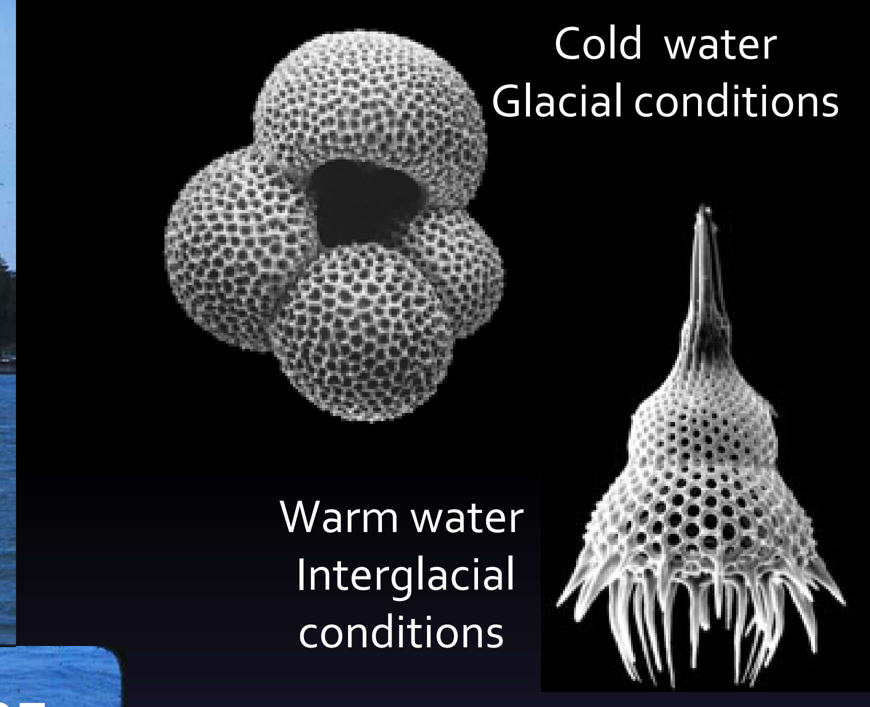
Neil deGrasse Tyson-Astrophysicist & Science Communicator

“Everyone is entitled to their own opinion, but not their own facts”.

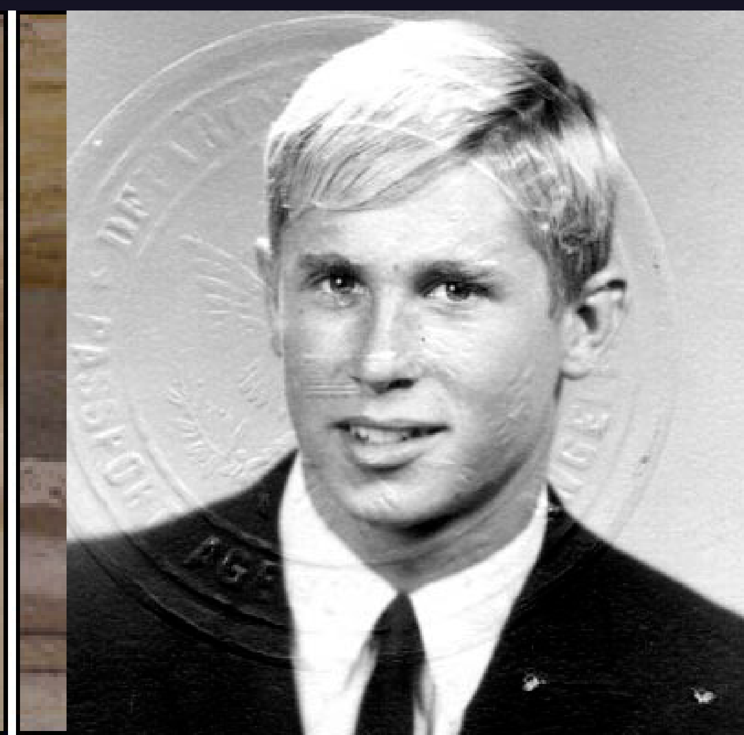
Daniel Patrick Moynihan – 4-Term United States Senator from New York



52 Years ago in the North Pacific

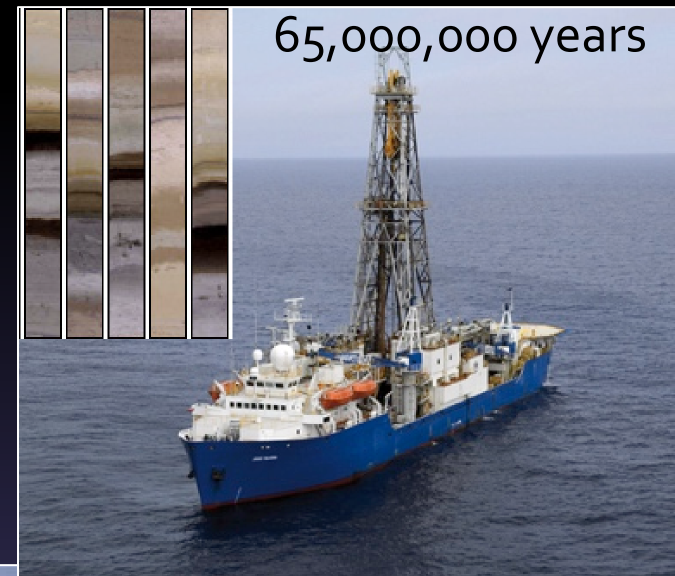

Cold water
Glacial conditions
Warm water
Interglacial
conditions

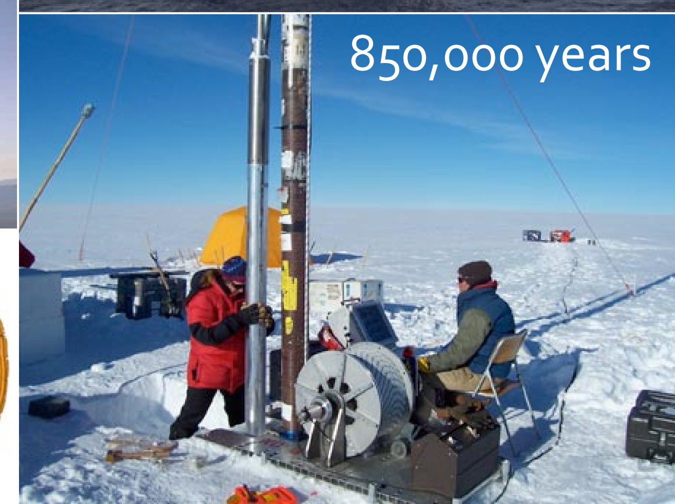

1965



Climate changes have been recorded in:

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



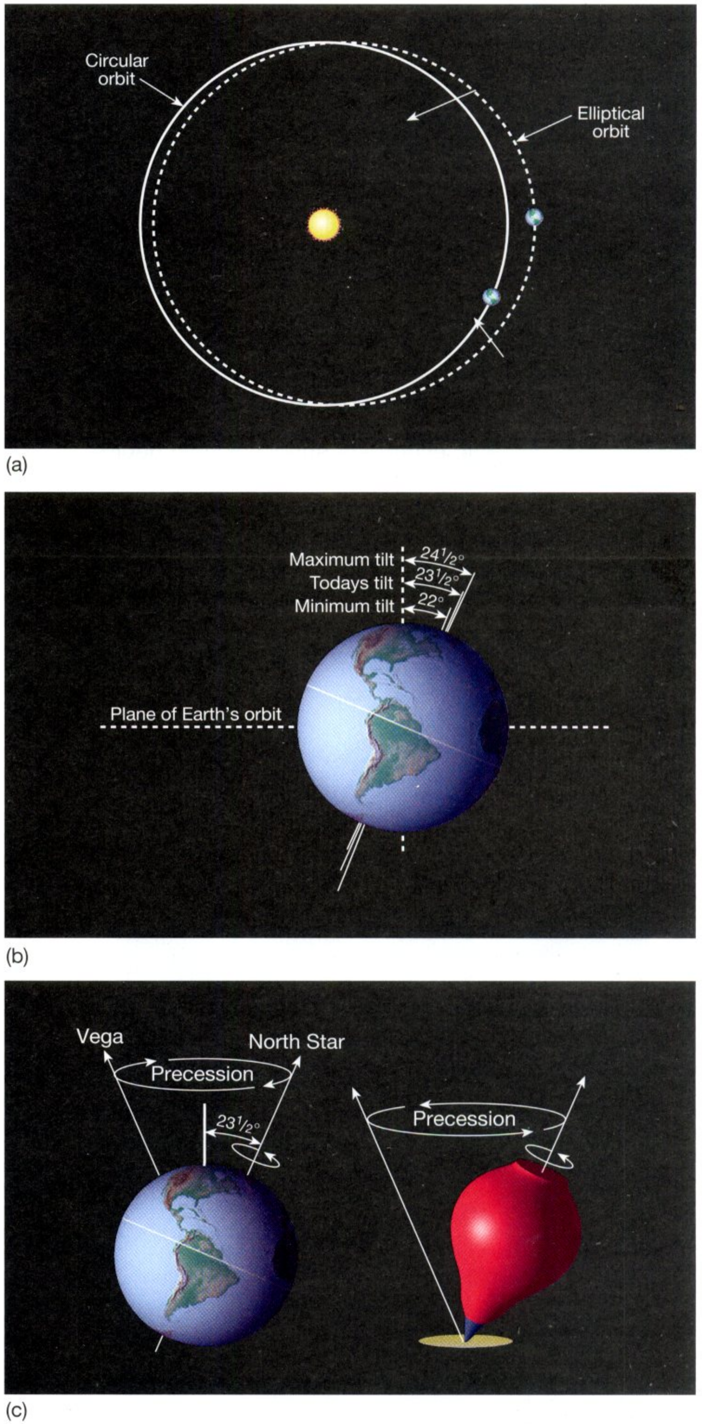


A MASSIVE IMPACT 4.4 BILLION YEARS AGO

That impact 4.4 billion years ago, created variations in the Earth's rotation and orbit around the Sun and played a major role in causing past climate change, ice ages, and sea level oscillations.

