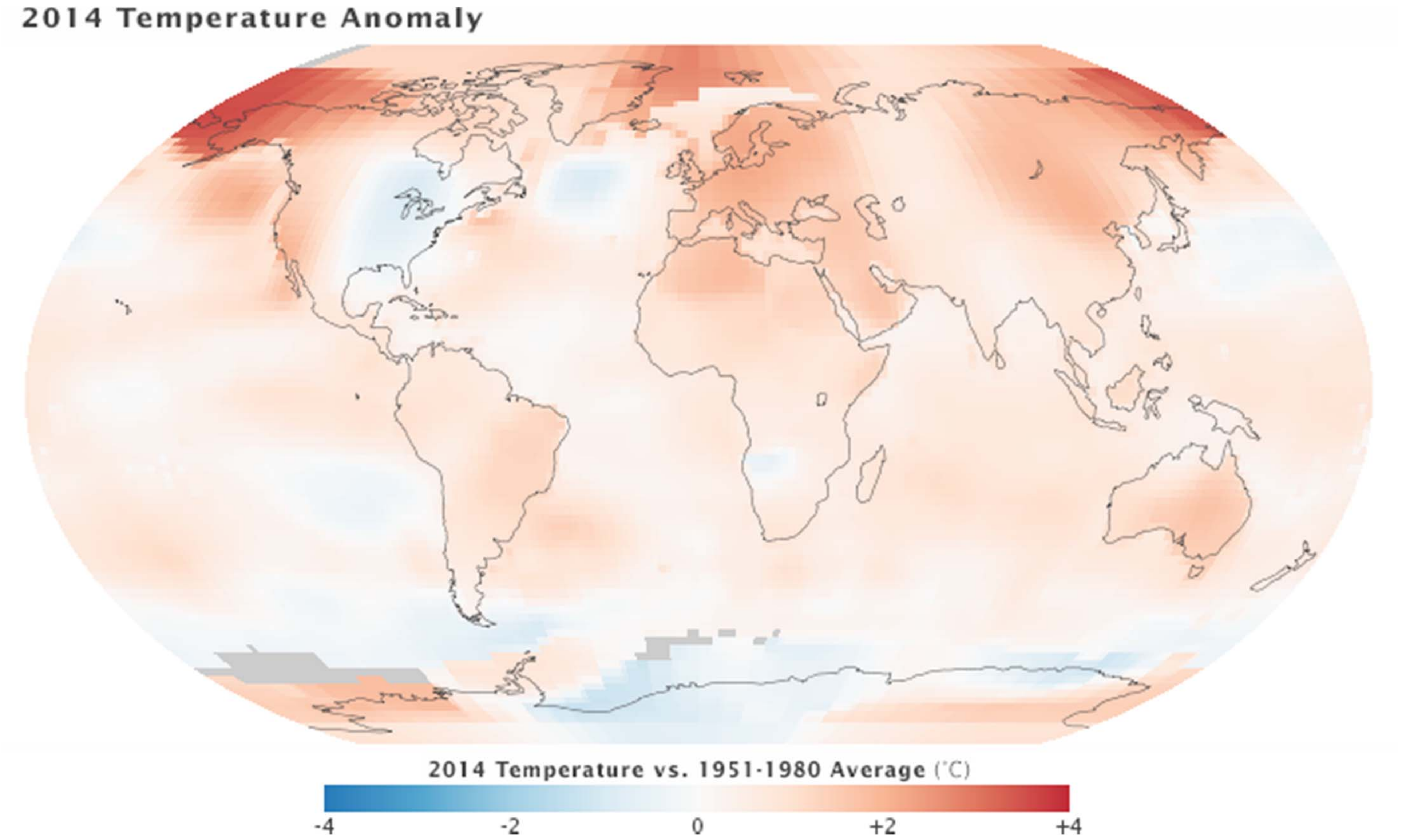
Climate change, sea level rise, and coastal impacts in Hawaii

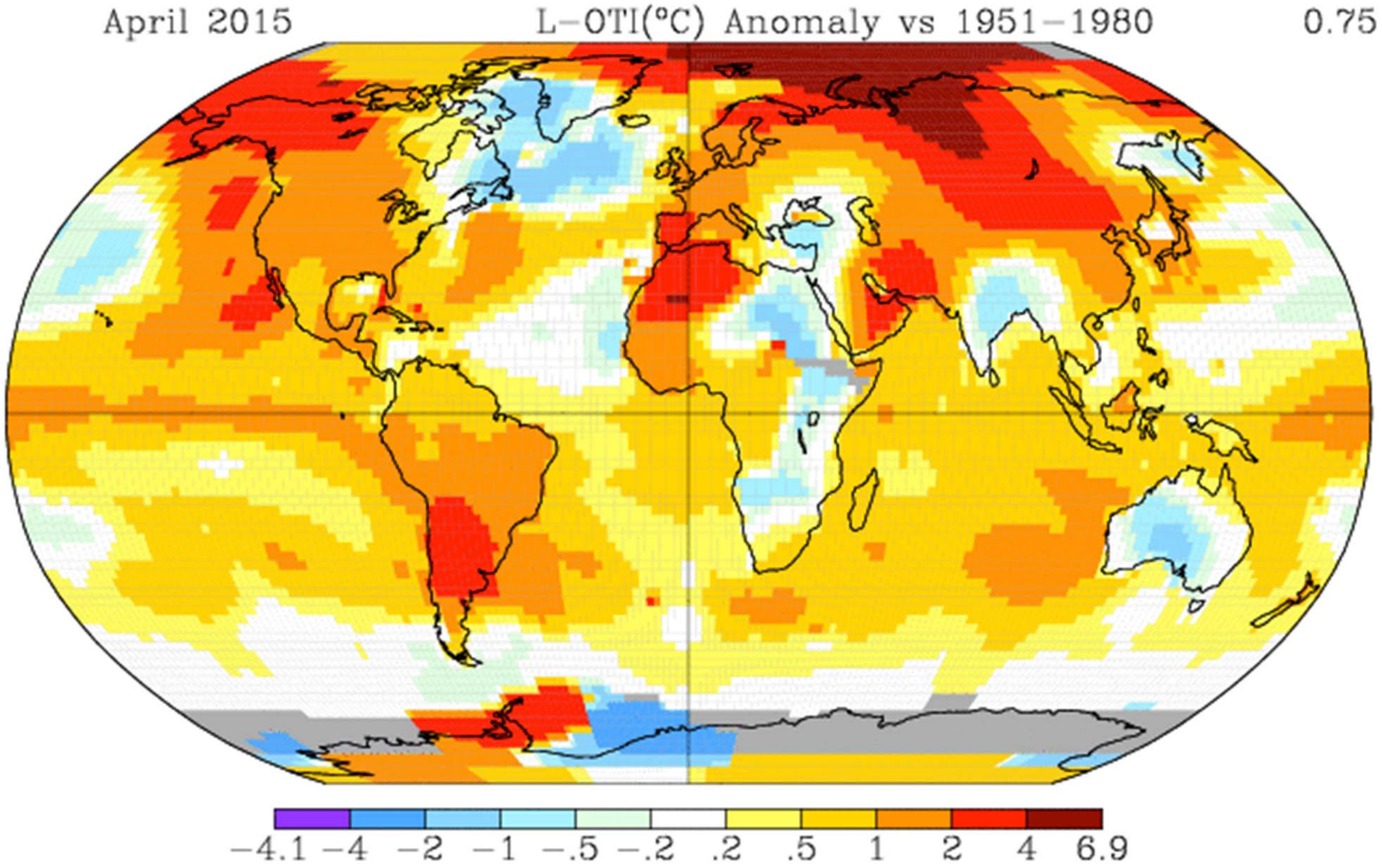
Dr. Chip Fletcher
SOEST, University of Hawaii, Manoa

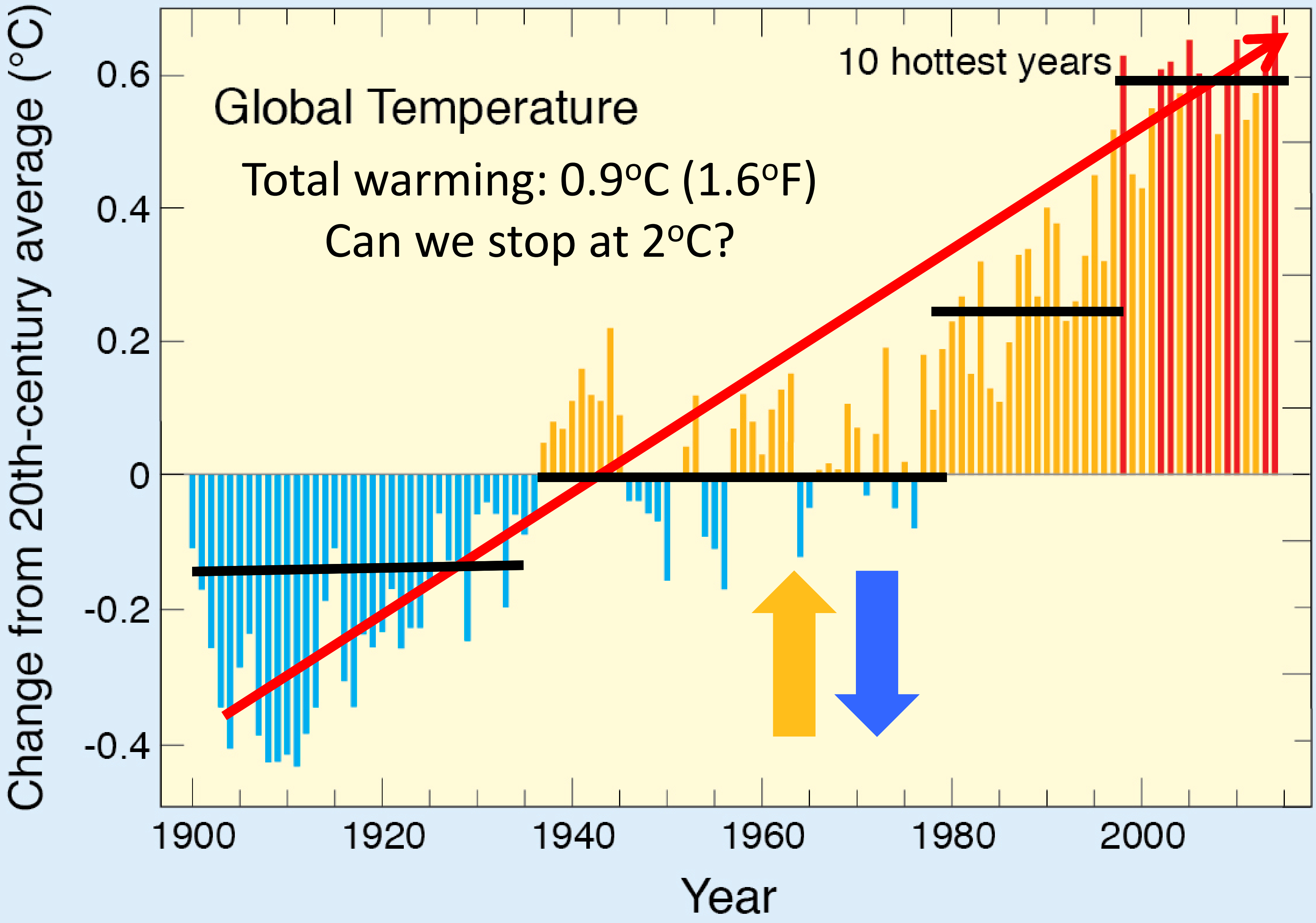
2014 hottest year on record



http://www.giss.nasa.gov/research/news/20150116/

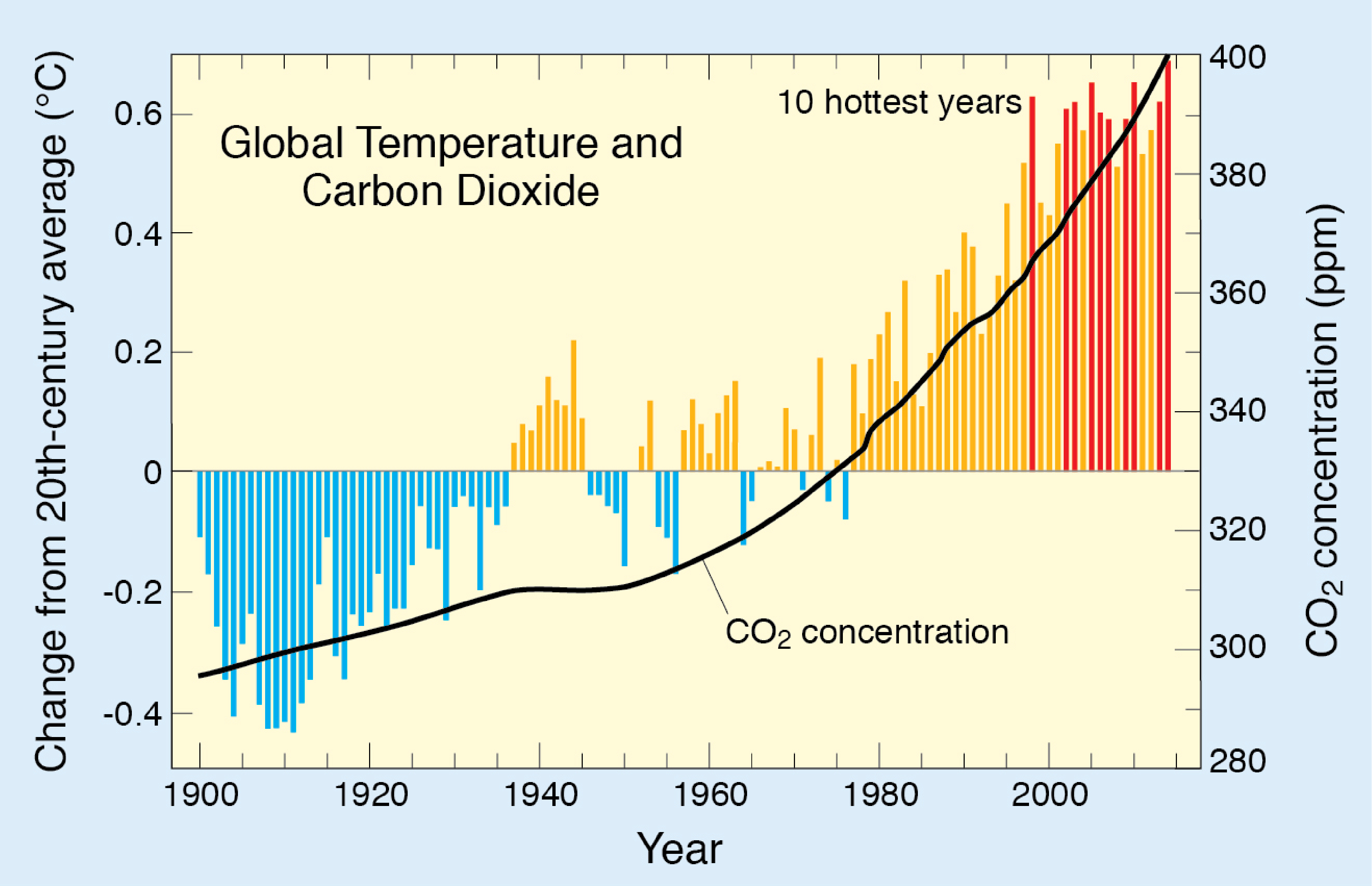
Jan-Feb-Mar-Apr was the hottest 4-month start of any year on record