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



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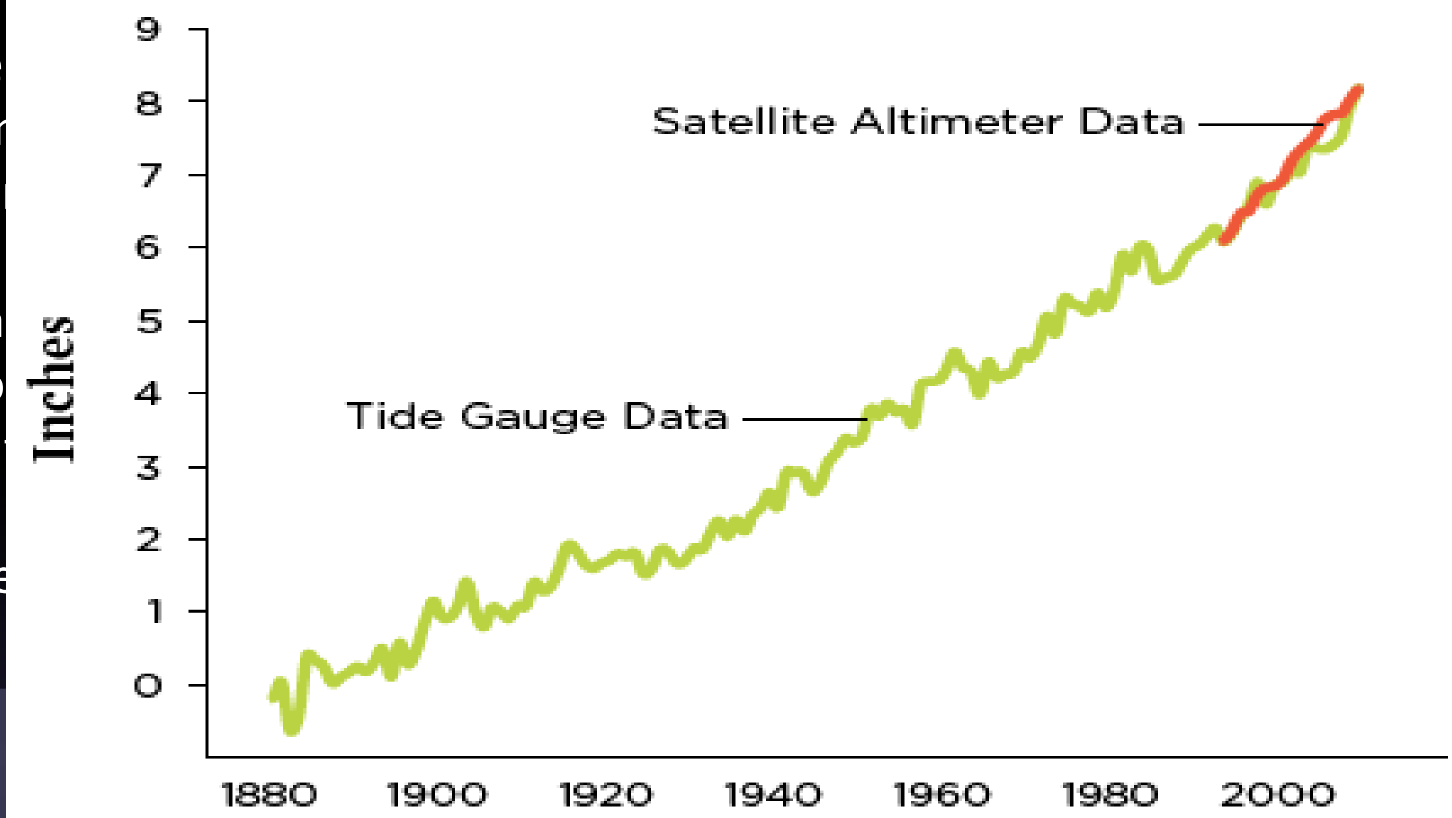
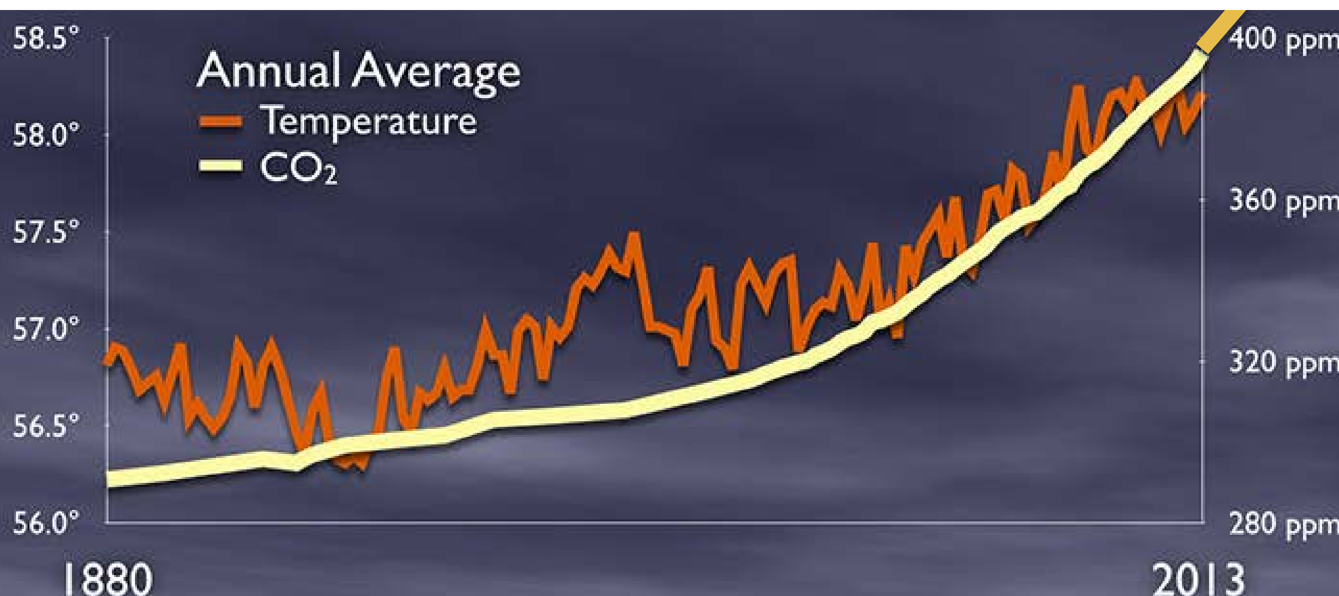
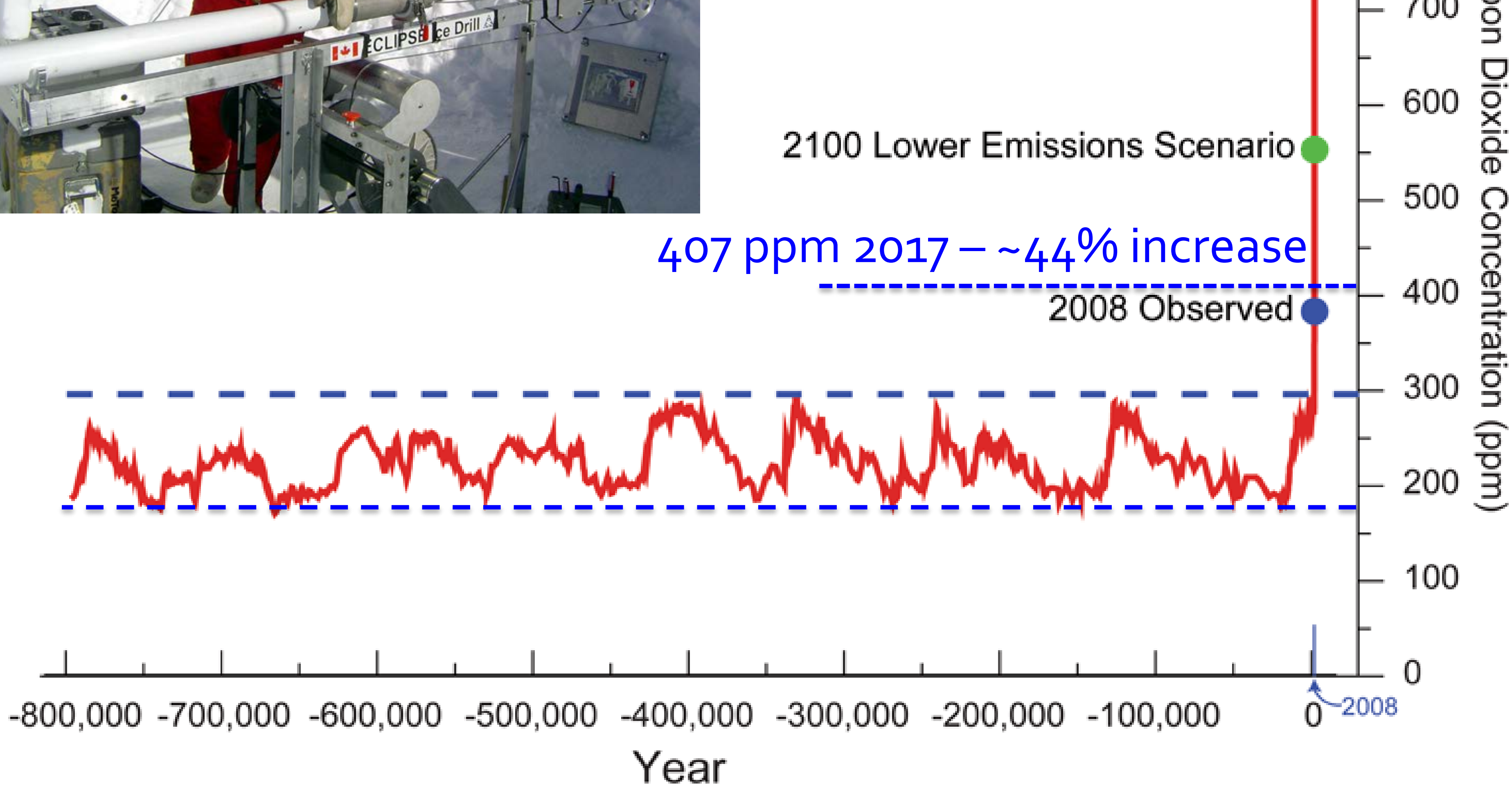
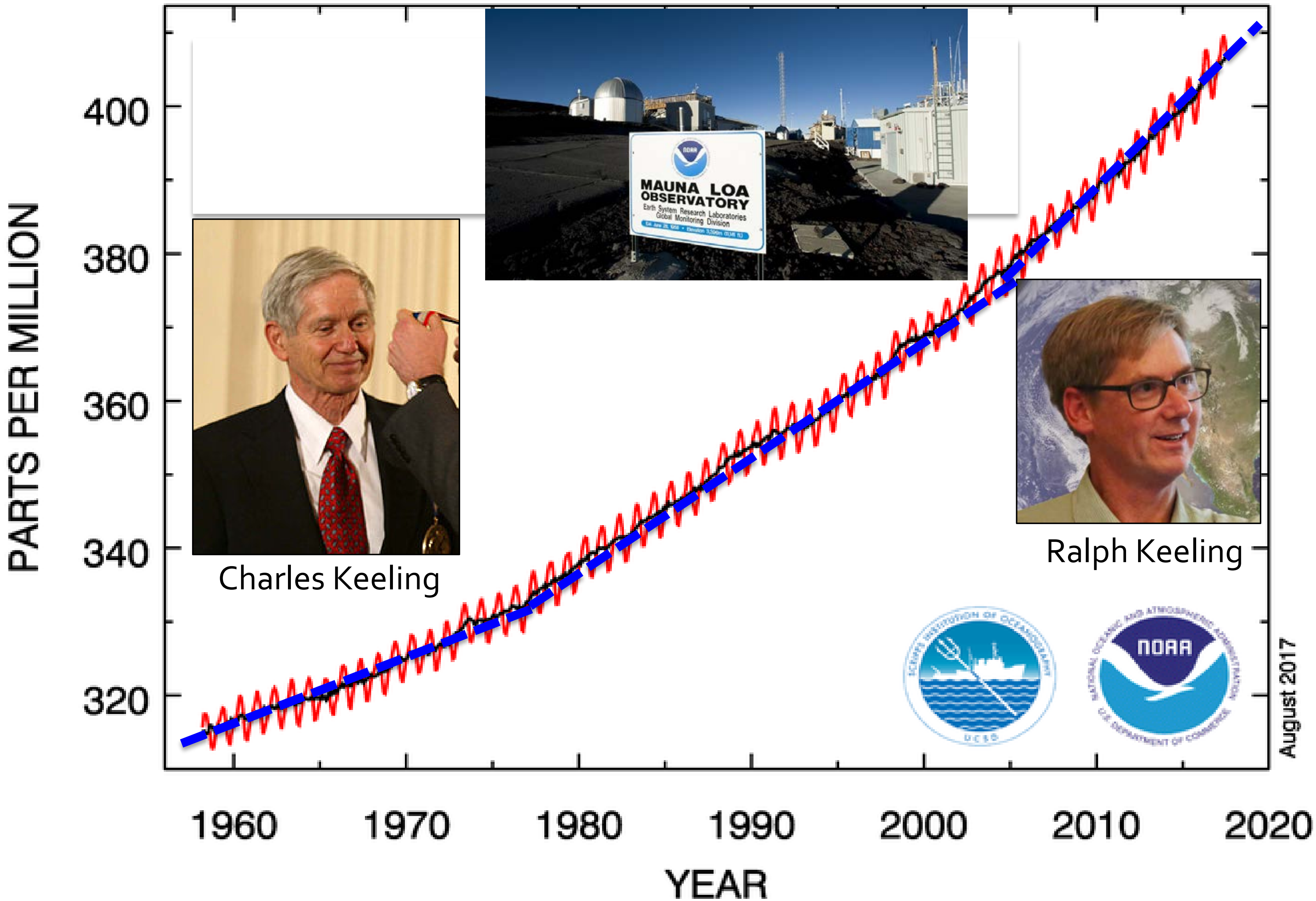


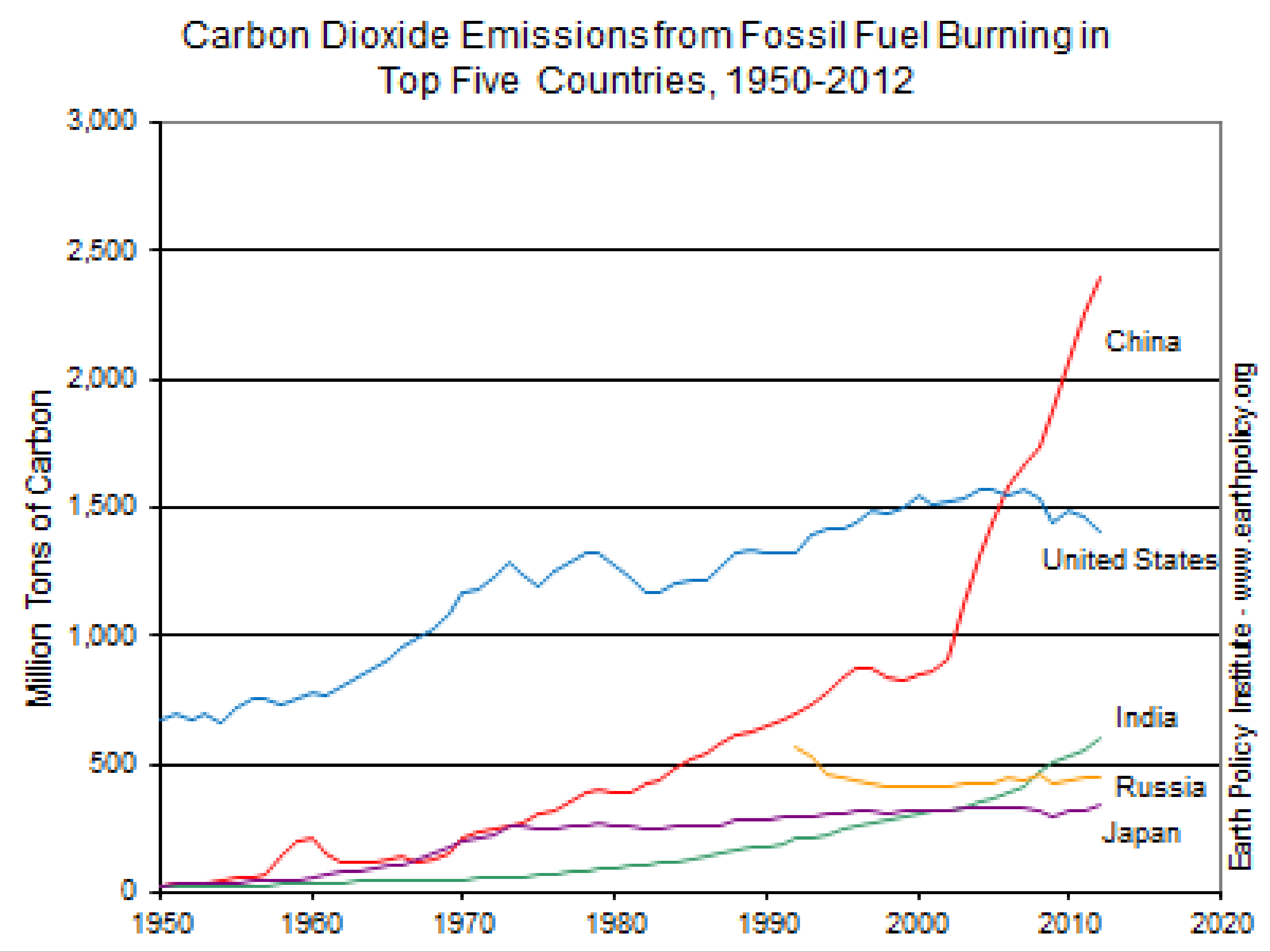


Carbon Dioxide and Climate- Antarctic ice cores 11,500 feet deep extend back 850,000 years



Atmospheric CO_2 at Mauna Loa Observatory





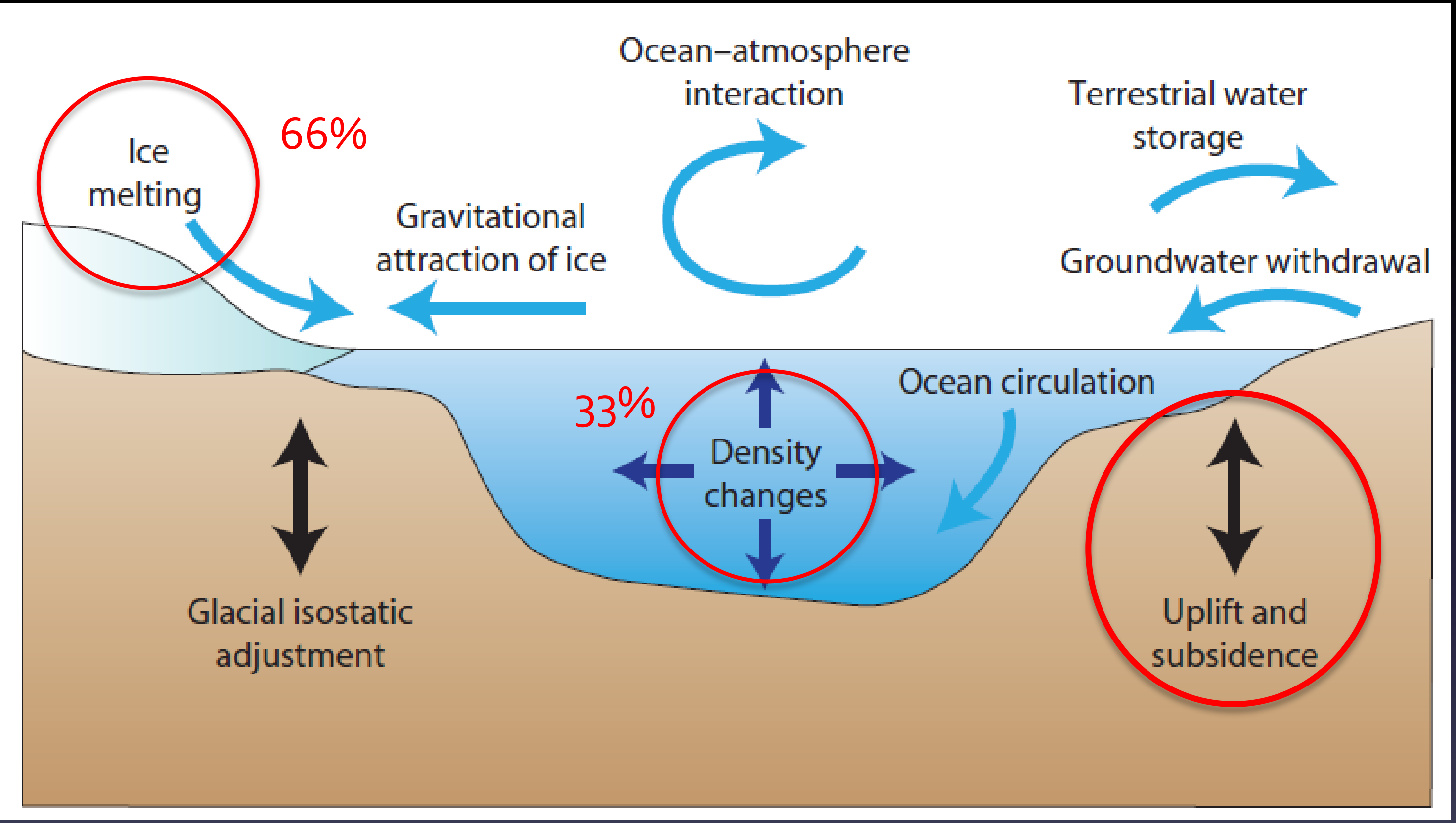
Carbon Dioxide Emissions from Fossil Fuel Burning in Top Five Countries, 1950-2012
Million Tons of Carbon
3,000
2,500
2,000
1,500
1,000
500
0
1950
1960
1970
1980
1990
2000
2010
2020
China
United States
India
Russia
Japan
Earth Policy Institute - www.earthpolicy.org

Where humanity's CO2 comes from
91% 33.4 billion metric tonnes
photo credit: Kodda
Fossil Fuels & Cement 2010
9% 3.3 billion metric tonnes
Land Use Change 2010
Where humanity's CO2 goes
44% 18.4 billion metric tonnes
photo credit: Gregory Heath
Atmosphere 2010
30% 9.5 billion metric tonnes
photo credit: H.-D. Viktor Boehm
Land 2010
26% 8.8 billion metric tonnes
1 million tons/hour
photo credit: BAS
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.

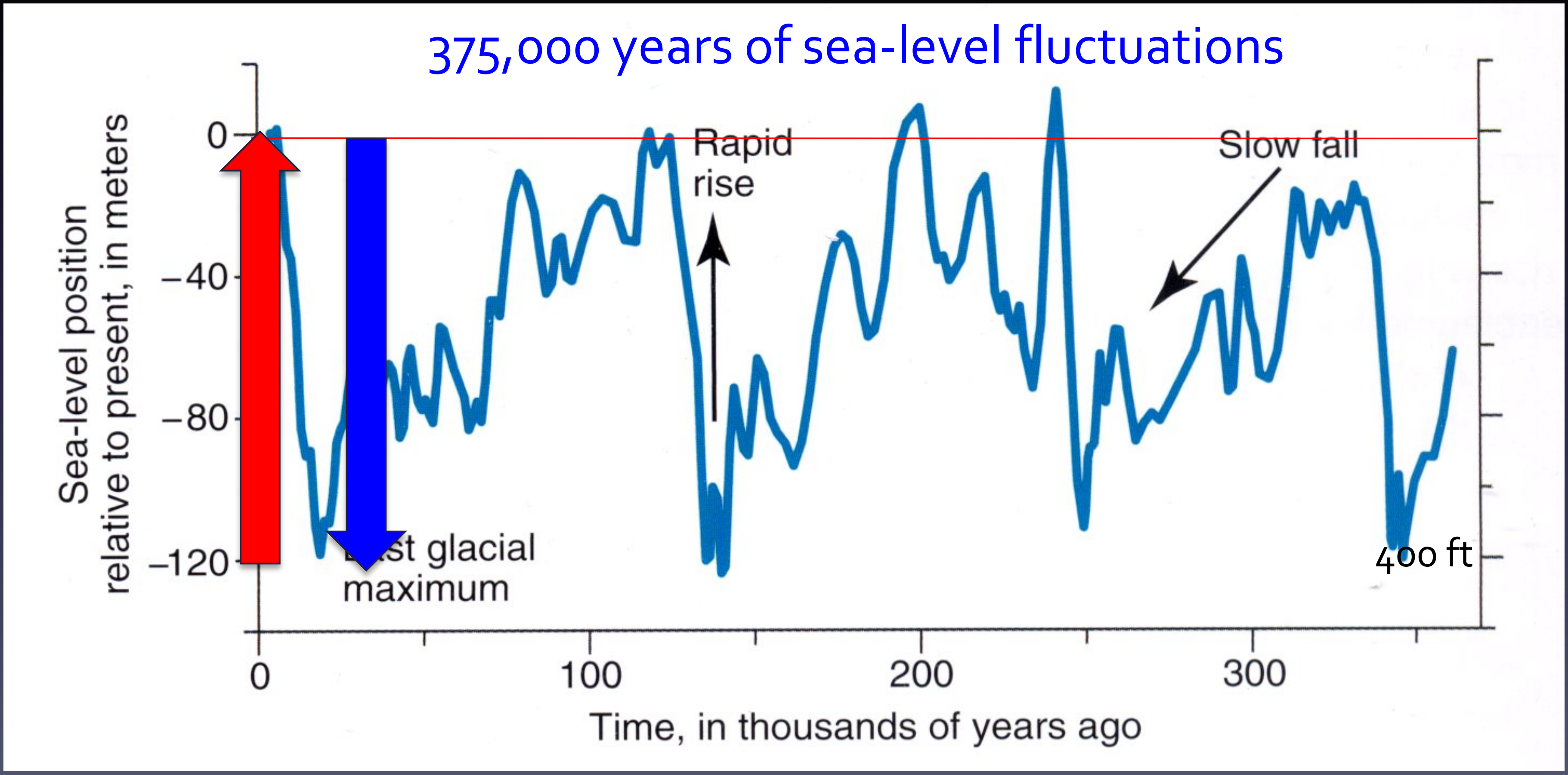
A warming planet drives sea-level rise.

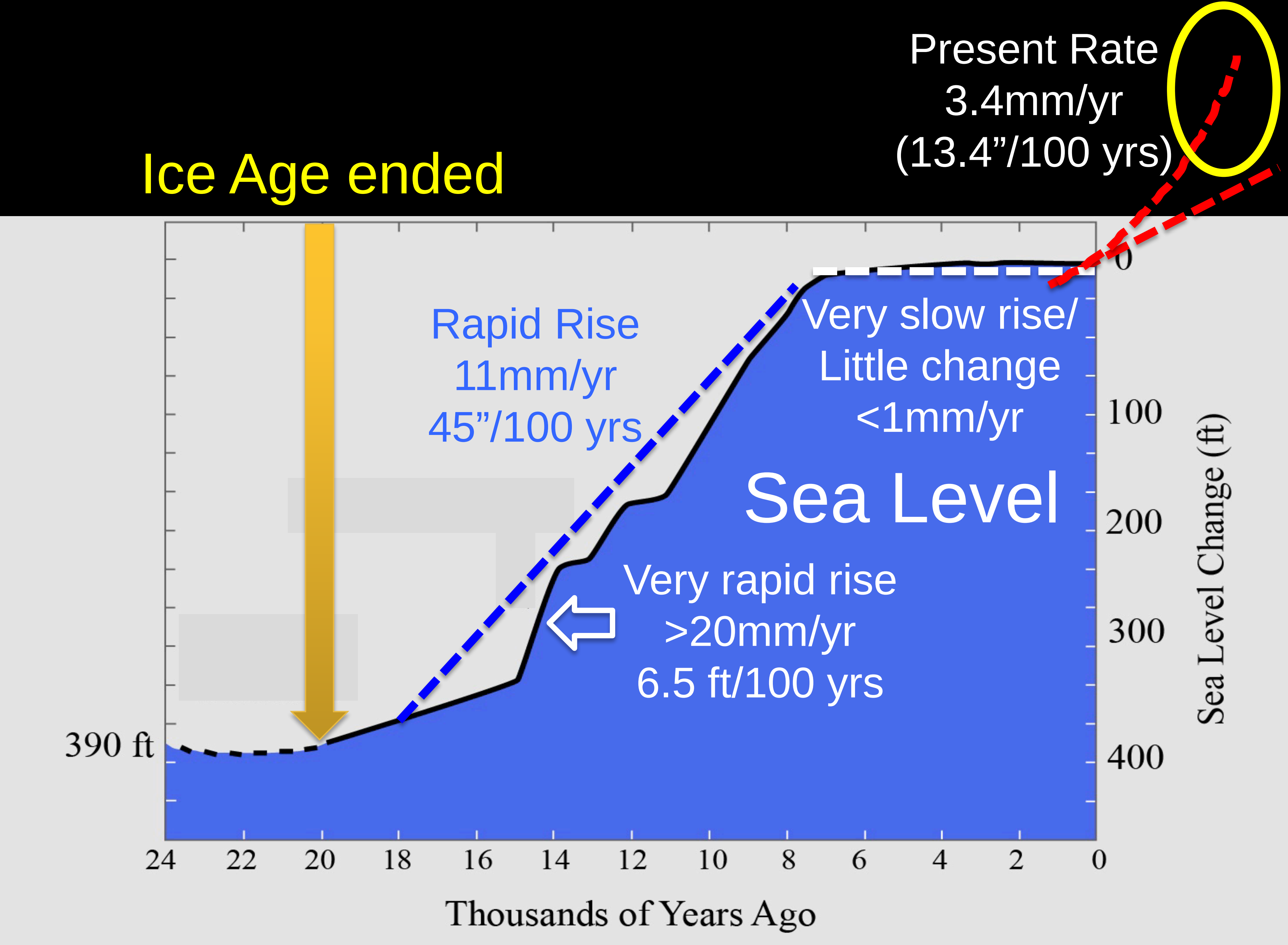


Sea-level rise at a particular place can be higher or lower than the global mean due to regional effects

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

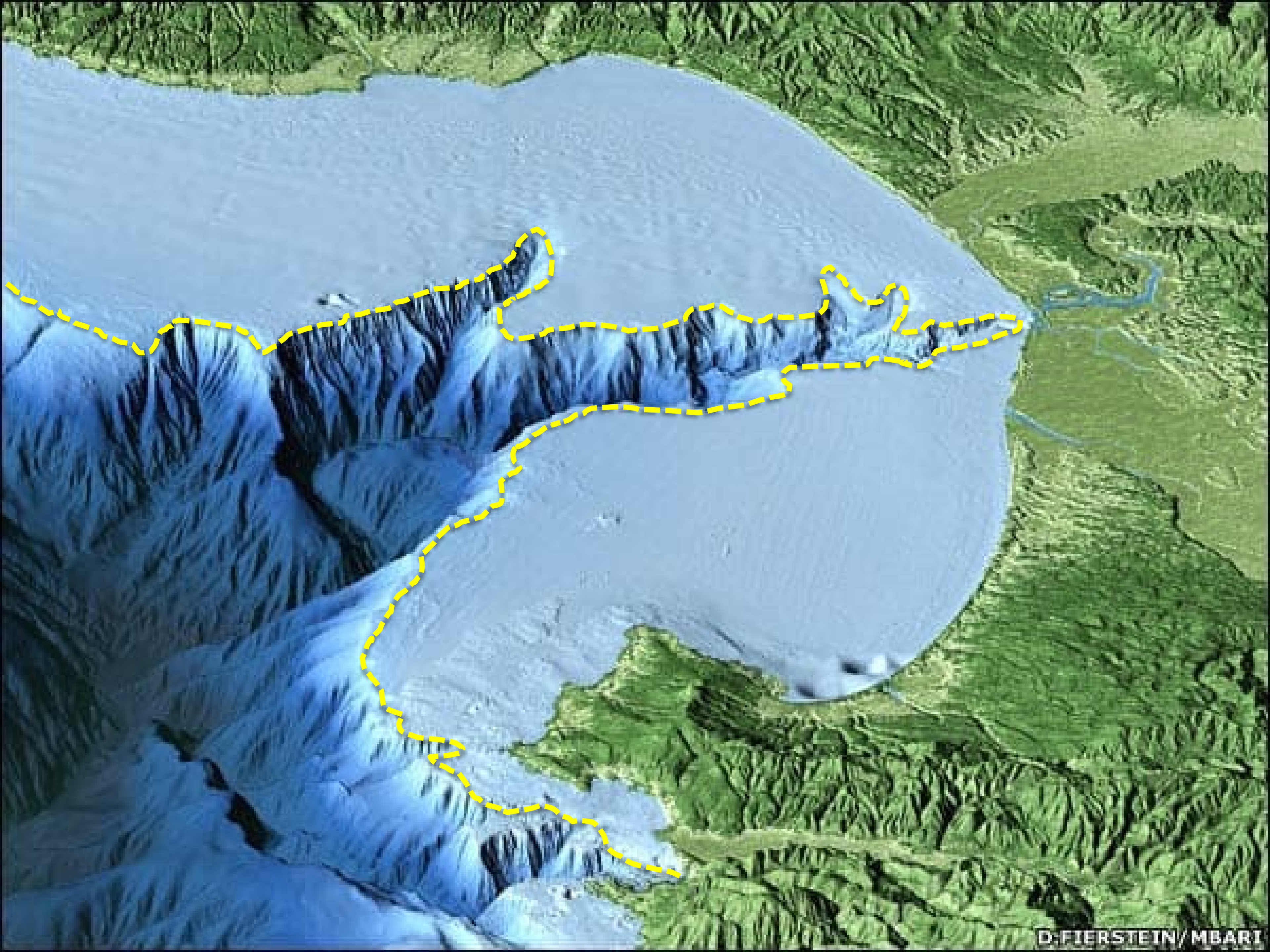
20,000 years ago, ~3% of the ocean's water, some 10 million cubic miles, was transferred to the continents as ice. Sea level dropped about 400 feet (125 meters) and then rose again.