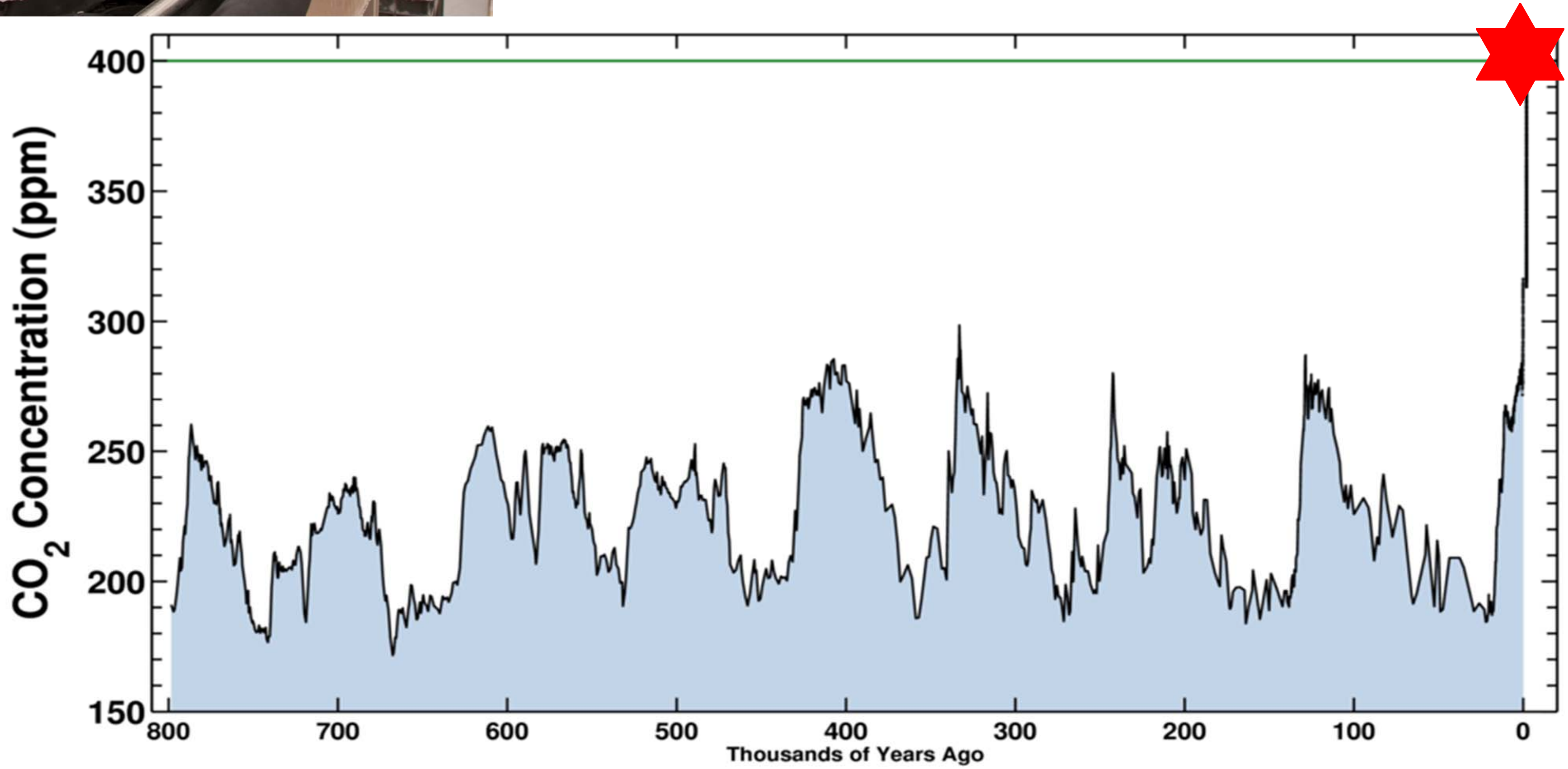
Total warming: 0.9°C (1.6°F)

Can we stop at 2°C?


Global Temperature and Carbon Dioxide
10 hottest years
CO_2 concentration
Change from 20th-century average (°C)
0.6
0.4
0.2
0
-0.2
-0.4
CO_2 concentration (ppm)
400
380
360
340
320
300
280
1900
1920
1940
1960
1980
2000
Year

Highest C0$_2$ levels in 800,000 yrs

(probably 2-4.6 million yrs)



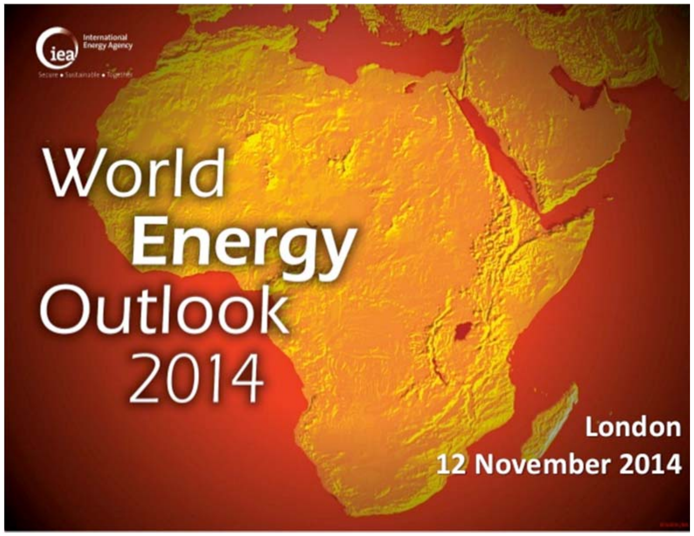
Jouzel et al., Orbital and millennial Antarctic climate variability over the past 800,000 years, Science 10 August 2007: Vol. 317 no. 5839 pp. 793-796 DOI: 10.1126/science.1141038;

Burning Coal and Petroleum

Deforestation

Demand for fossil fuels is likely to keep growing for at least another 20 years.

- Consumption of raw fossil fuels will increase 37% by 2040
- Growing demand in Asia, Africa, the Middle East and Latin America
- Coal demand will level off in the 2020s (thanks to air pollution concerns - China)
- Oil demand will plateau in the 2040's
- Natural gas will continue growing past 2040's
- Nuclear power will decline due to safety concerns and lack of options to dispose of radioactive waste
- By 2040, ~25% of energy will come from low carbon sources (mostly wind and solar)
- By 2040 1 trillion tons of carbon dioxide will be added to the atmosphere.
- **This will push us past the 2^{o}C threshold.**



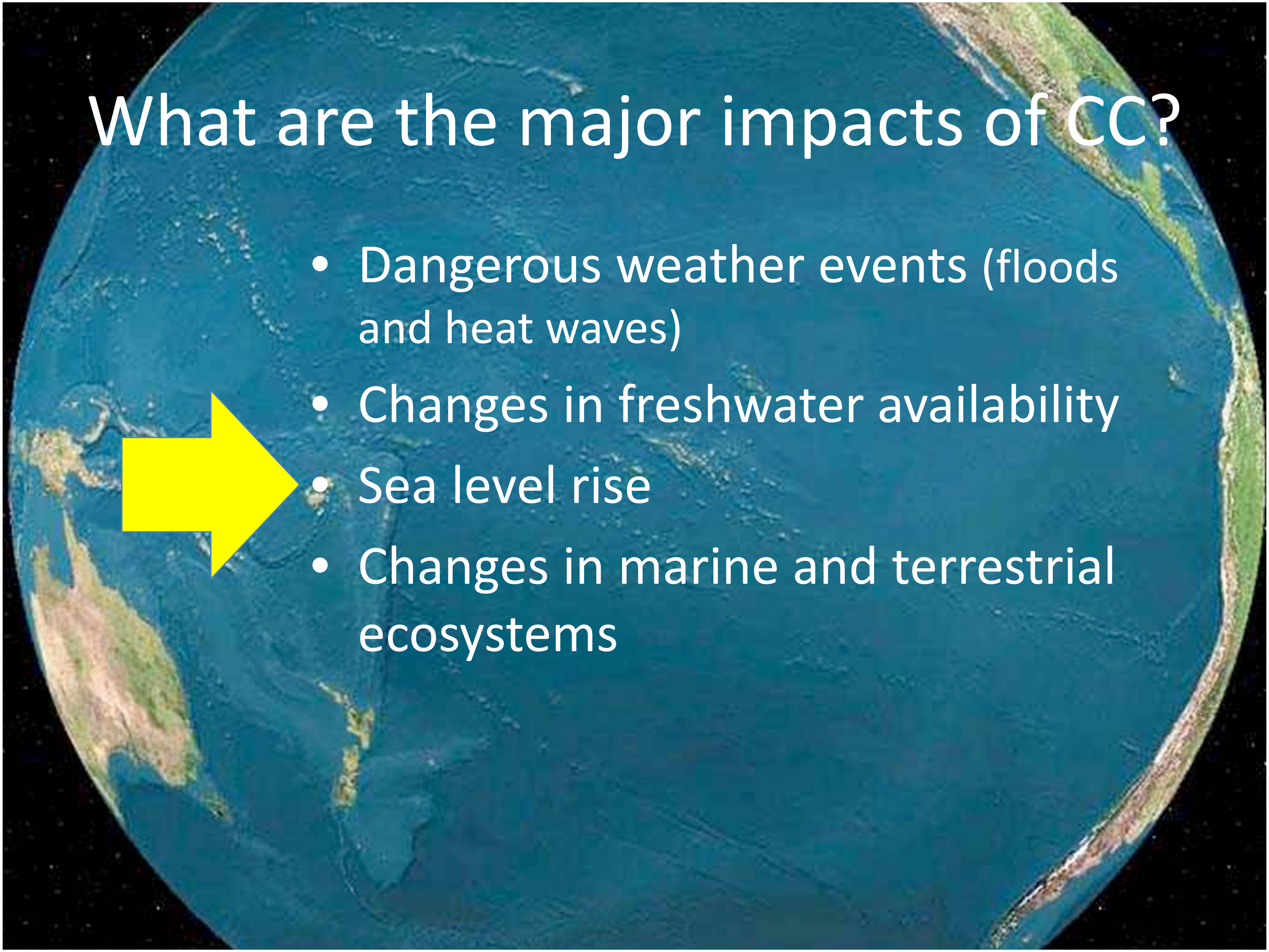
iea International Energy Agency

World Energy Outlook 2014

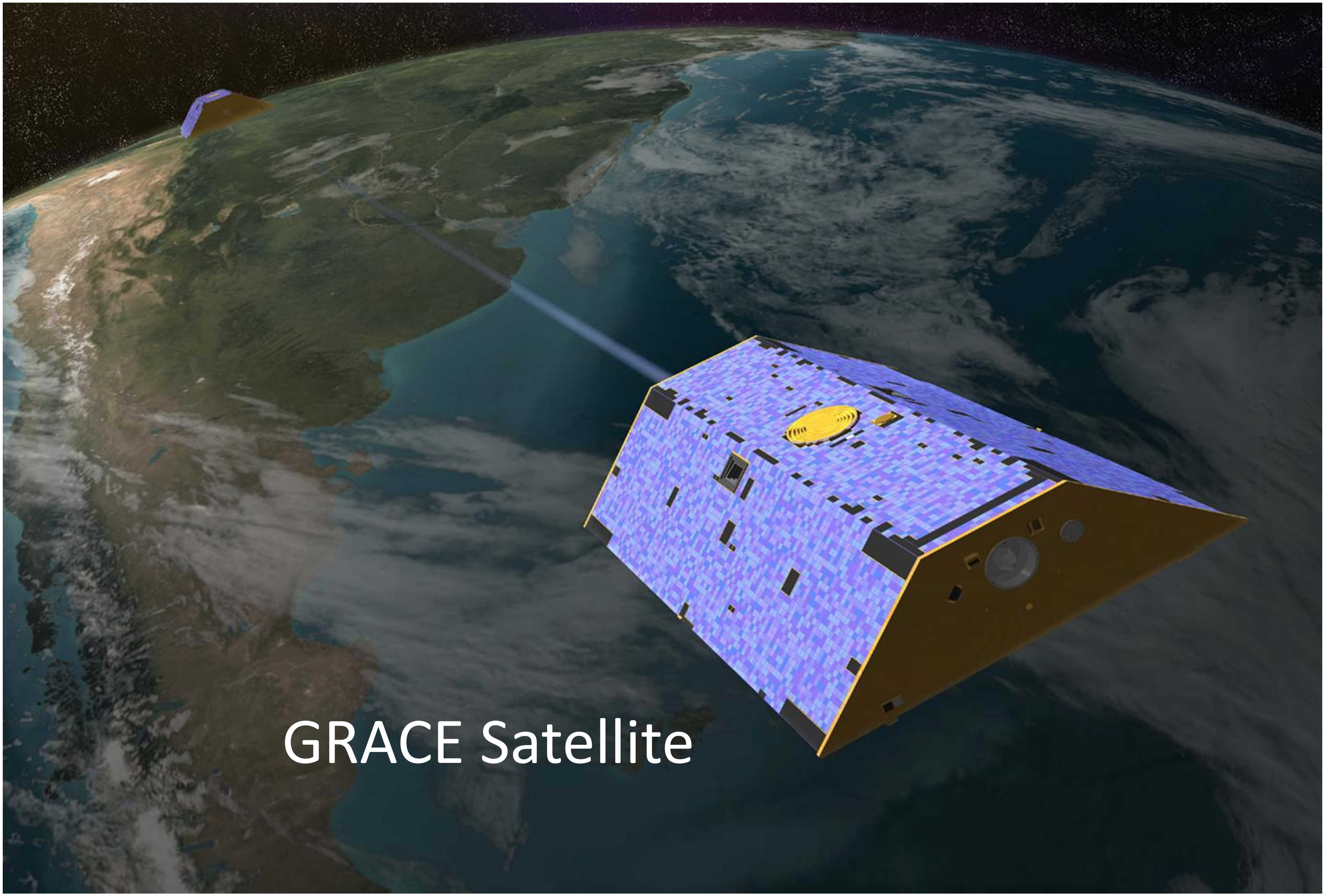
London
12 November 2014

International Energy Agency - http://www.worldenergyoutlook.org/publications/weo-2014/

What are the major impacts of CC?