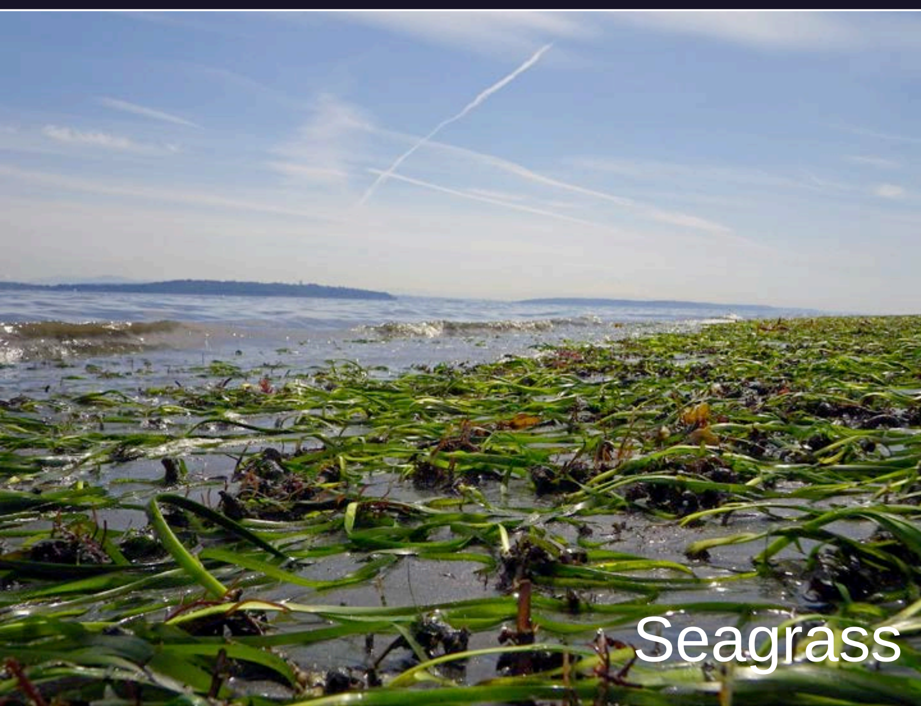


Present Rate
3.4mm/yr
(13.4”/100 yrs)
Ice Age ended
Rapid Rise
11mm/yr
45”/100 yrs
Very slow rise/
Little change
<1mm/yr
Sea Level
Very rapid rise
>20mm/yr
6.5 ft/100 yrs
390 ft
0
100
200
300
400
Sea Level Change (ft)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago

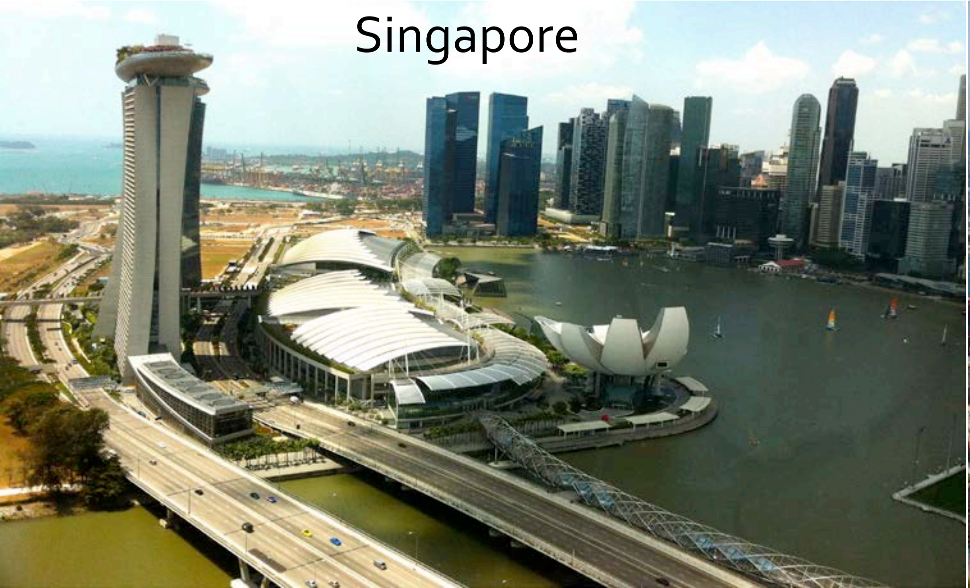

Sacramento
San Francisco
Farallons
SFO
Palo Alto
18.0 ka


D:FIERSTEIN/MBARI

Natural coastal environments have been adjusting to sea-level fluctuations of hundreds of feet for millions of years and will continue to do so in the future.



Cities, however, don’t adjust well to sea-level rise.
About 150 million people today live within a meter of sea level,
and 8 of the world’s 10 largest cities are on the coast.



Estimated costs of natural disasters

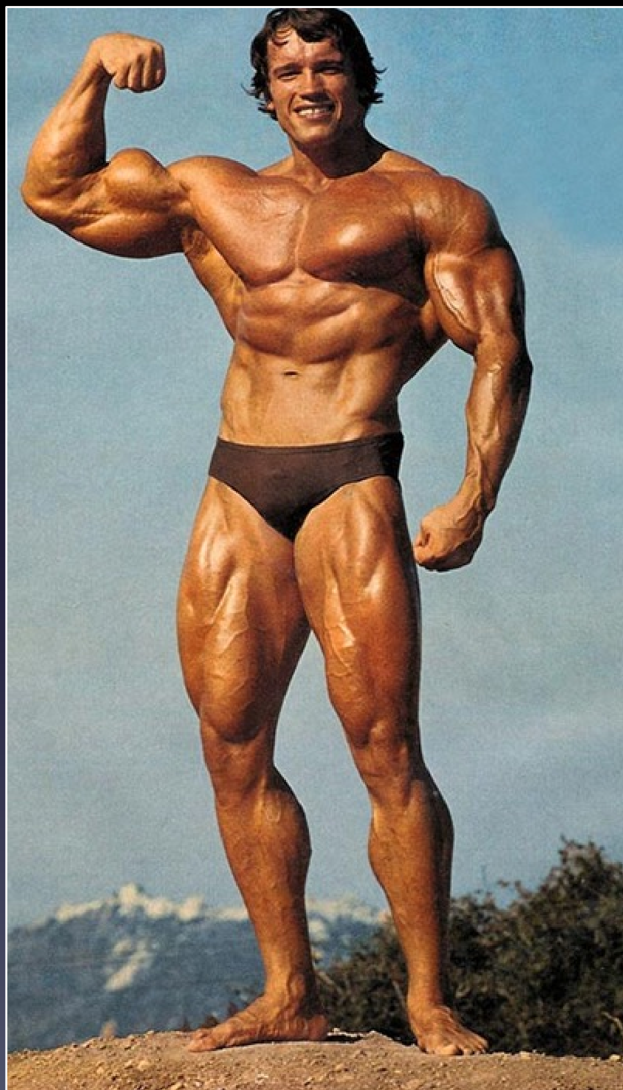
Storms can have a devastating impact on businesses. Here's a look at the damages disasters bring and the prospect of greater losses.

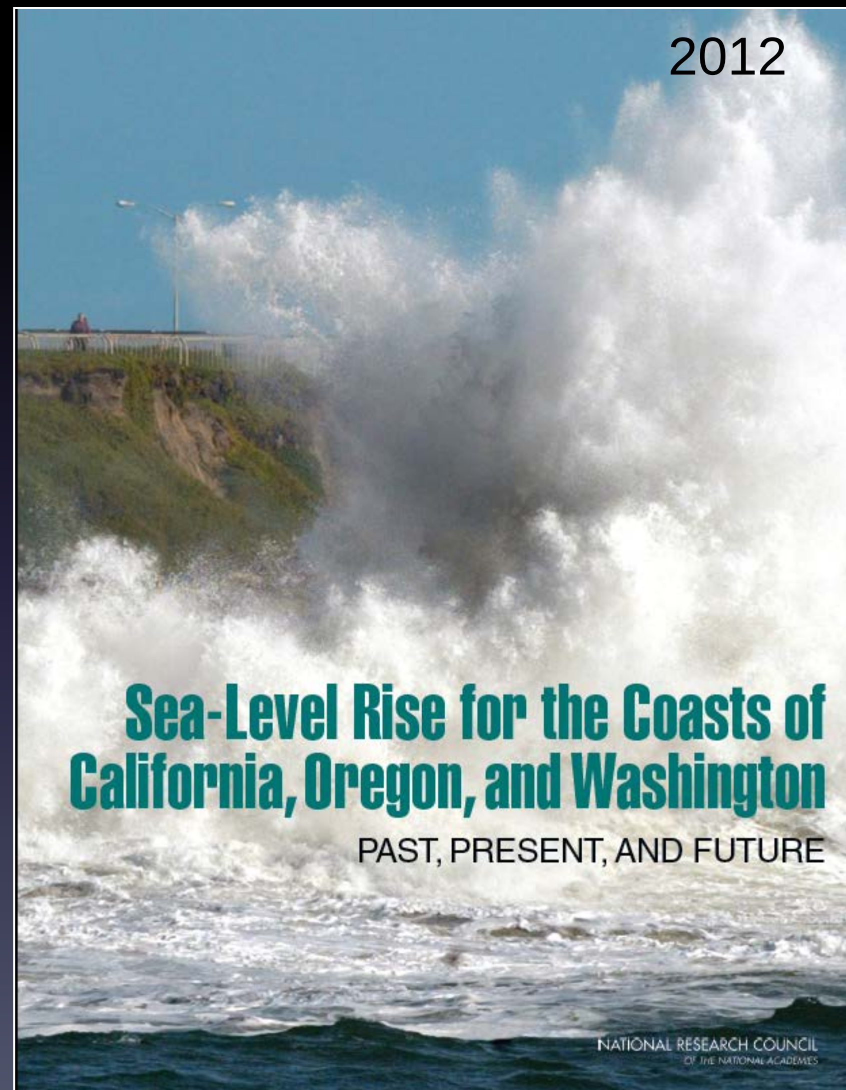
Top 10 cities ranked by asset exposure to coastal flooding in the 2070s (US$bn)

			Year 2005	Year 2070
1	Miami		416	3,513
2	Guangzhou	4	84	3,358
3	New York - Newark		320	2,147
4	Kolkata (Calcutta)		32	1,961
5	Shanghai	1	73	1,771
6	Mumbai		46	1,598
7	Tianjin	8	30	1,231
8	Tokyo		174	1,207
9	Hong Kong	12	36	1,164
10	Bangkok		39	1,118
	Houston	16		

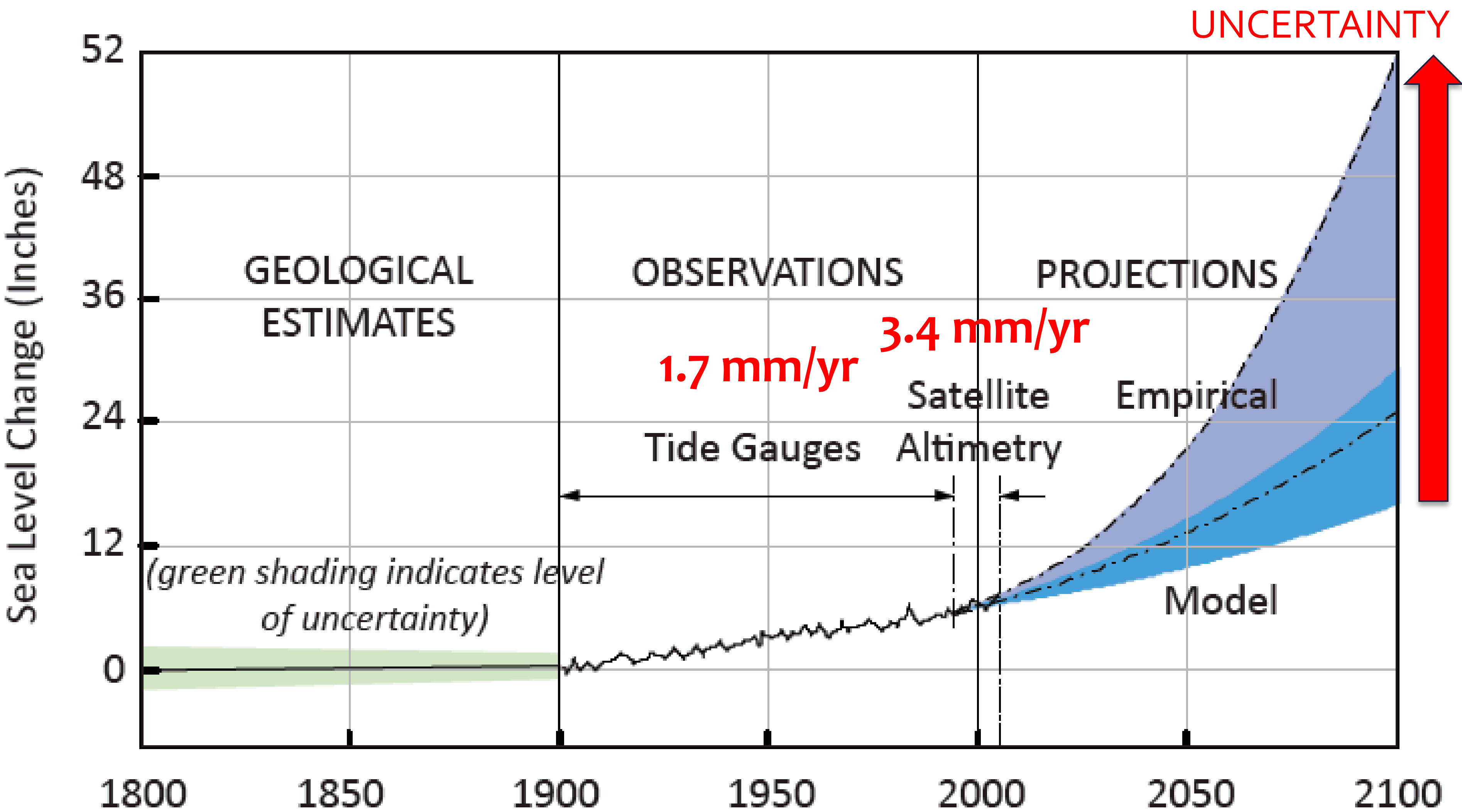
In 2070, Asian cities are projected to dominate the top 10. In 2005, the top 10 cities with exposure to coastal flooding as a result of storms and strong winds were in the United States (including New Orleans), the Netherlands and Japan.

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".