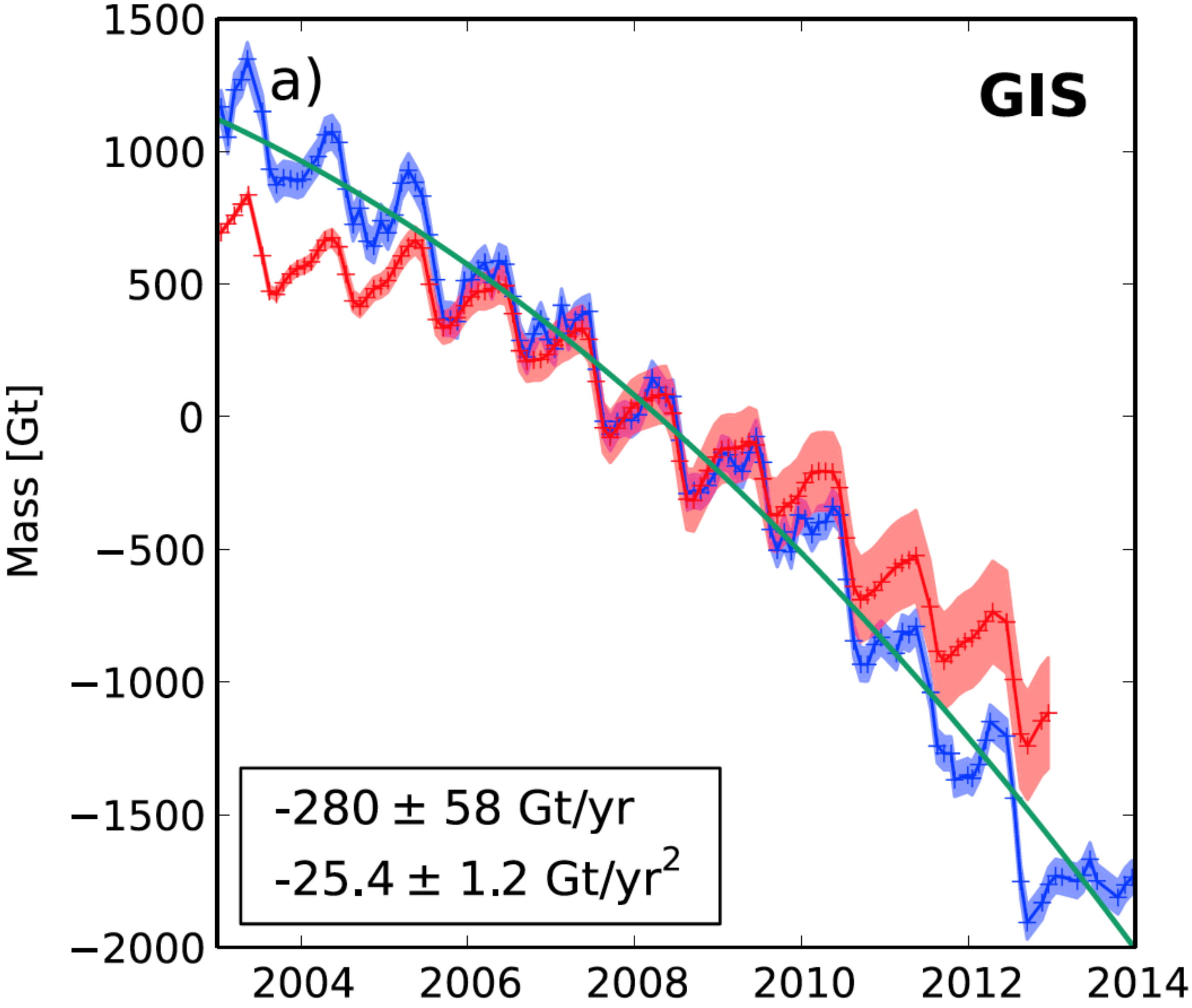


- Dangerous weather events (floods and heat waves)
- Changes in freshwater availability
- Sea level rise
- Changes in marine and terrestrial ecosystems



GRACE Satellite

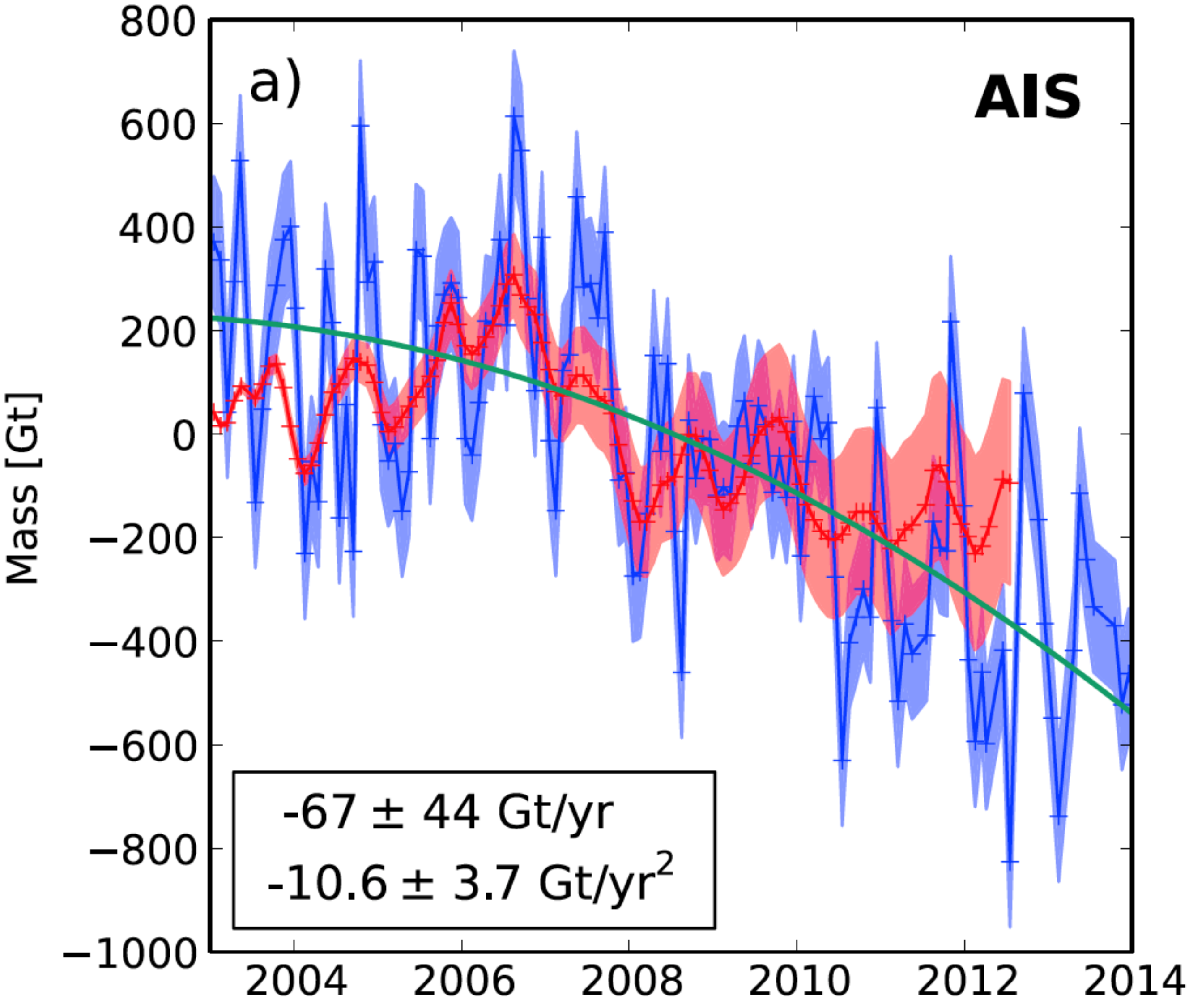
Rate of Greenland ice loss has doubled since 2009



Velicogna et al., 2014, Regional acceleration in ice mass loss from Greenland and Antarctica using GRACE time-variable gravity data, GRL, 10.1002/2014GL06105

Greenland is losing Ice

Rate of Antarctic ice loss has tripled since 2004



-67 ± 44 Gt/yr
-10.6 ± 3.7 Gt/yr^2

Velicogna et al., 2014, Regional acceleration in ice mass loss from Greenland and Antarctica using GRACE time-variable gravity data, GRL, 10.1002/2014GL061052
Harig and Simons, 2015 Accelerated West Antarctica ice mass loss continues to outpace east Antarctic gains, Earth and Planetary Science Letters, 214, 134-141

Antarctica is losing Ice

Published Online May 12 2014
Science 16 May 2014:
Vol. 344 no. 6185 pp. 735-738
DOI: 10.1126/science.1249055

REPORT

Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica

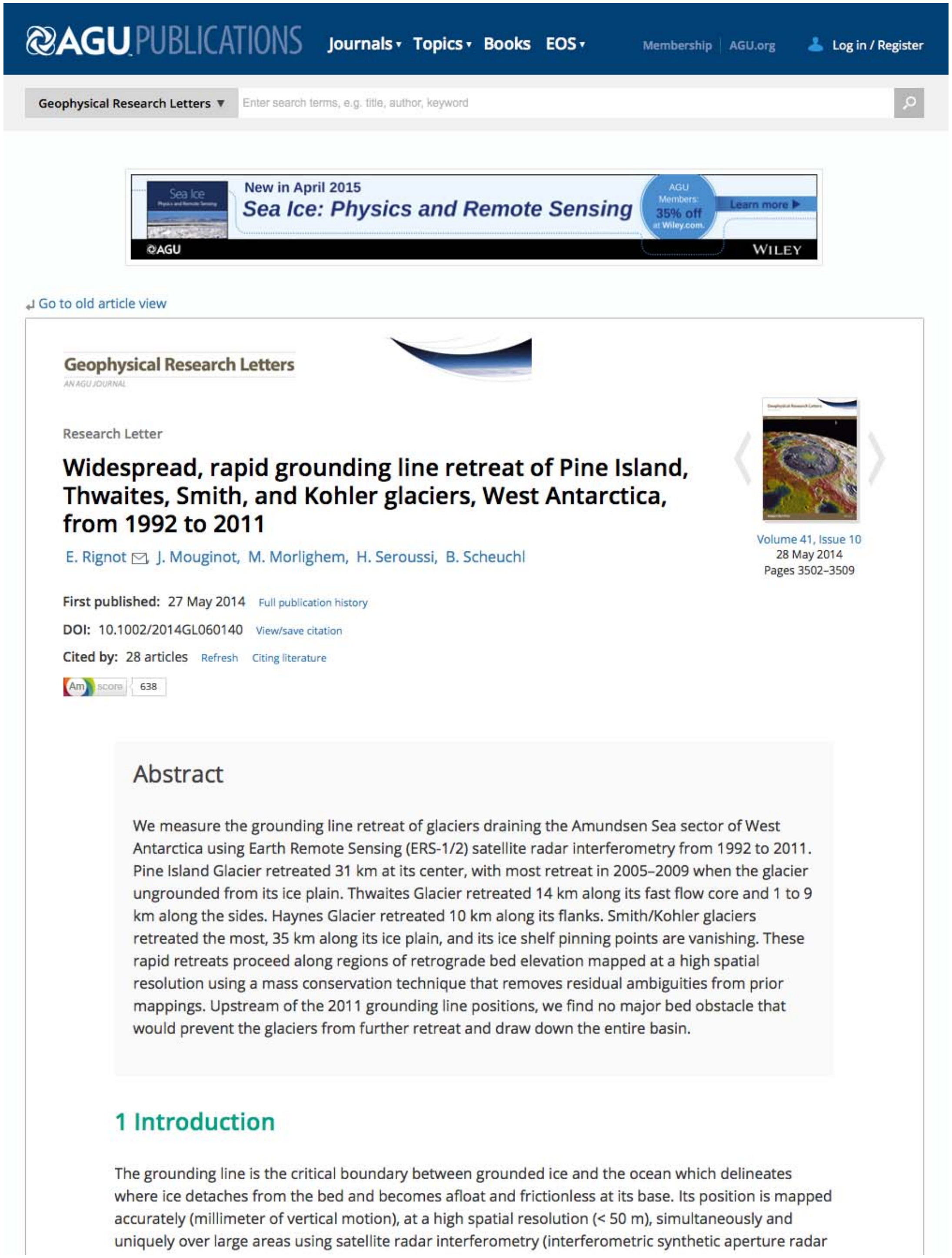
Ian Joughin, Benjamin E. Smith, Brooke Medley

± Author Affiliations

Resting atop a deep marine basin, the West Antarctic Ice Sheet has long been considered prone to instability. Using a numerical model, we investigated the sensitivity of Thwaites Glacier to ocean melt and whether its unstable retreat is already under way. Our model reproduces observed losses when forced with ocean melt comparable to estimates. Simulated losses are moderate (<0.25 mm per year at sea level) over the 21st century but generally increase thereafter. Except possibly for the lowest-melt scenario, the simulations indicate that early-stage collapse has begun. Less certain is the time scale, with the onset of rapid (>1 mm per year of sea-level rise) collapse in the different simulations within the range of 200 to 900 years.

Received for publication 27 November 2013.
Accepted for publication 21 April 2014.

The editors suggest the following Related Resources on *Science* sites



Go to old article view

Geophysical Research Letters
AN AGU JOURNAL

Research Letter

Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011

E. Rignot, J. Mouginot, M. Morlighem, H. Seroussi, B. Scheuchl

Volume 41, Issue 10
28 May 2014
Pages 3502–3509

First published: 27 May 2014 Full publication history
DOI: 10.1002/2014GL060140 View/save citation
Cited by: 28 articles Refresh Citing literature
Am score 638

Abstract

We measure the grounding line retreat of glaciers draining the Amundsen Sea sector of West Antarctica using Earth Remote Sensing (ERS-1/2) satellite radar interferometry from 1992 to 2011. Pine Island Glacier retreated 31 km at its center, with most retreat in 2005–2009 when the glacier ungrounded from its ice plain. Thwaites Glacier retreated 14 km along its fast flow core and 1 to 9 km along the sides. Haynes Glacier retreated 10 km along its flanks. Smith/Kohler glaciers retreated the most, 35 km along its ice plain, and its ice shelf pinning points are vanishing. These rapid retreats proceed along regions of retrograde bed elevation mapped at a high spatial resolution using a mass conservation technique that removes residual ambiguities from prior mappings. Upstream of the 2011 grounding line positions, we find no major bed obstacle that would prevent the glaciers from further retreat and draw down the entire basin.

1 Introduction

The grounding line is the critical boundary between grounded ice and the ocean which delineates where ice detaches from the bed and becomes afloat and frictionless at its base. Its position is mapped accurately (millimeter of vertical motion), at a high spatial resolution (< 50 m), simultaneously and uniquely over large areas using satellite radar interferometry (interferometric synthetic aperture radar

A centuries-long, process that could raise sea levels by 1.2 to 3.6 m (3.9–11.8 ft)

“unstoppable”

“melted past the point of no return”

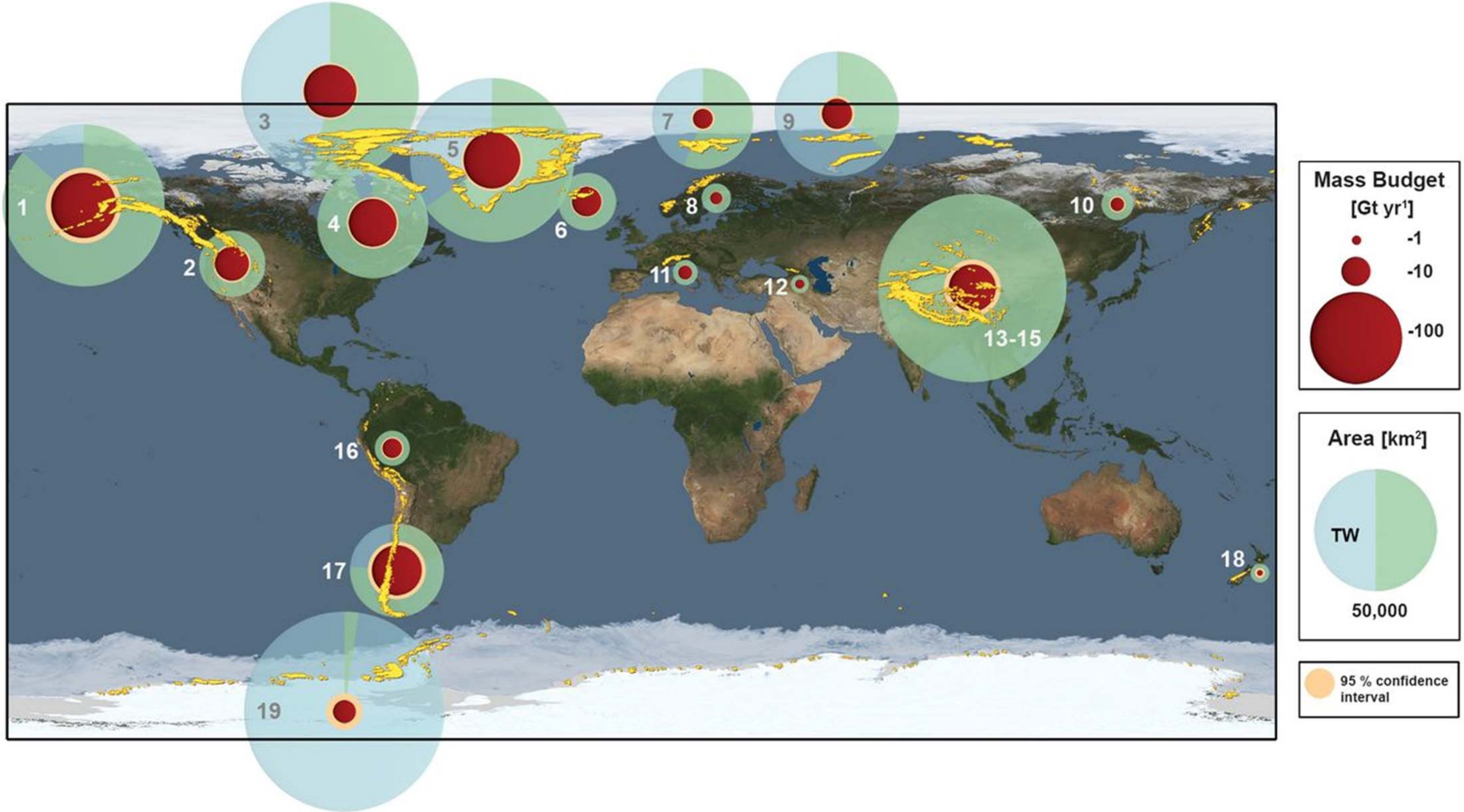
“past its tipping point”

“irreversible”

Mountain glaciers – all regions are losing mass

combined loss of Greenland and Antarctica

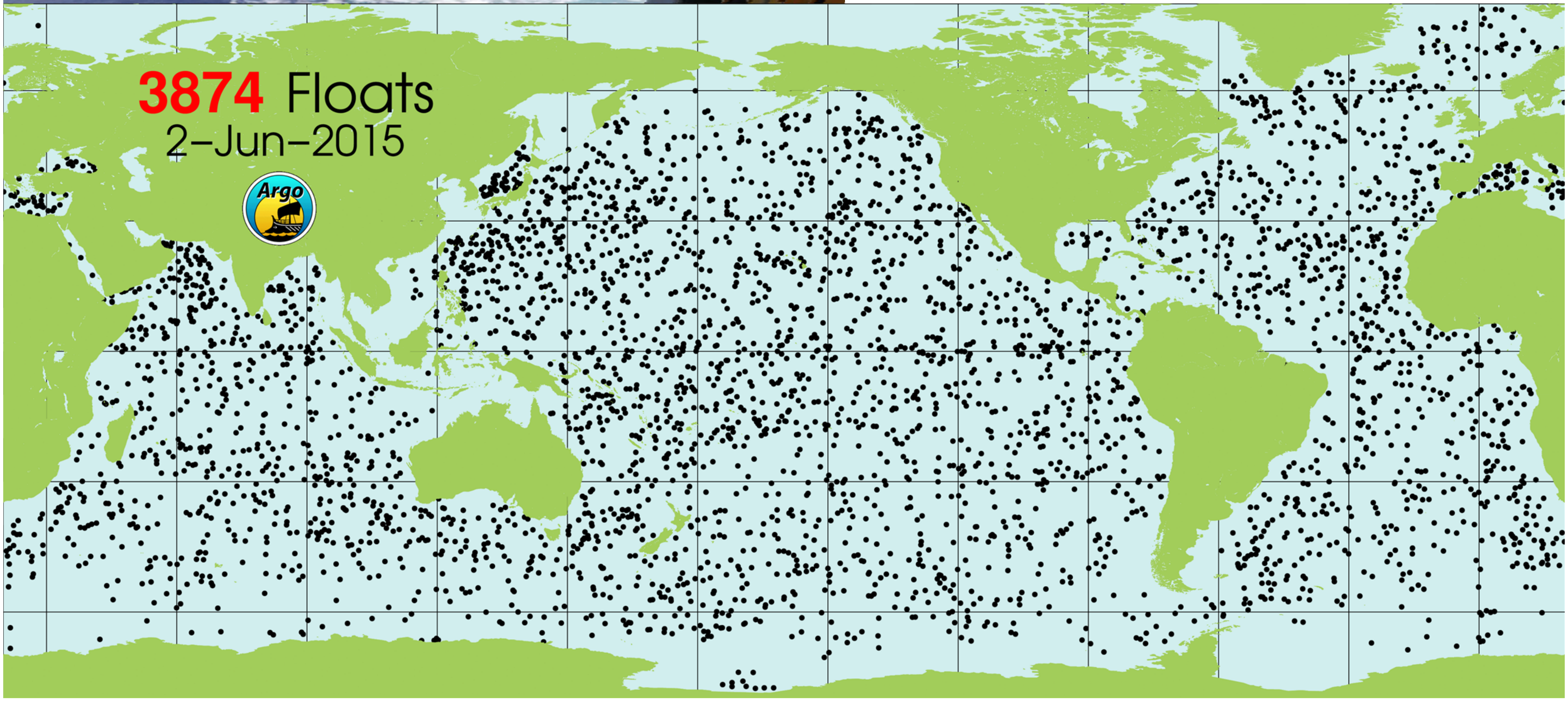
= 30% of observed sea level rise

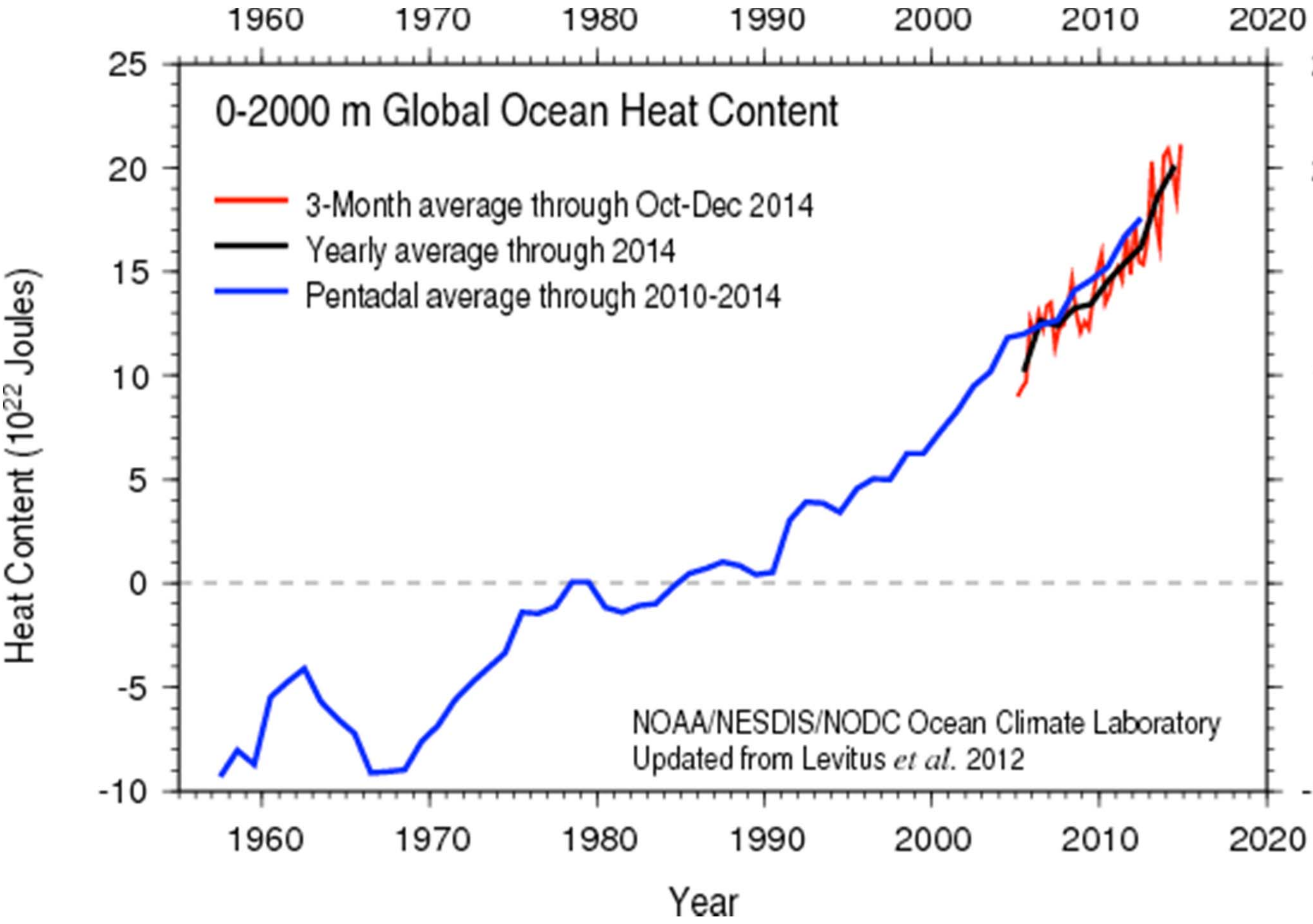


Gardner et al., 2013, A reconciled estimate of glacier contributions to sea level rise: Science: v. 340 no. 6134 pp. 852-857 DOI: 10.1126/science.1234532