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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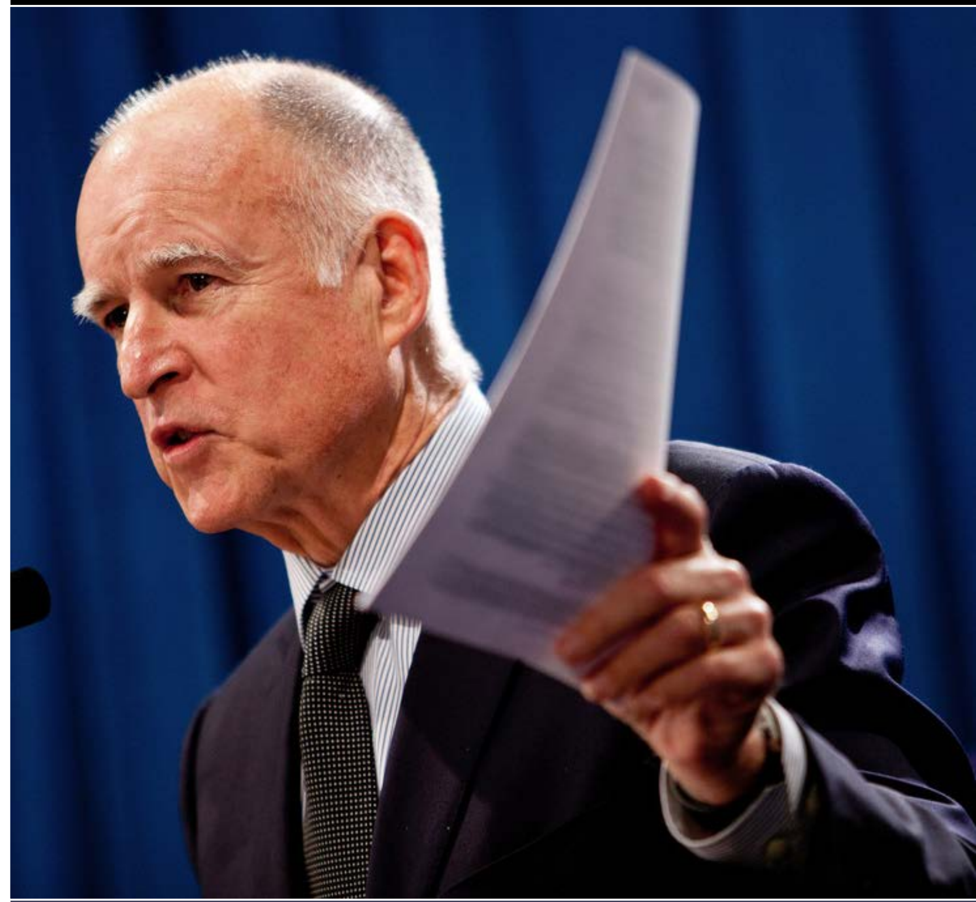
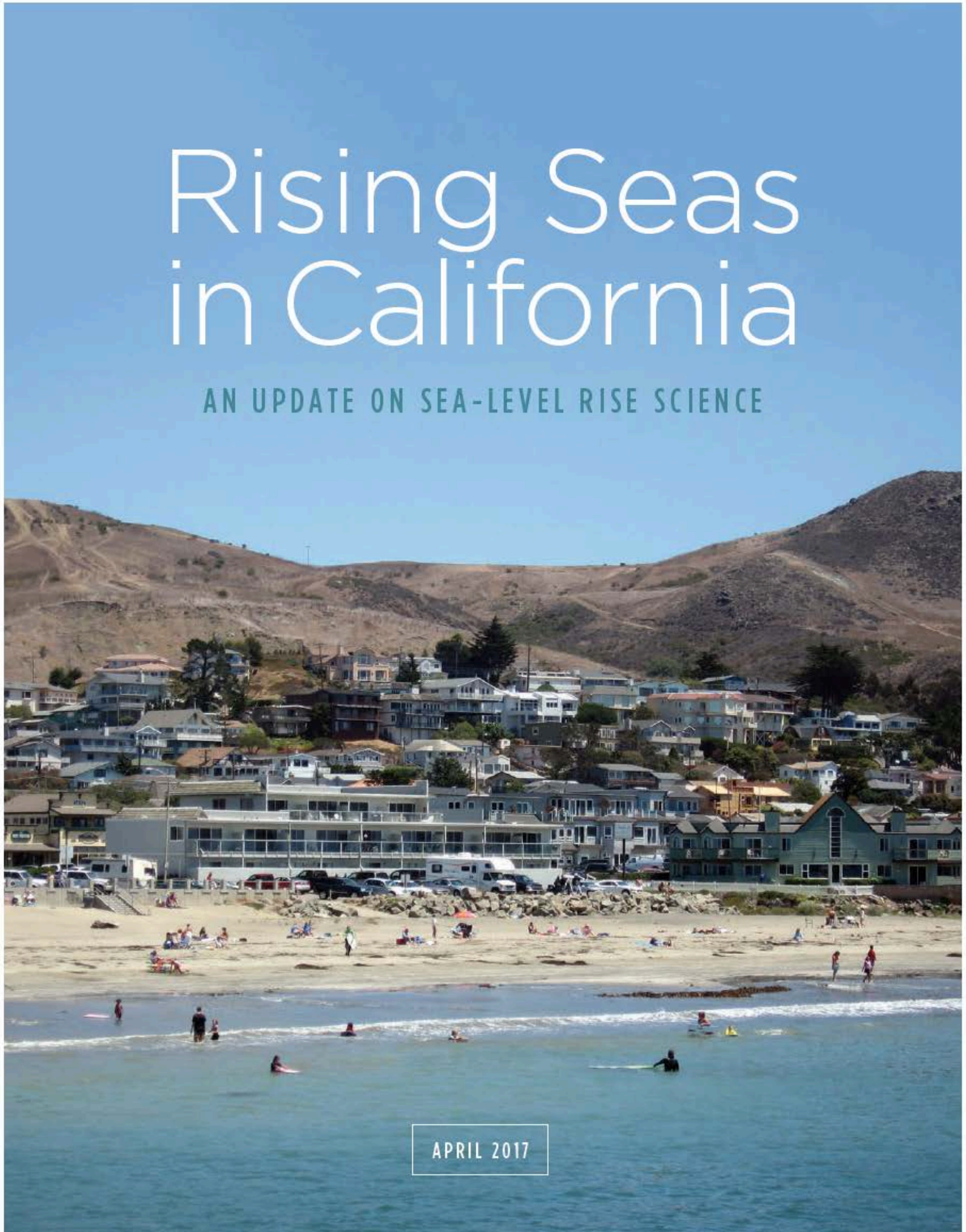
Abstract

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.





CALIFORNIA OCEAN SCIENCE TRUST

California Ocean Protection Council
OPC-SAT
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Potential future sea-level rise is very large (~216 feet total), but uncertainties in rate of rise.

KEY FINDINGS - 2017

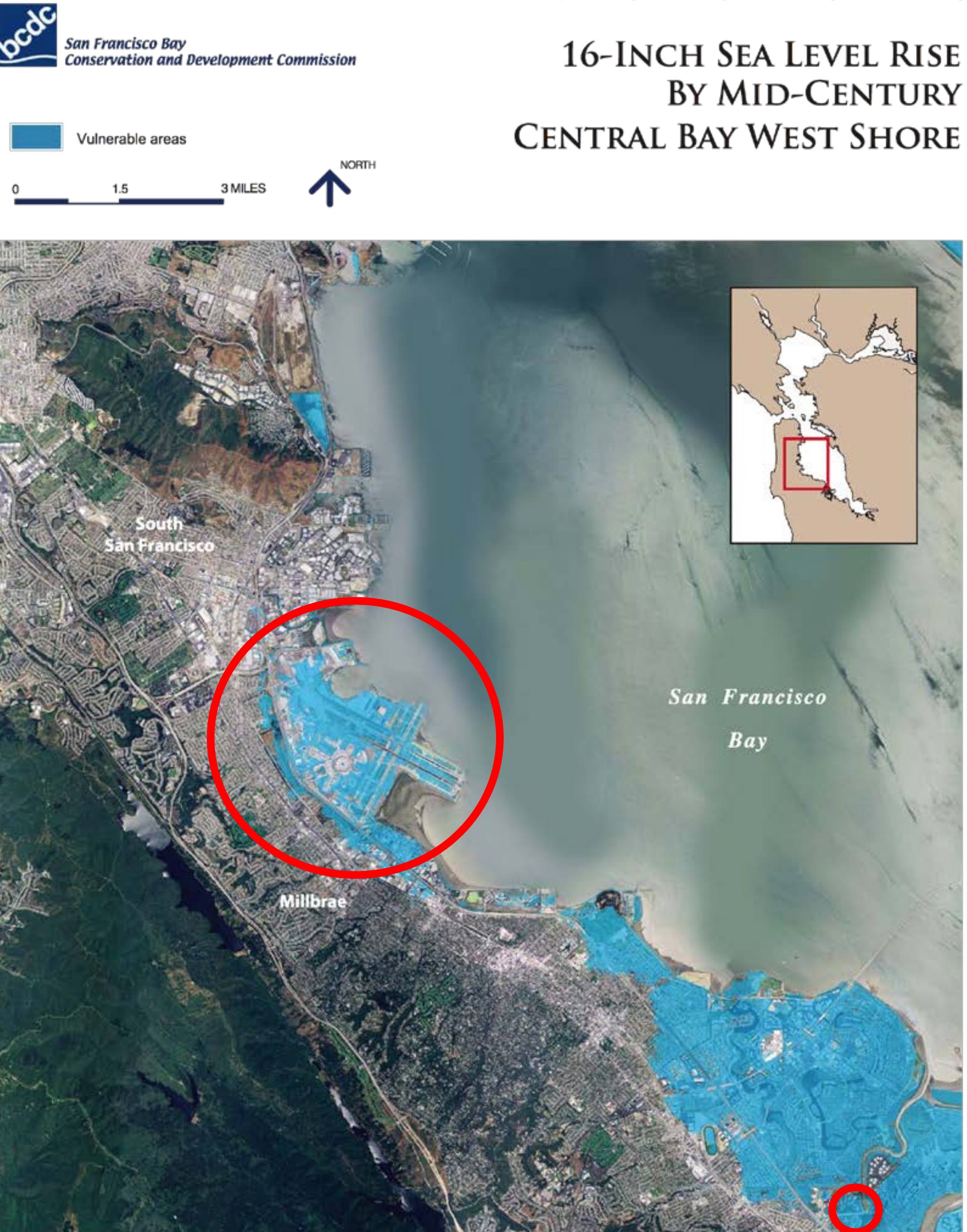
- Scientific understanding of sea-level rise advancing at rapid pace.
- Direction of sea-level rise is clear
- Rate of ice loss from Greenland and Antarctic Ice Sheets is increasing
- New evidence has highlighted the potential for extreme sea-level rise
- Probabilities of specific sea-level increases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

FUTURE SEA-LEVEL RISE PROJECTIONS

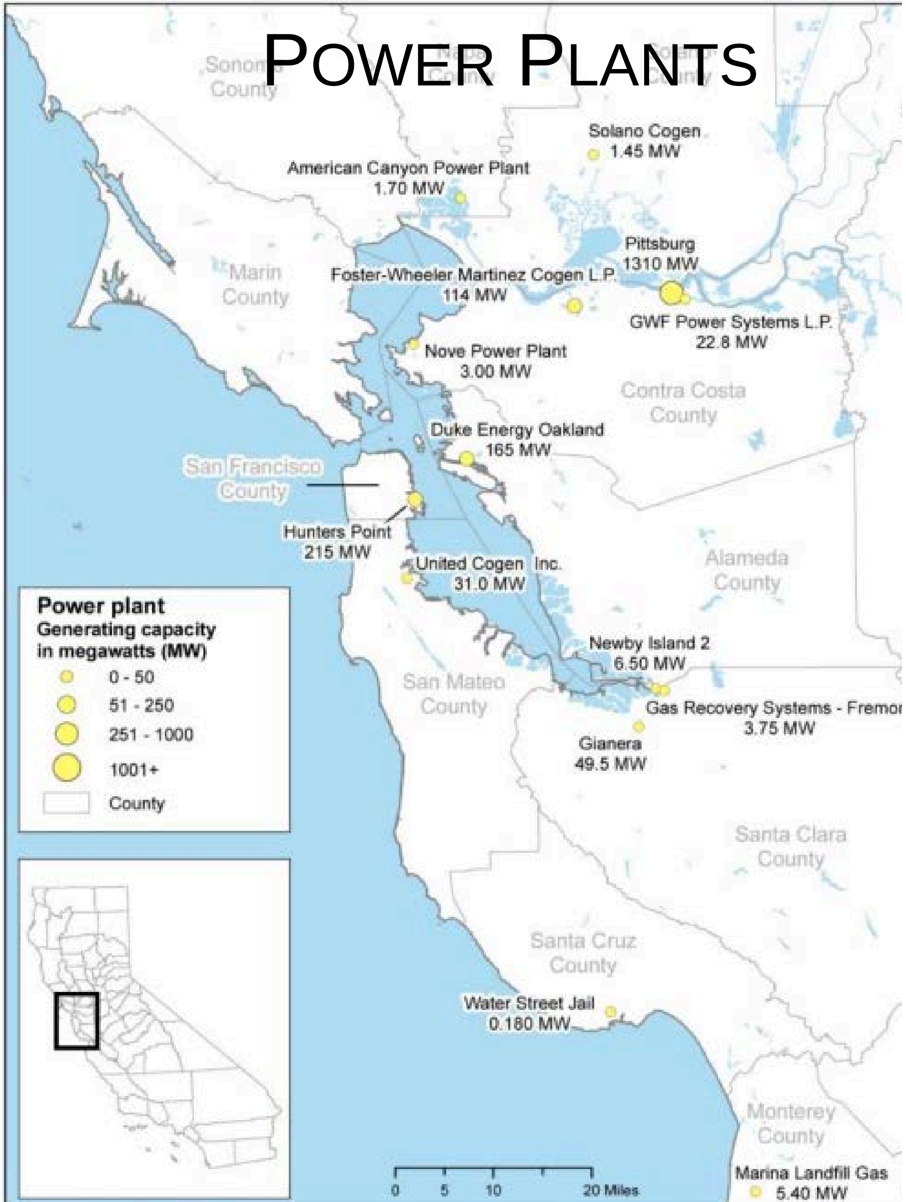
(b) San Francisco, Golden Gate

Feet above 1991-2009 mean	MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE
Year / Percentile	*50% probability SLR meets or exceeds...* NRC	*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 International Airport and Oracle with a 16-inch rise in sea level.