Argos Floats

Programmed to measure ocean temperature and salinity through the water column

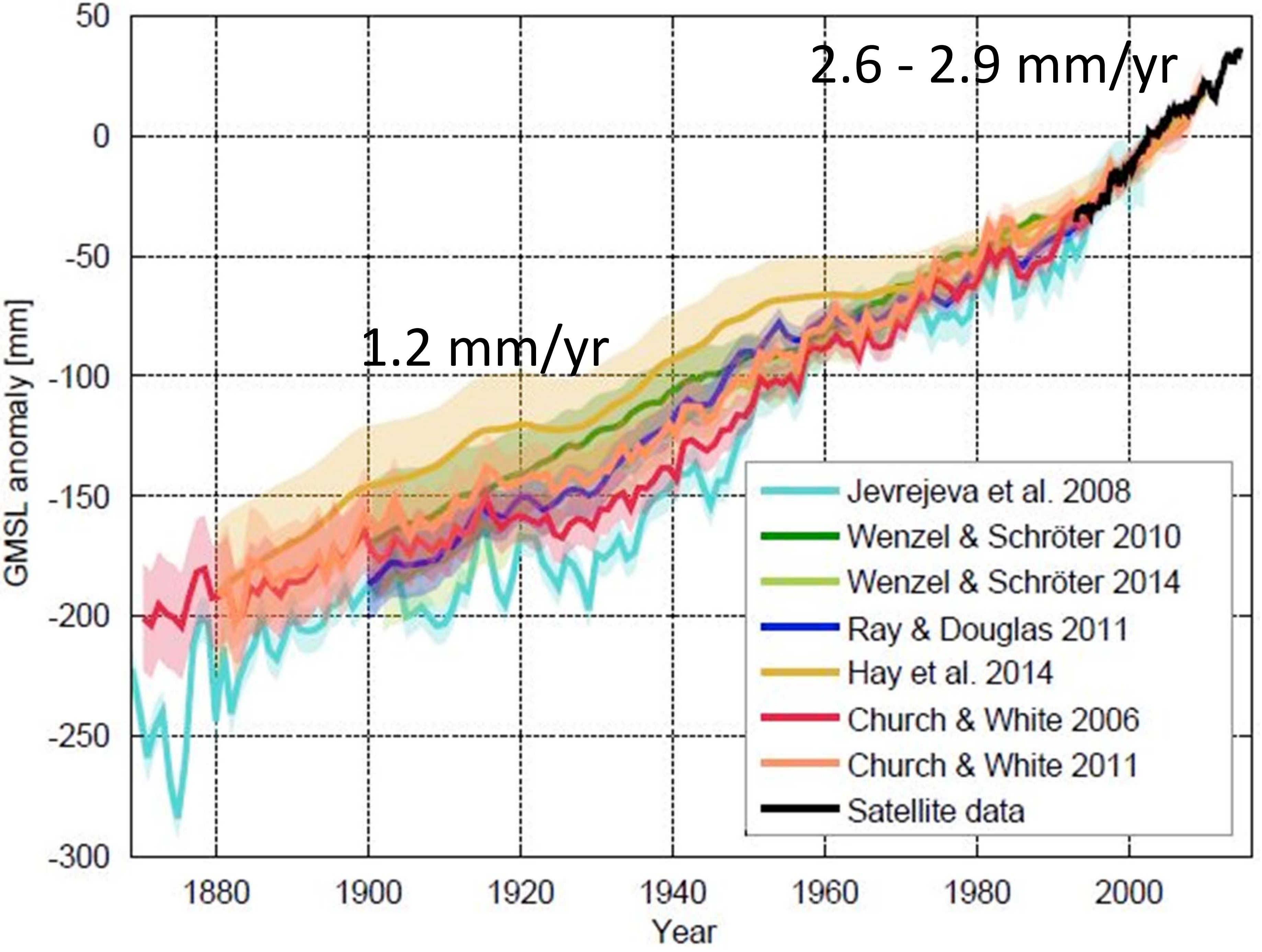




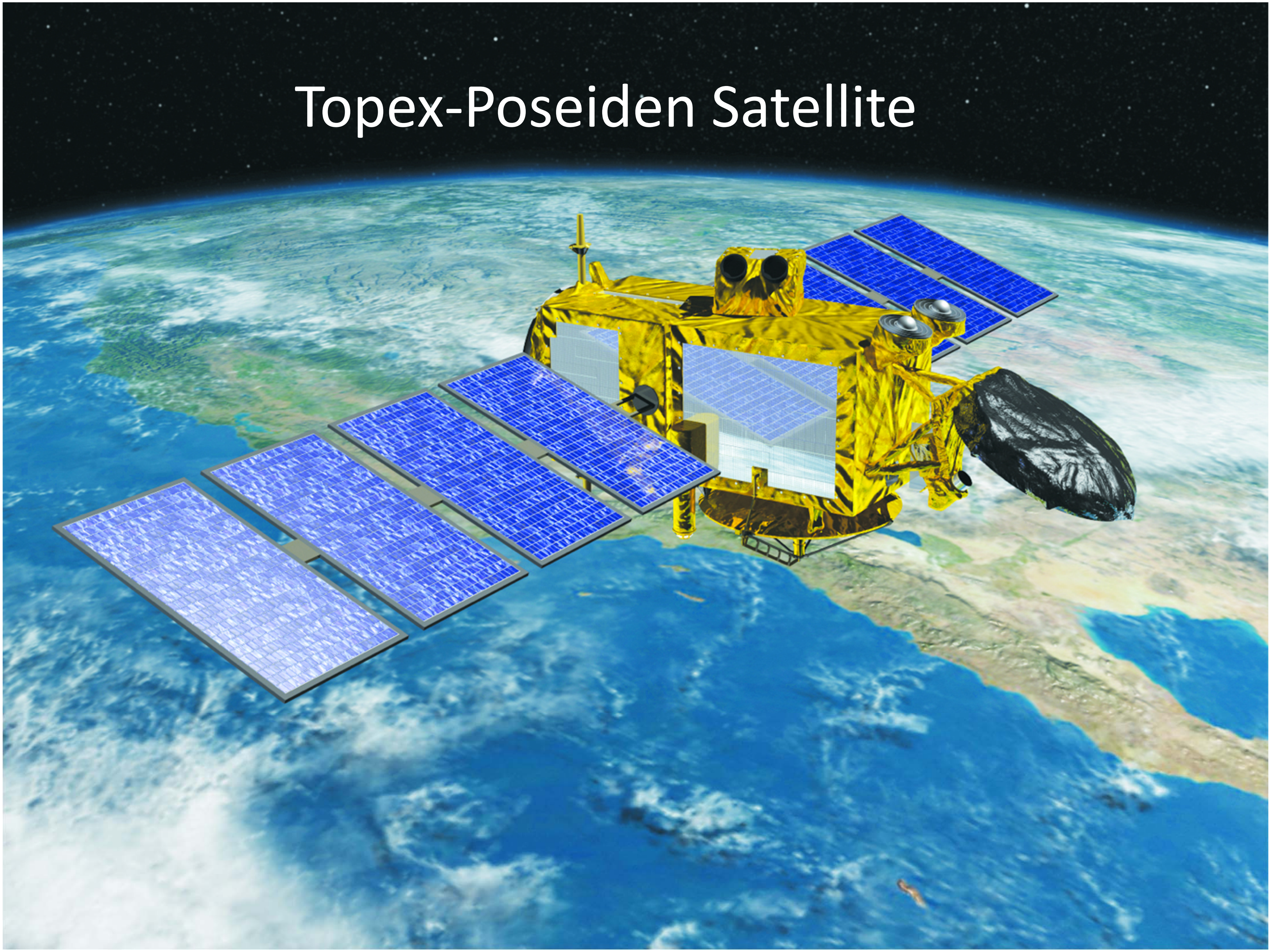
0-2000 m Global Ocean Heat Content

NOAA/NESDIS/NODC Ocean Climate Laboratory
Updated from Levitus *et al.* 2012

Global Tide Gauge Network

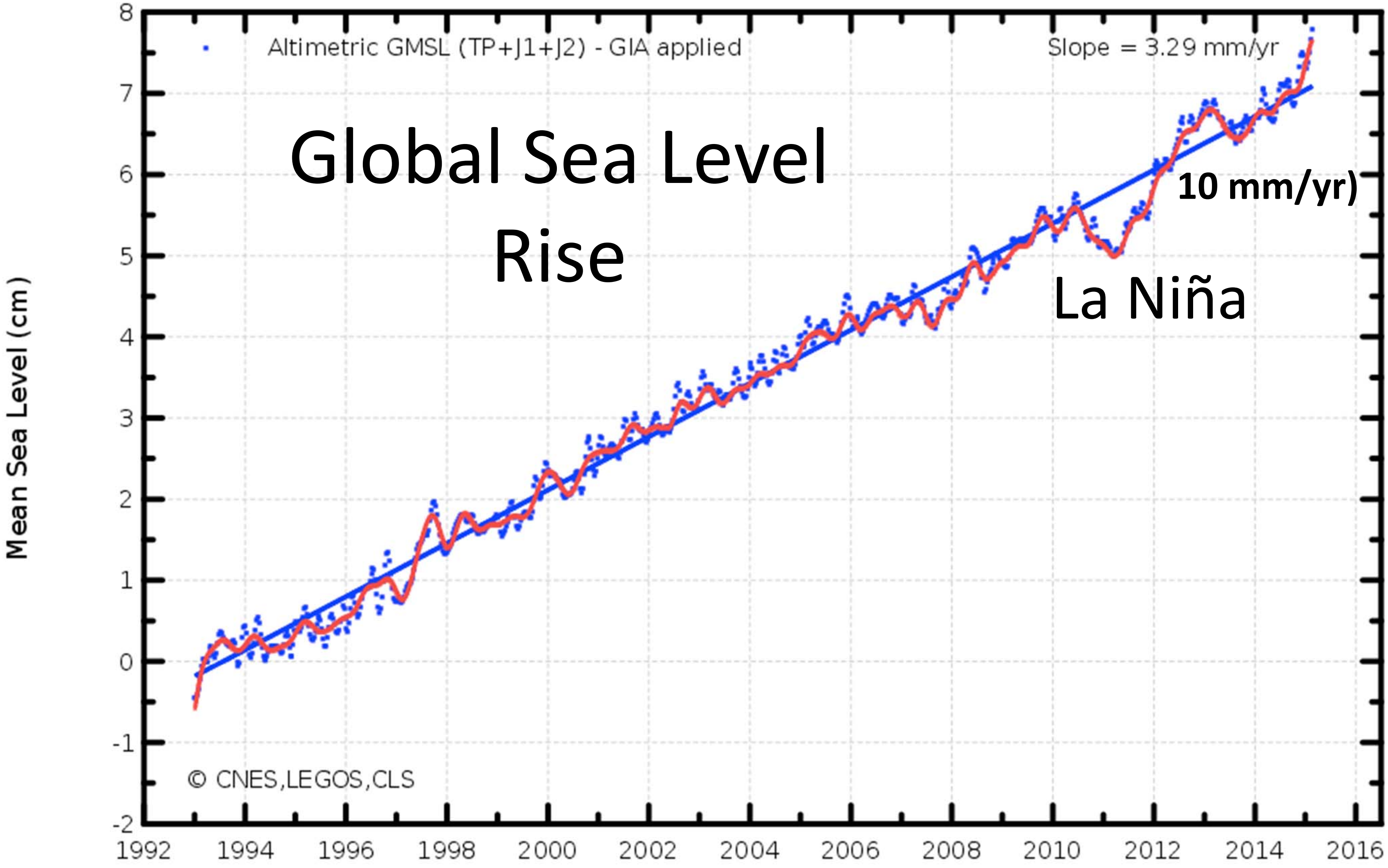

2.6 - 2.9 mm/yr
1.2 mm/yr
GMSL anomaly [mm]
50
0
-50
-100
-150
-200
-250
-300
1880
1900
1920
1940
1960
1980
2000
Year
Jevrejeva et al. 2008
Wenzel & Schröter 2010
Wenzel & Schröter 2014
Ray & Douglas 2011
Hay et al. 2014
Church & White 2006
Church & White 2011
Satellite data

Topex-Poseiden Satellite



Global Sea Level Rise

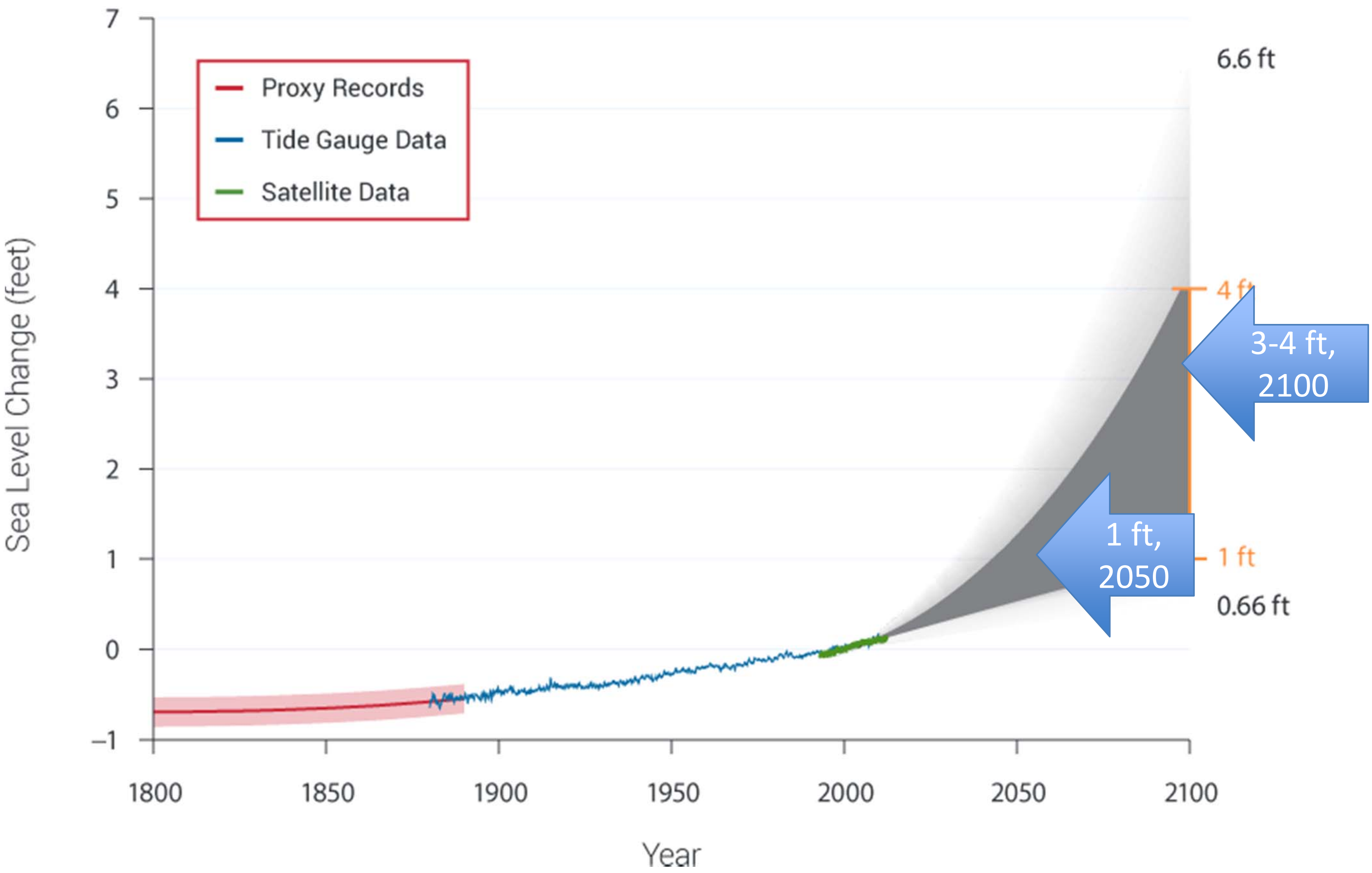
El Niño



10 mm/yr)

La Niña

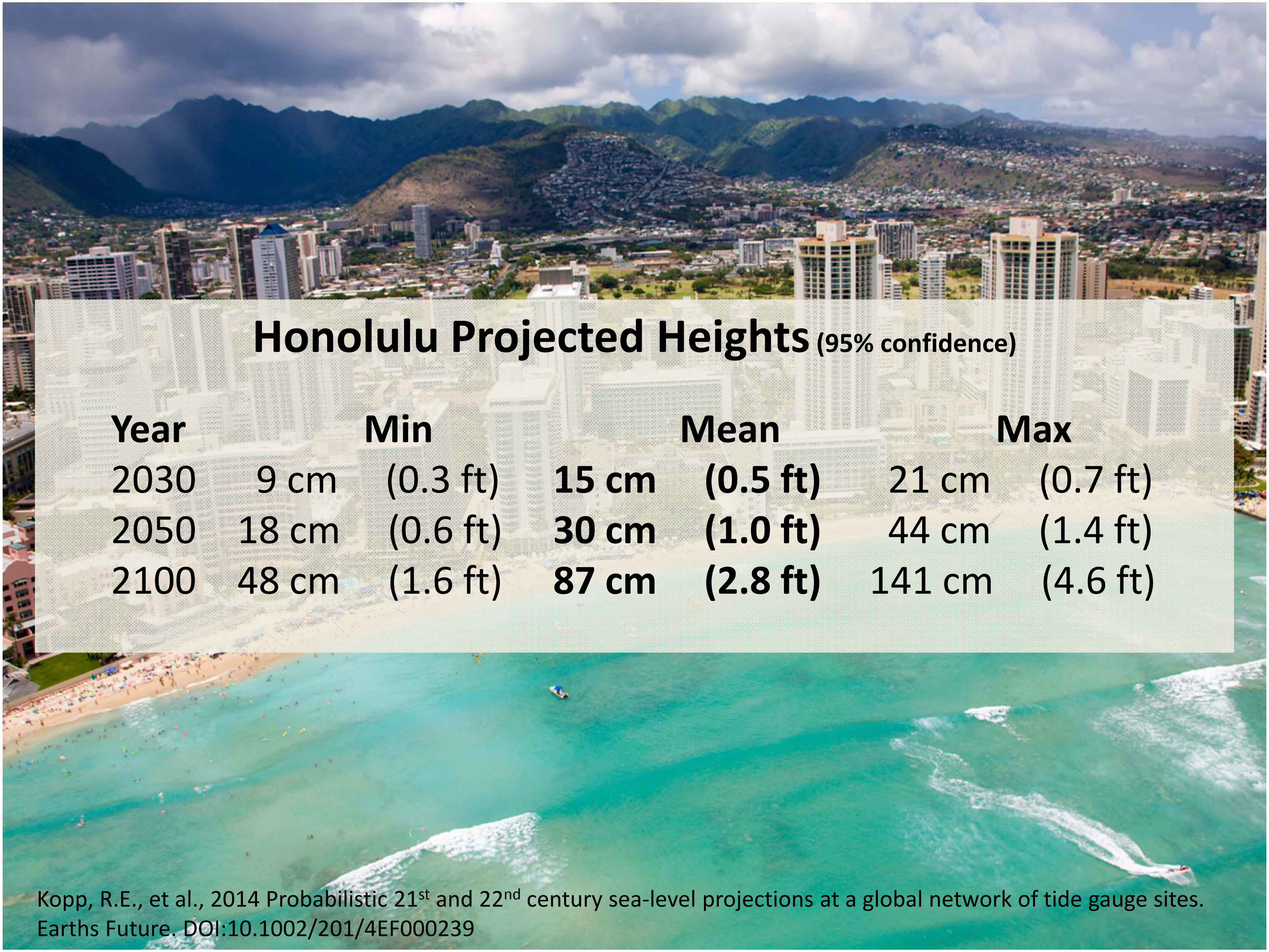
Past and Projected Changes in Global Sea Level



3-4 ft, 2100

1 ft, 2050

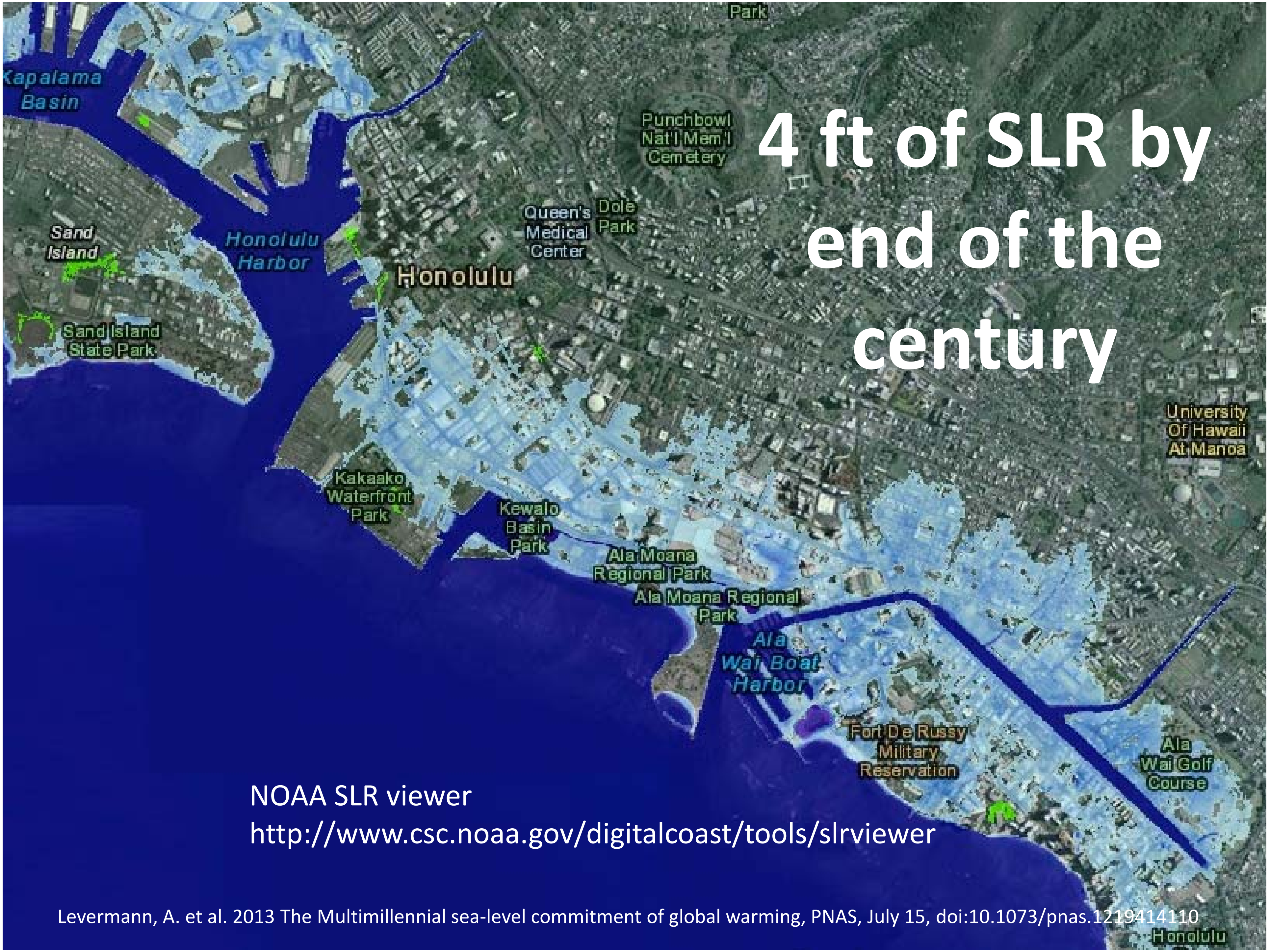
Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.



Honolulu Projected Heights (95% confidence)

Year	Min		Mean		Max	
2030	9 cm	(0.3 ft)	**15 cm**	**(0.5 ft)**	21 cm	(0.7 ft)
2050	18 cm	(0.6 ft)	**30 cm**	**(1.0 ft)**	44 cm	(1.4 ft)
2100	48 cm	(1.6 ft)	**87 cm**	**(2.8 ft)**	141 cm	(4.6 ft)

Kopp, R.E., et al., 2014 Probabilistic 21st and 22nd century sea-level projections at a global network of tide gauge sites. Earths Future. DOI:10.1002/201/4EF000239

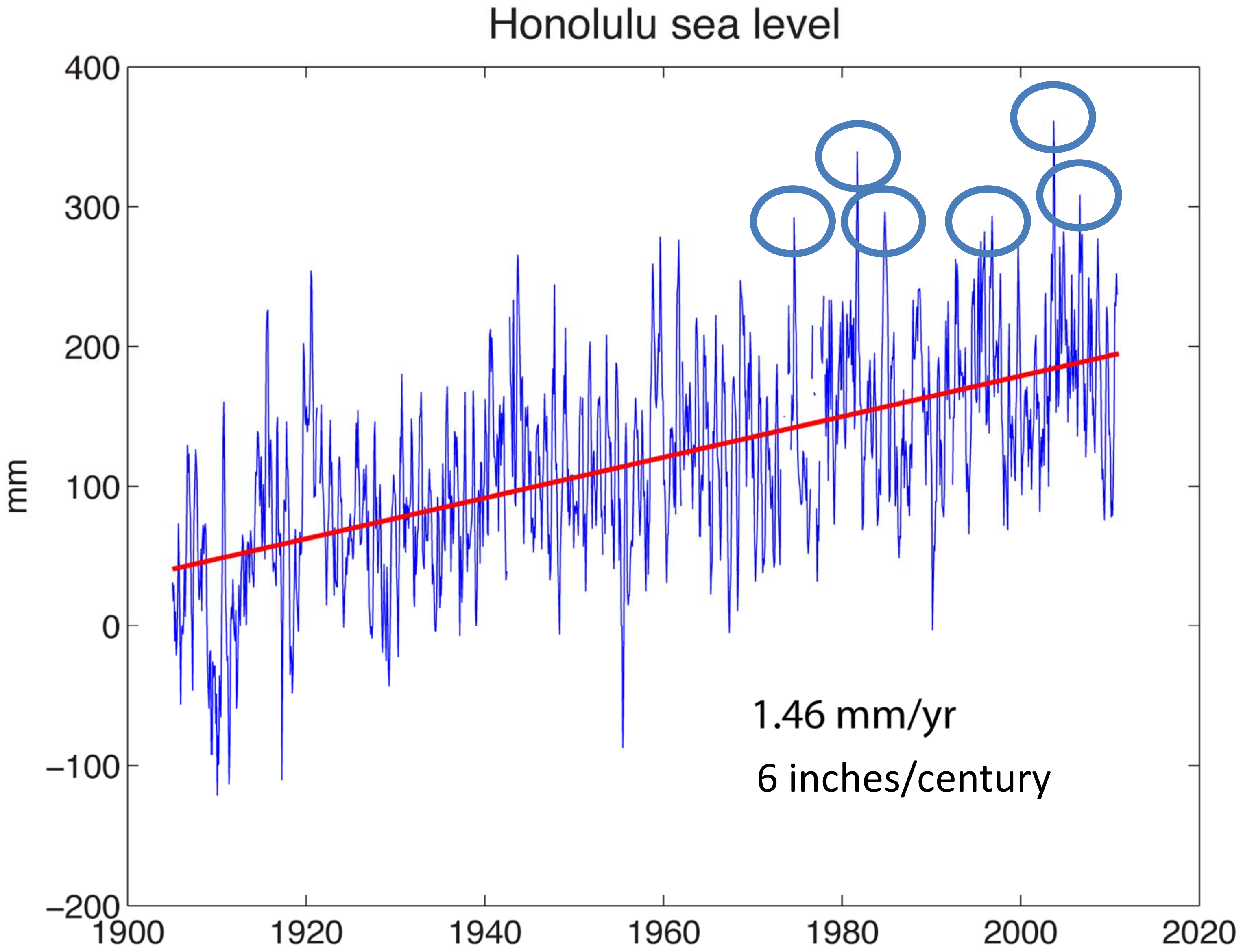


4 ft of SLR by end of the century

NOAA SLR viewer
http://www.csc.noaa.gov/digitalcoast/tools/slrviewer

Levermann, A. et al. 2013 The Multimillennial sea-level commitment of global warming, PNAS, July 15, doi:10.1073/pnas.1219414110