Power Plants

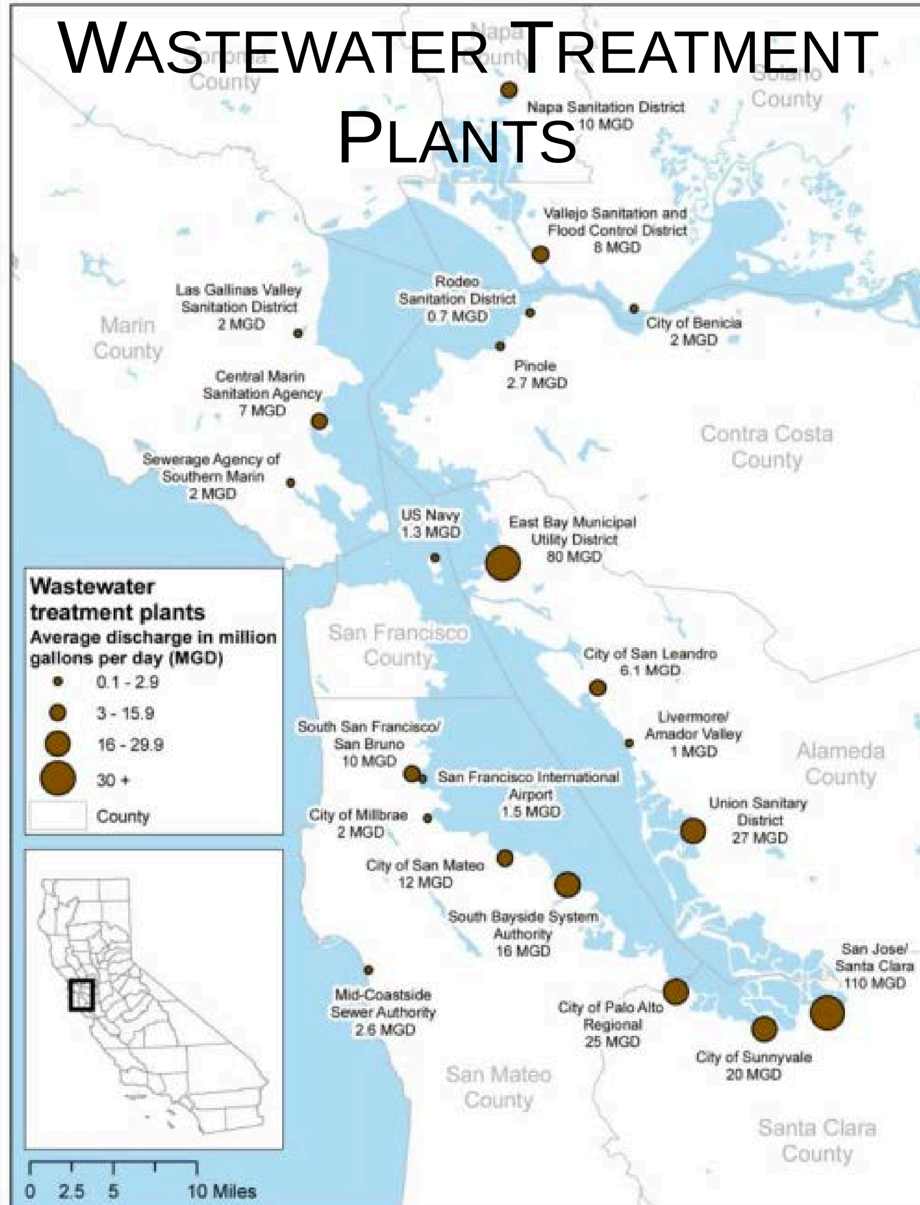


San Francisco Bay power plants vulnerable to a 100-year coastal flood with a 1.4 meter sea-level rise

PACIFIC INSTITUTE

Data sources: USGS/Scripps Institution of Oceanography, California Energy Commission, CaSIL, ESRI.
http://www.pacinst.org/reports/sea_level_rise

Wastewater Treatment Plants



San Francisco Bay wastewater treatment plants vulnerable to a 100-year coastal flood with a 1.4-meter sea-level rise

PACIFIC INSTITUTE

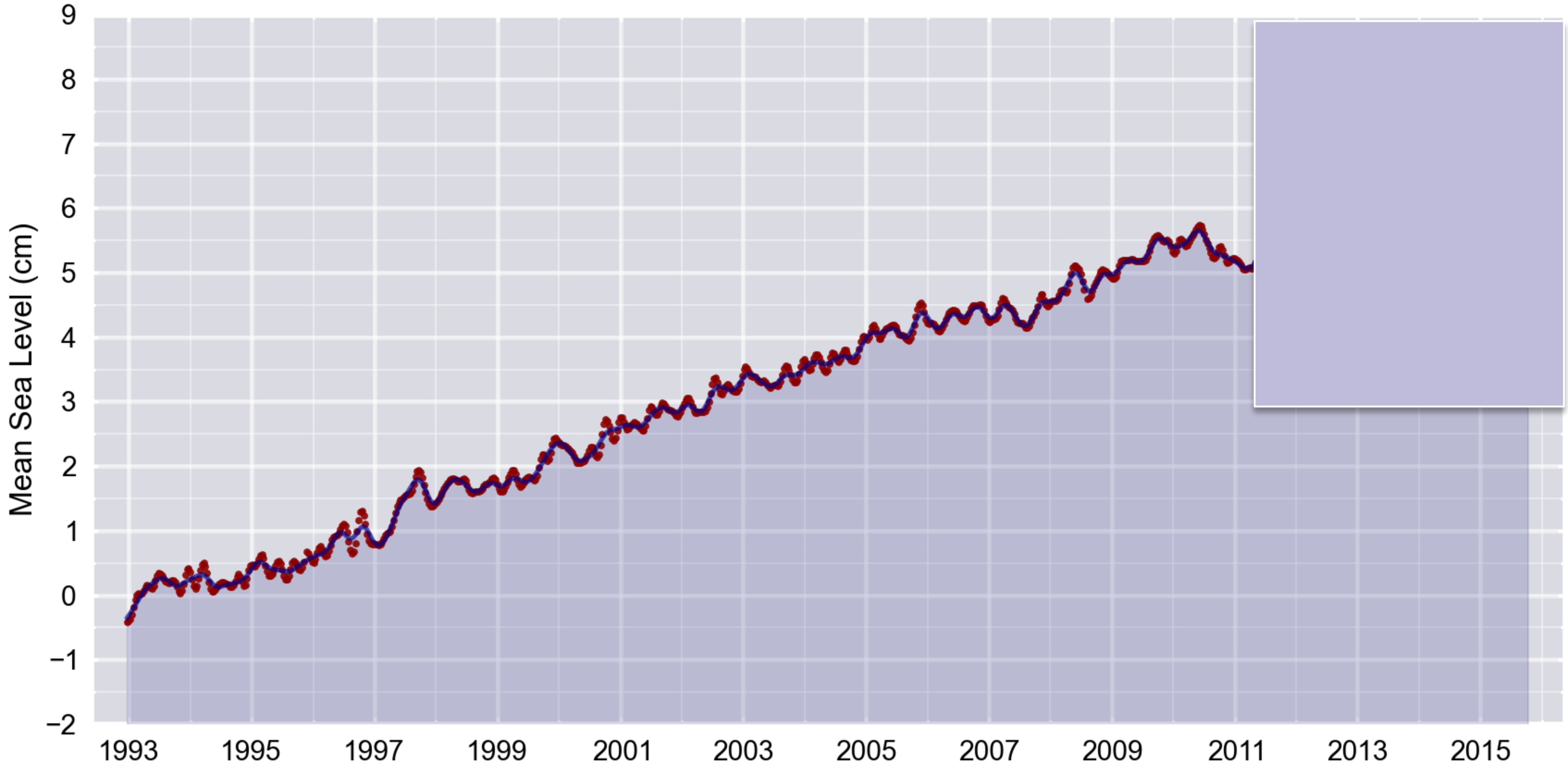
Data sources: USGS/Scripps Institution of Oceanography, EPA PCS Database, CaSIL, ESRI.
http://www.pacinst.org/reports/sea_level_rise

Ocean water extends 100 miles inland from the Golden Gate to the port of West Sacramento

MEASURING SEA LEVEL FROM SATELLITES

+3.34 mm/yr

Altimetric Global MSL (TOPEX/Poseidon + Jason-1 + Jason-2), corrected for GIA



© CNES, CLS, LEGOS

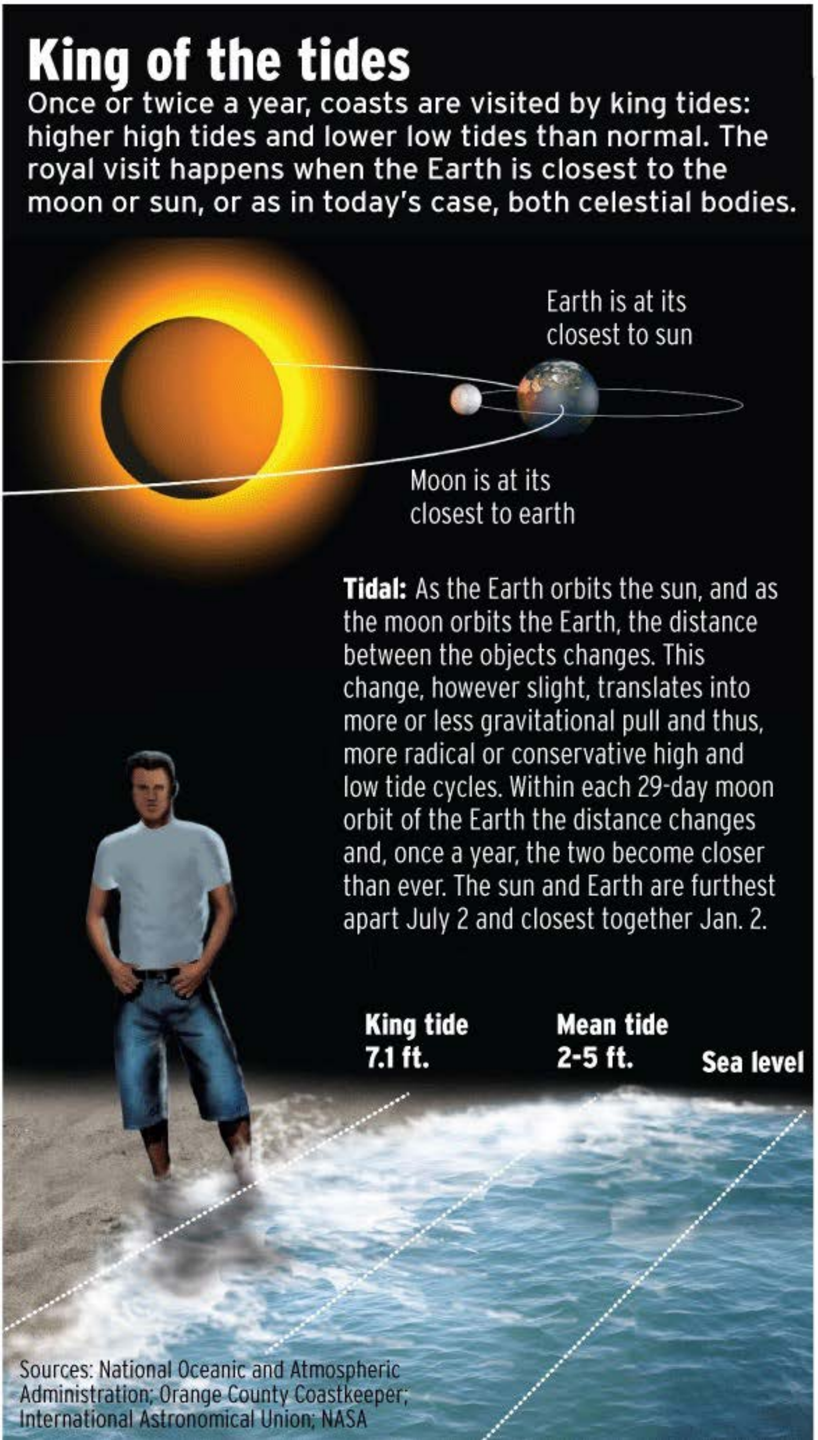
Sea level is rising and the shoreline is slowly moving inland, but it will be extreme events that will of greater concern in the near term

TSUNAMIS 2011

Santa Cruz Small Craft Harbor

Crescent City Harbor

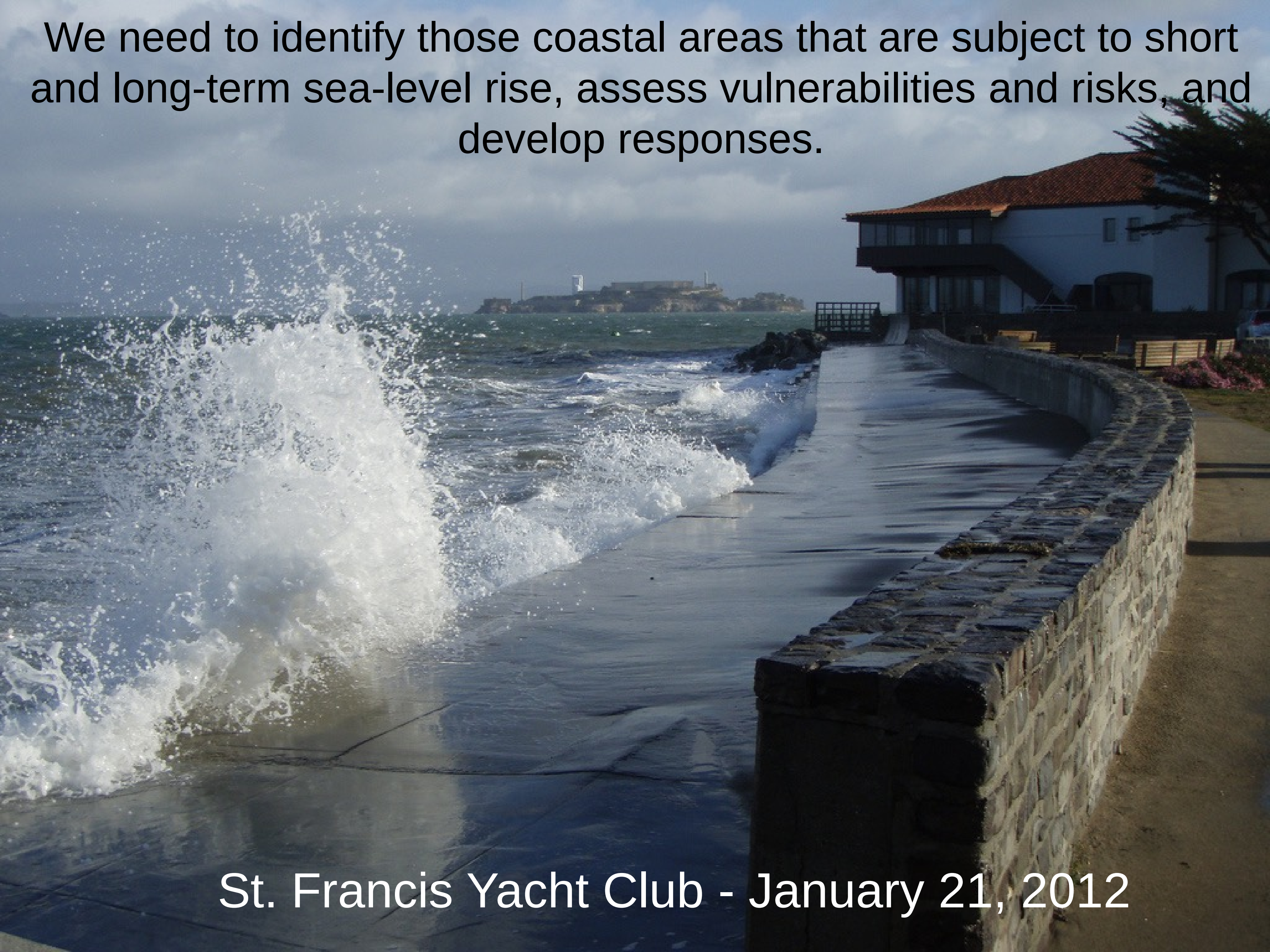
TIDES


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.
Earth is at its closest to sun
Moon is at its closest to earth
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.
King tide 7.1 ft.
Mean tide 2-5 ft.
Sea level
Sources: National Oceanic and Atmospheric Administration; Orange County Coastkeeper; International Astronomical Union; NASA