Honolulu Sea Level

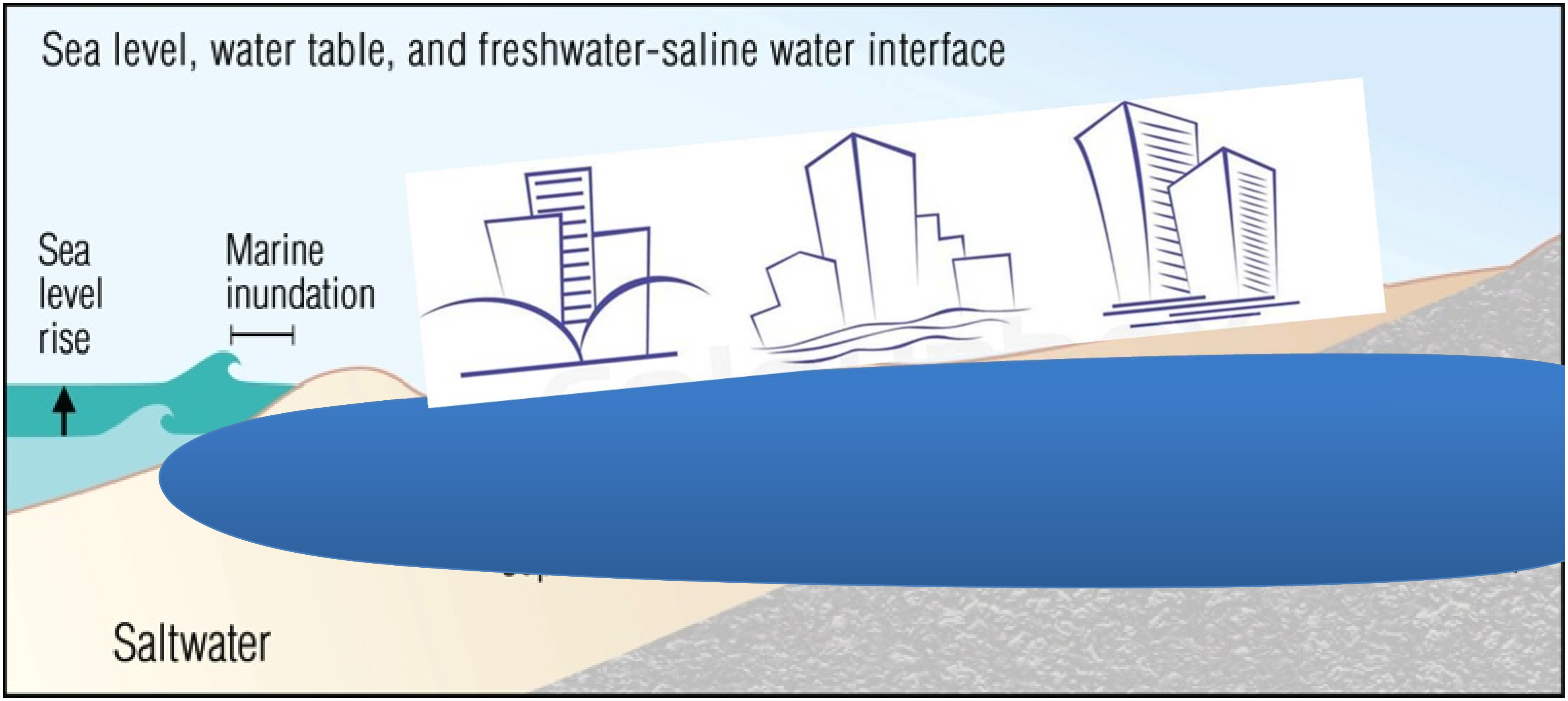


Mahalos to UH Oceanography Professor Mark Merrifield, UH Sea Level Center, Joint Institutes for Marine and Atmospheric Research

Storm drains back up at high tide.

High Tide, Miami - $400 M in pumps and cisterns

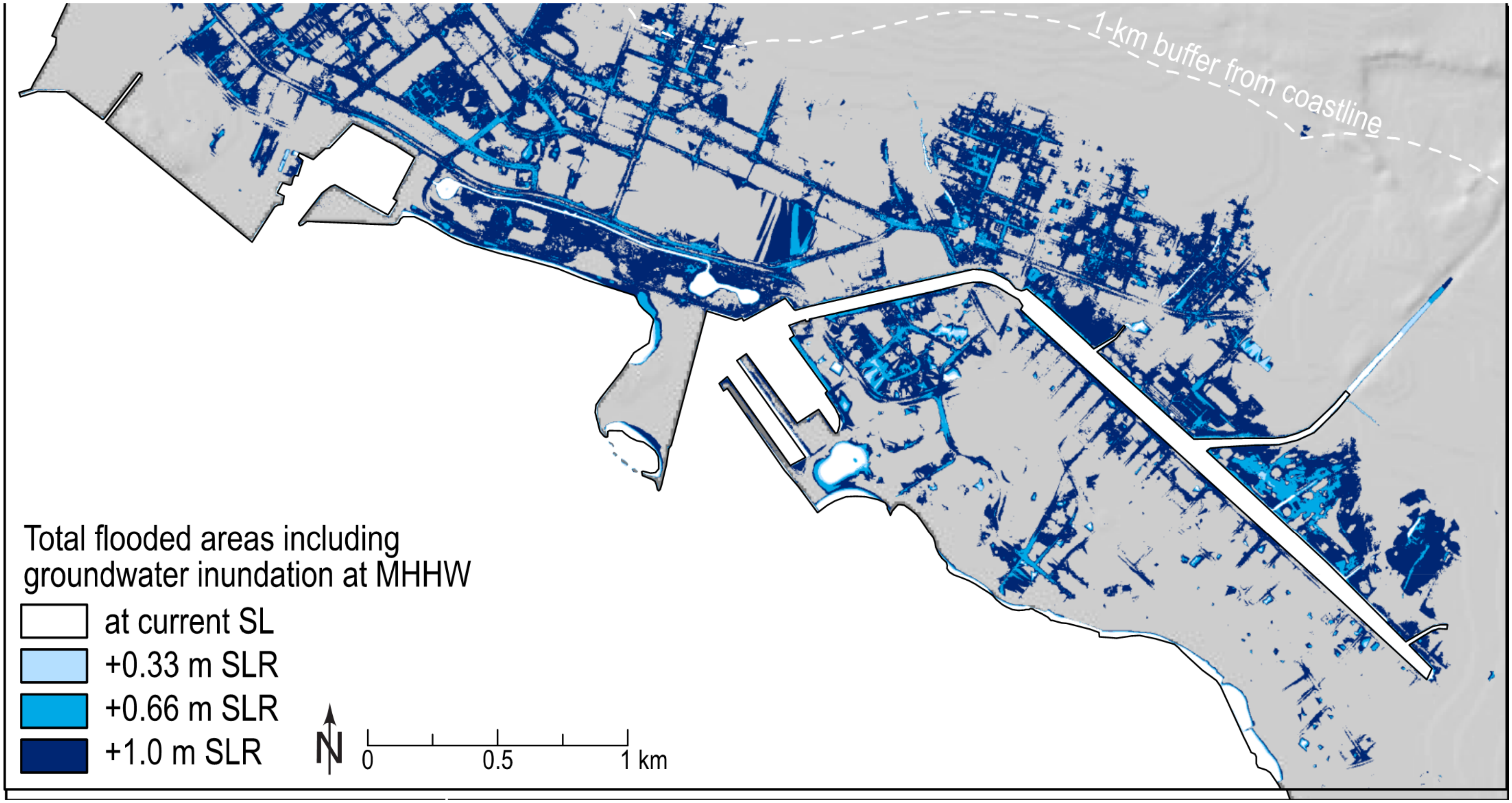
Groundwater Inundation



Rotzoll, K., and Fletcher, C. *in press*, Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Science

Marine and Groundwater Inundation

At 0.66 m, 69% of total flooded area is due to groundwater inundation



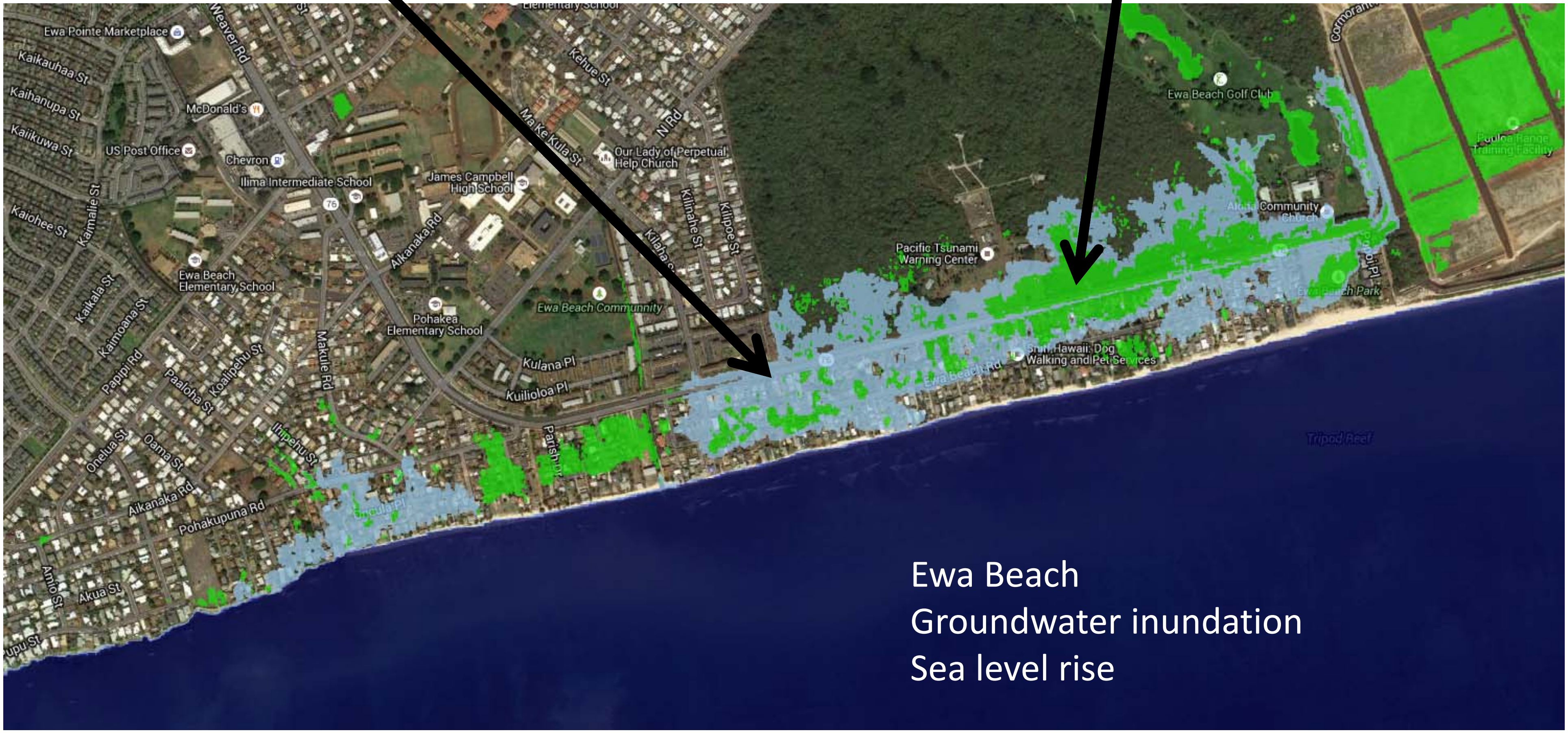
Rotzoll, K., and Fletcher, C. *in press*, Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Science