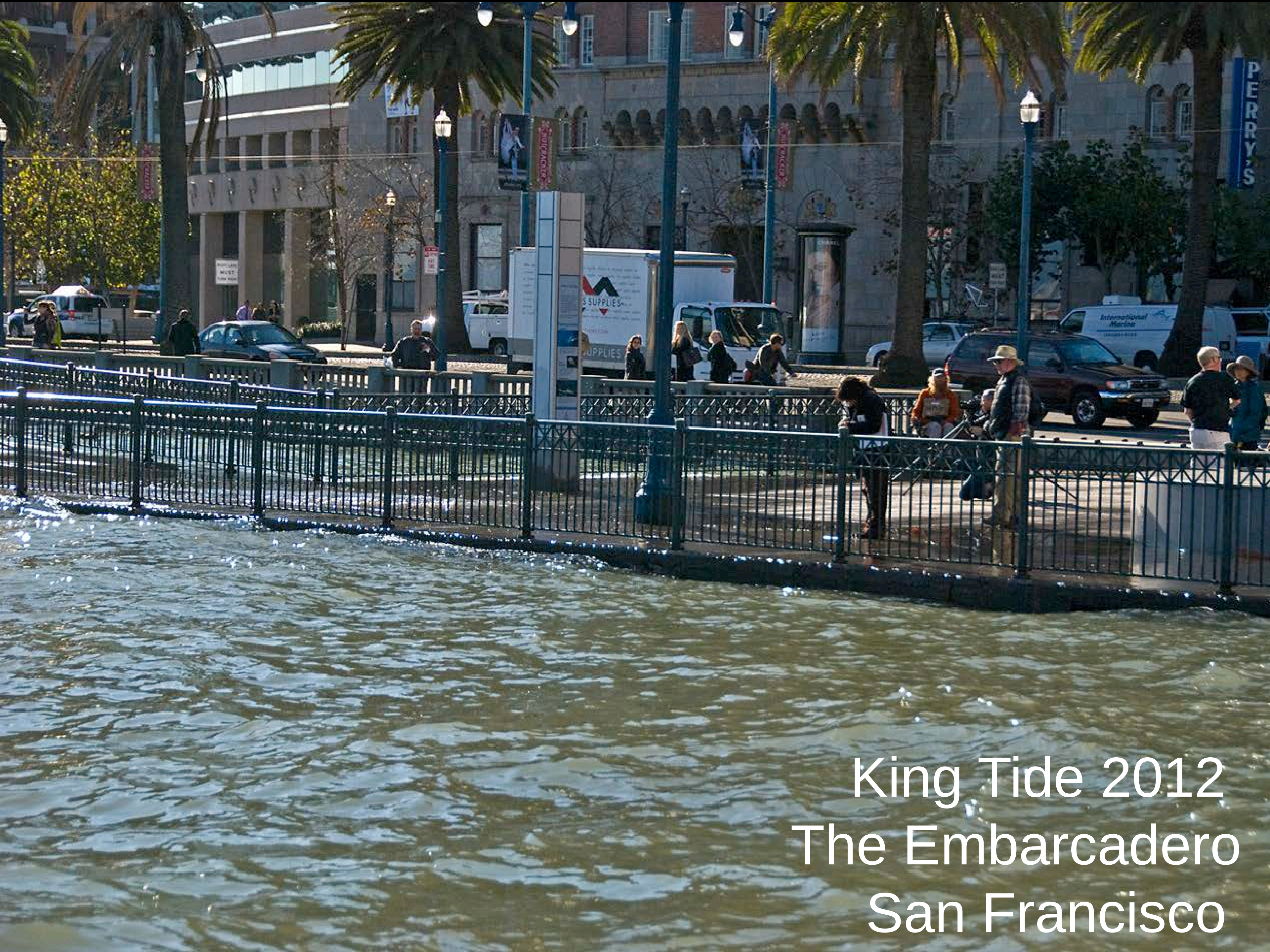
NEWPORT BAY

Sequoia Yacht Club- Redwood City December 31, 2013

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



St. Francis Yacht Club - January 21, 2012



King Tide 2012
The Embarcadero
San Francisco

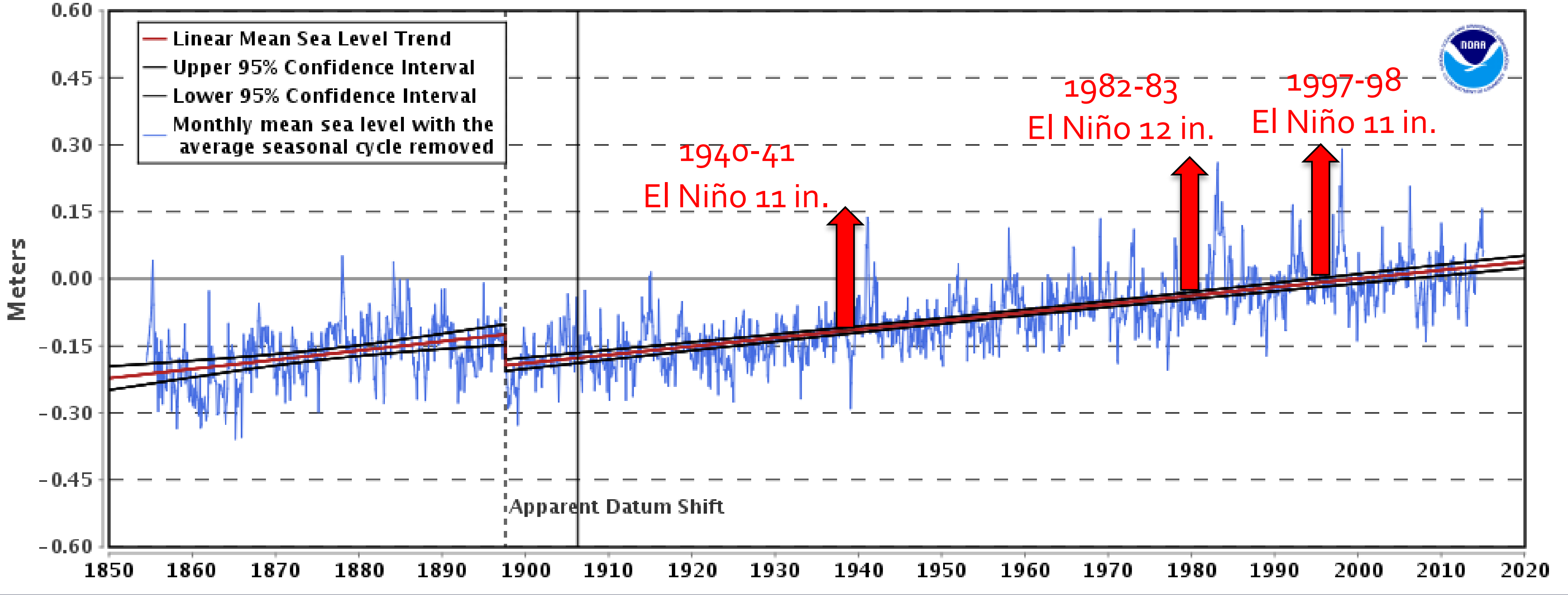
Mill Valley, Marin County King Tide December 12, 2012

HIGH TIDES AND LARGE WAVES

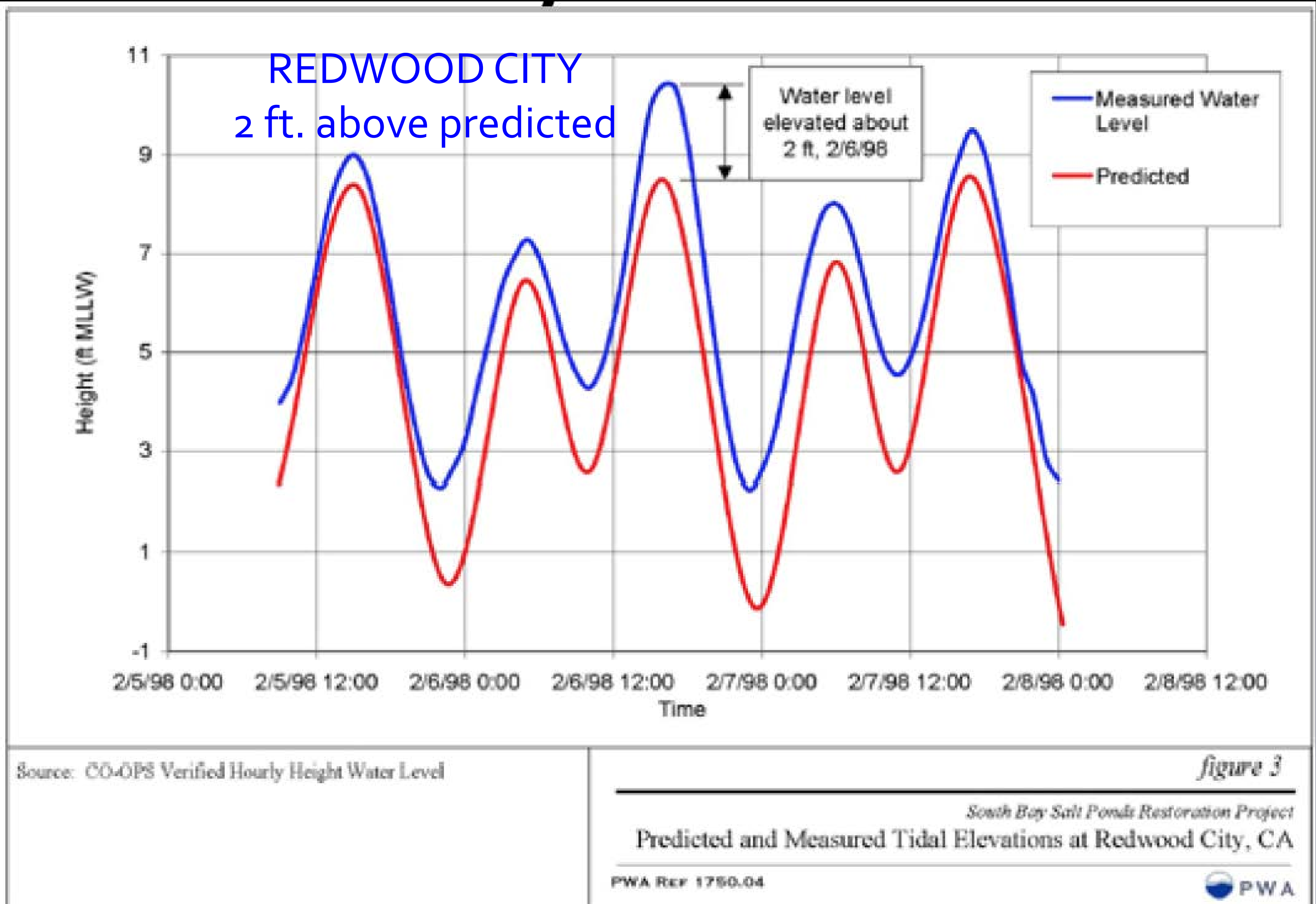
California Recent Sea-Level Rise

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: 1.94 mm/yr. (7.6"/100 years)



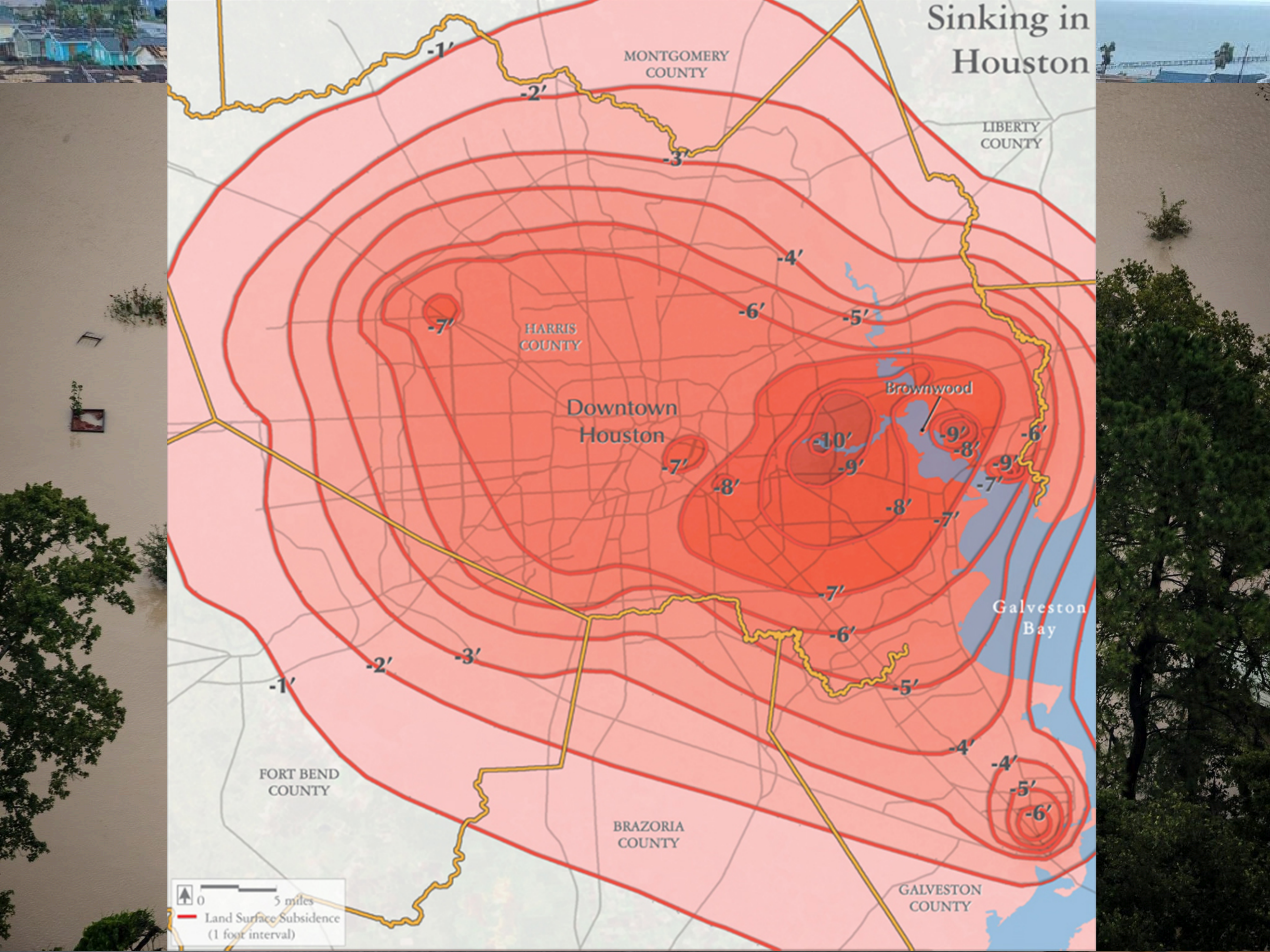
El Niño 1997-98 Elevated Water Levels



MIAMI DURING HURRICANES HAS HIGH WATER

NEW ORLEANS AND HURRICANE KATRINA


NEW YORK AND NEW JERSEY
AND SUPERSTORM SANDY



Sinking in Houston
MONTGOMERY COUNTY
LIBERTY COUNTY
HARRIS COUNTY
Downtown Houston
Brownwood
Galveston Bay
FORT BEND COUNTY
BRAZORIA COUNTY
GALVESTON COUNTY
-1′
-2′
-3′
-4′
-5′
-6′
-7′
-8′
-9′
-10′
0
5 miles
Land Surface Subsidence (1 foot interval)

What Next? Options for the future

We basically have three choices for responding to climate change and sea-level rise: Mitigation, Adaptation and Suffering. We are already doing some of each, and the only question is what the mix will be. The more mitigation we do, the less adaptation and suffering will be required.

ADAPTATION OR RESPONSES TO SEA-LEVEL RISE AND EXTREME EVENTS

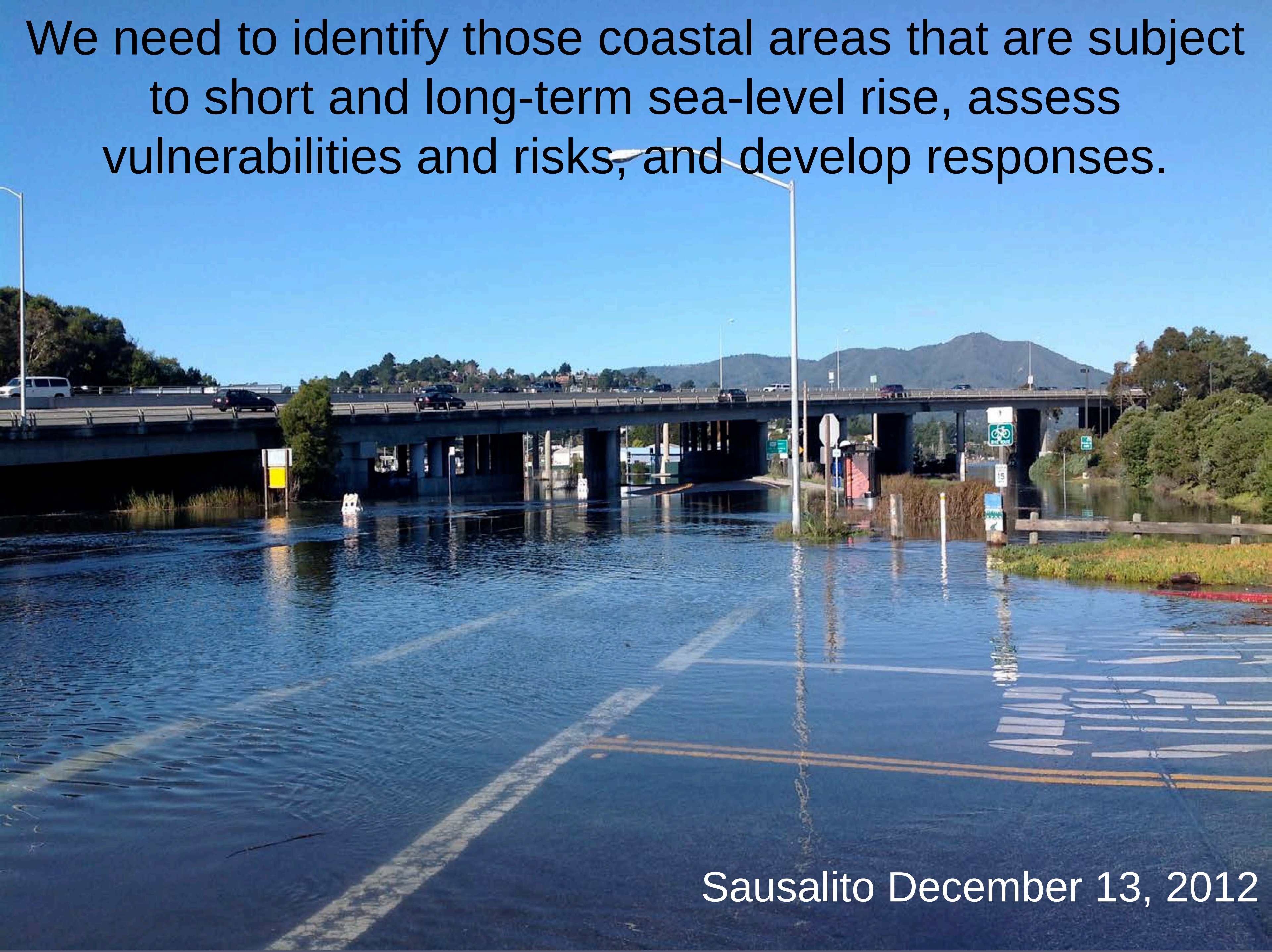
1. IGNORE SEA-LEVEL RISE

2. BUILD FLOATING CITIES

3. BUILD BARRIERS: SEAWALLS/LEVEES

4. PLAN FOR MANAGED RETREAT

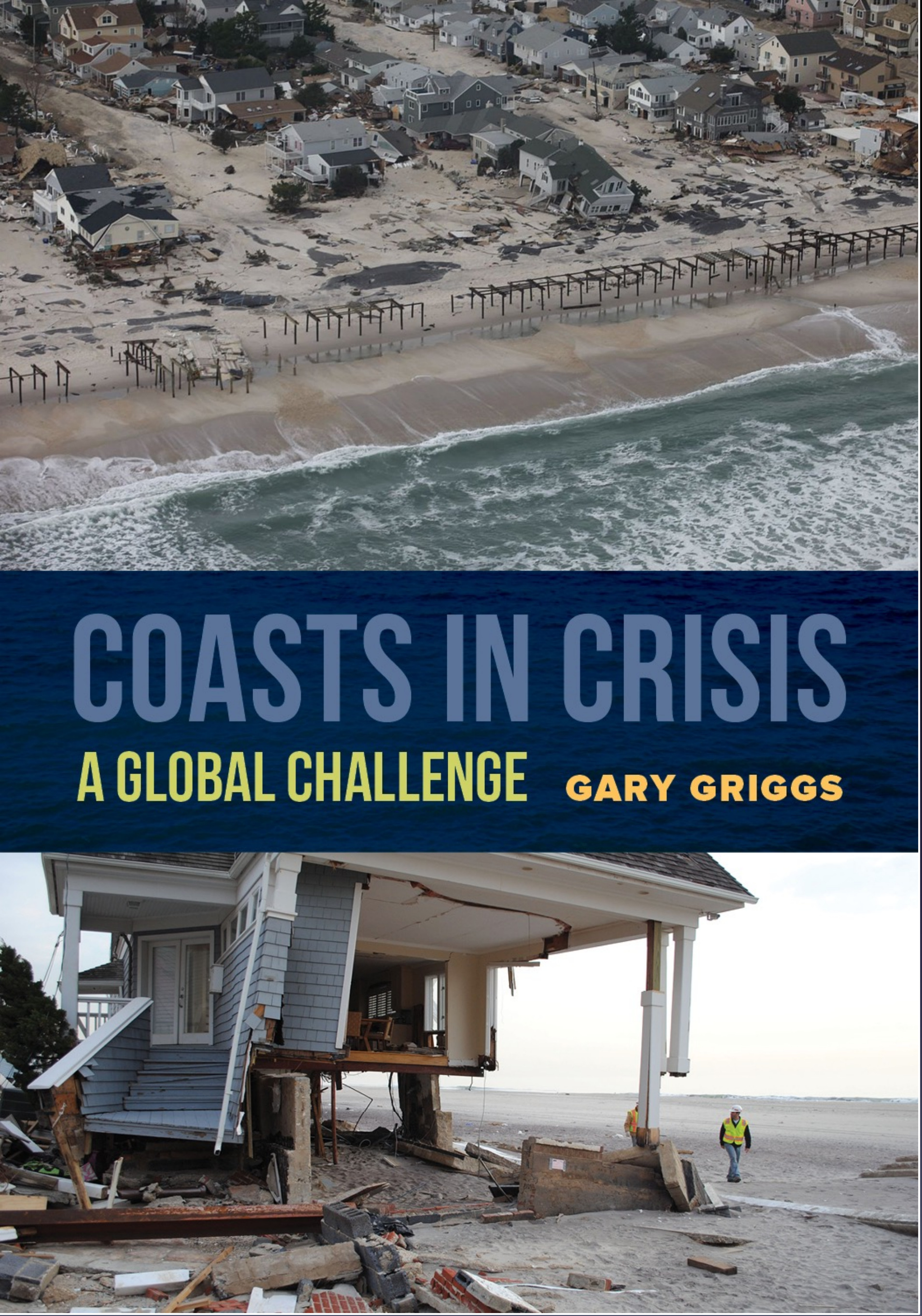
We need to identify those coastal areas that are subject to short and long-term sea-level rise, assess vulnerabilities and risks, and develop responses.

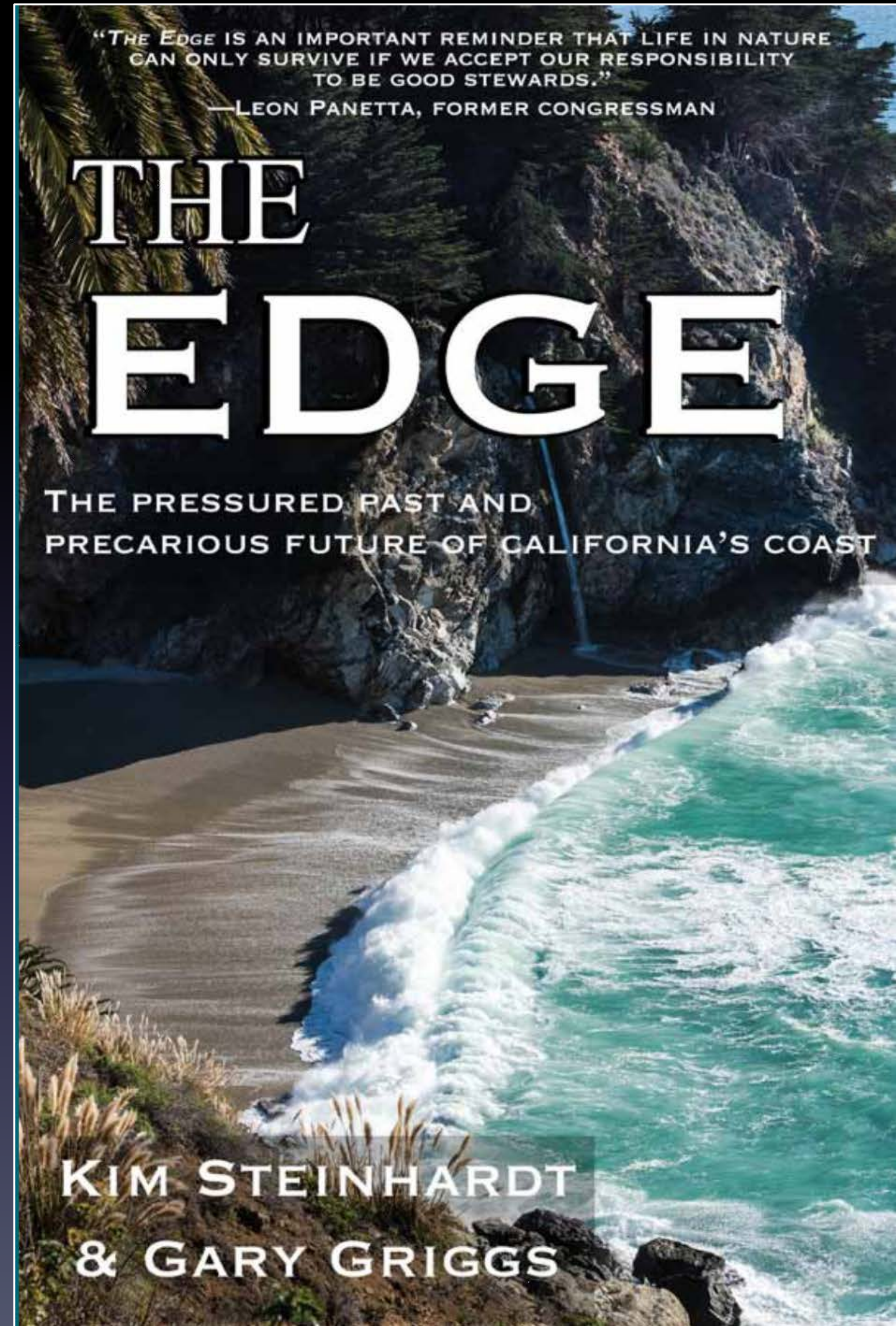


Sausalito December 13, 2012

We have exactly enough time if we start now.

It’s real.
It’s bad.
It’s us.
Scientists agree.
There’s hope.
(In California)


COASTS IN CRISIS
A GLOBAL CHALLENGE
GARY GRIGGS


"THE EDGE IS AN IMPORTANT REMINDER THAT LIFE IN NATURE CAN ONLY SURVIVE IF WE ACCEPT OUR RESPONSIBILITY TO BE GOOD STEWARDS."
—LEON PANETTA, FORMER CONGRESSMAN
THE EDGE
THE PRESSURED PAST AND PRECARIOUS FUTURE OF CALIFORNIA'S COAST
KIM STEINHARDT
& GARY GRIGGS