HONOLULU ZOO


Fort DeRussy
C&C HON

Green – Groundwater inundation

Blue– Marine inundation

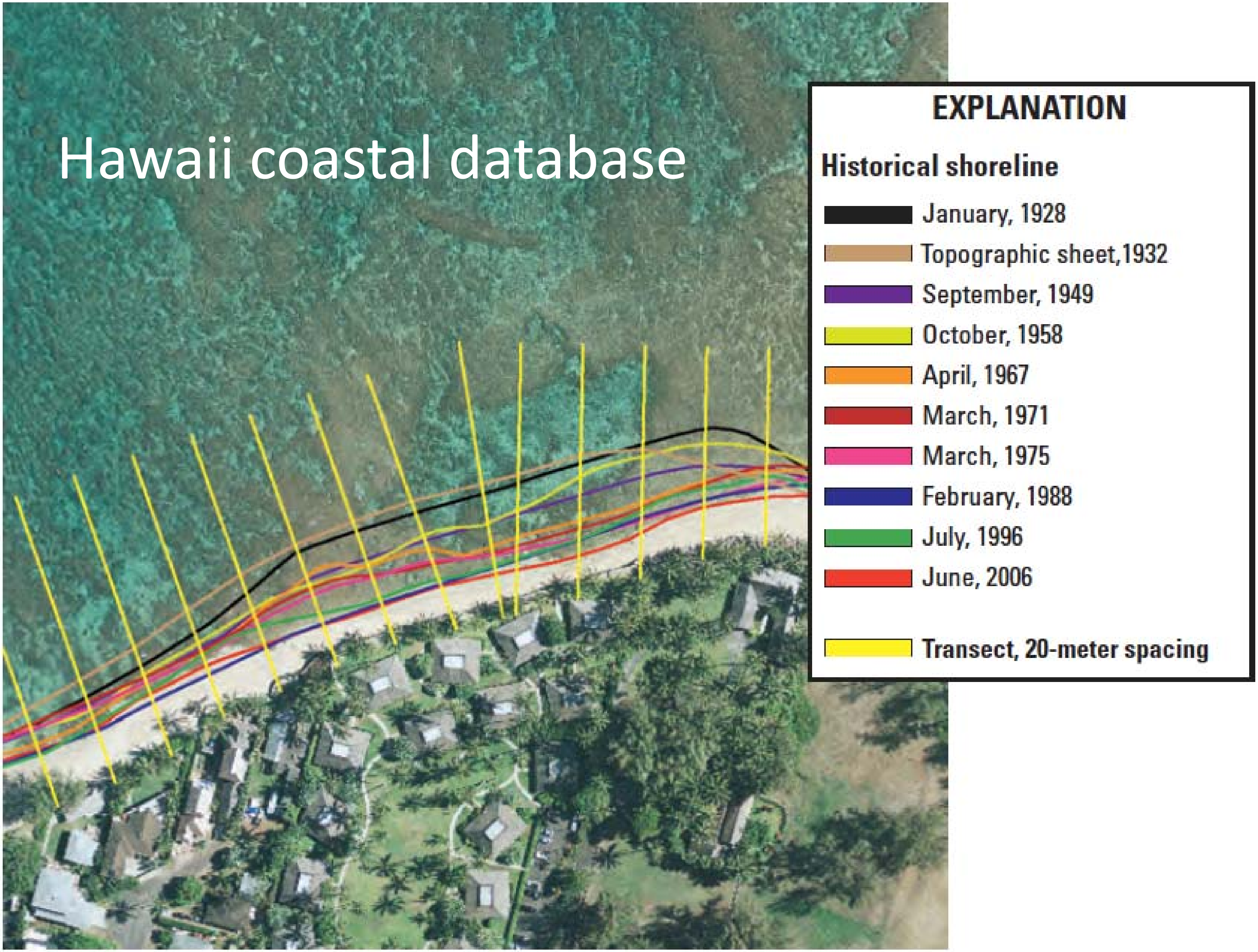


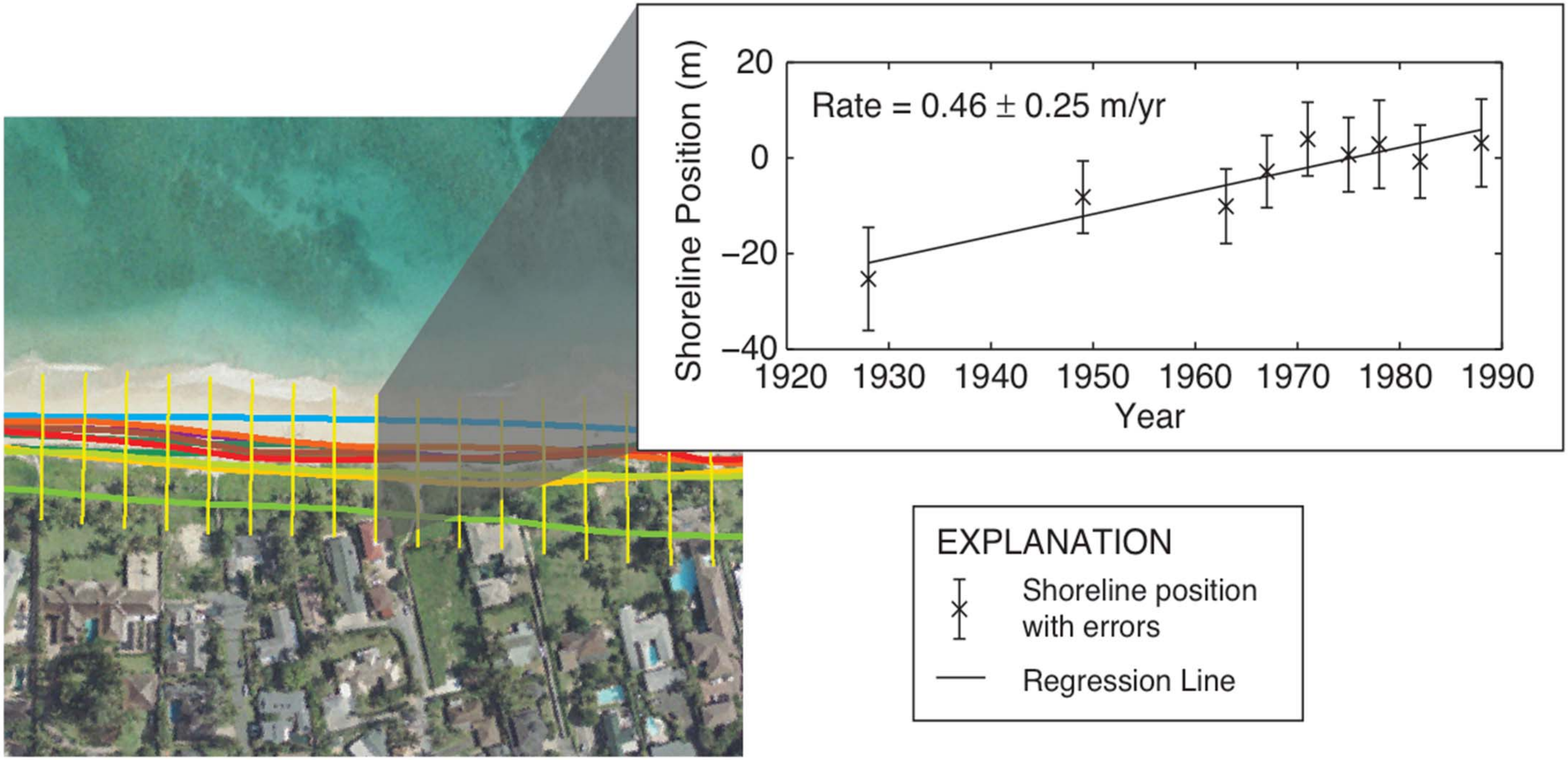
Ewa Beach
Groundwater inundation
Sea level rise

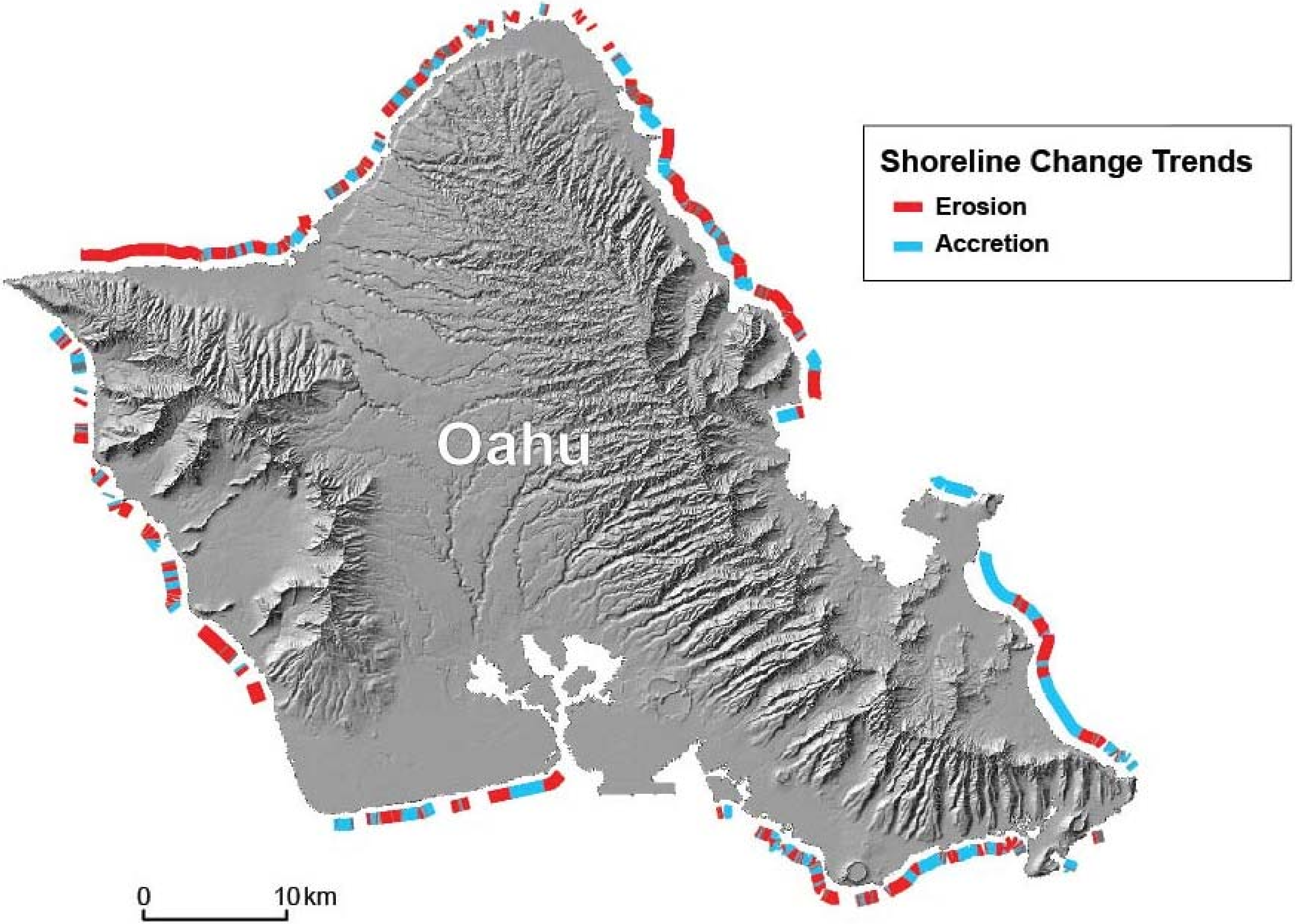
Coastal Erosion

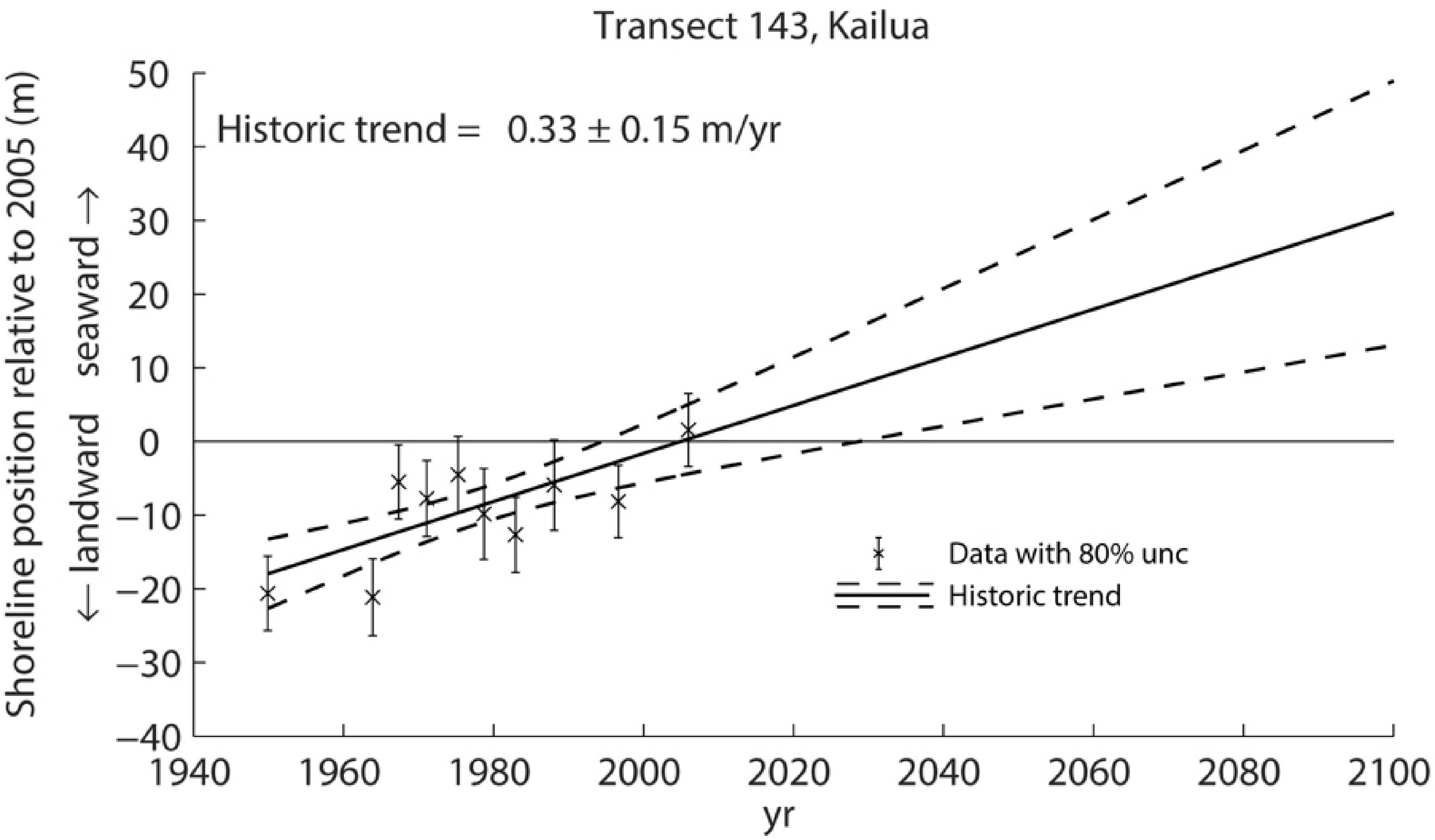
Romine, B., et al., 2013, Are beach erosion rates and sea level rise related in Hawaii? Global and Planetary Change. P. 149-157.

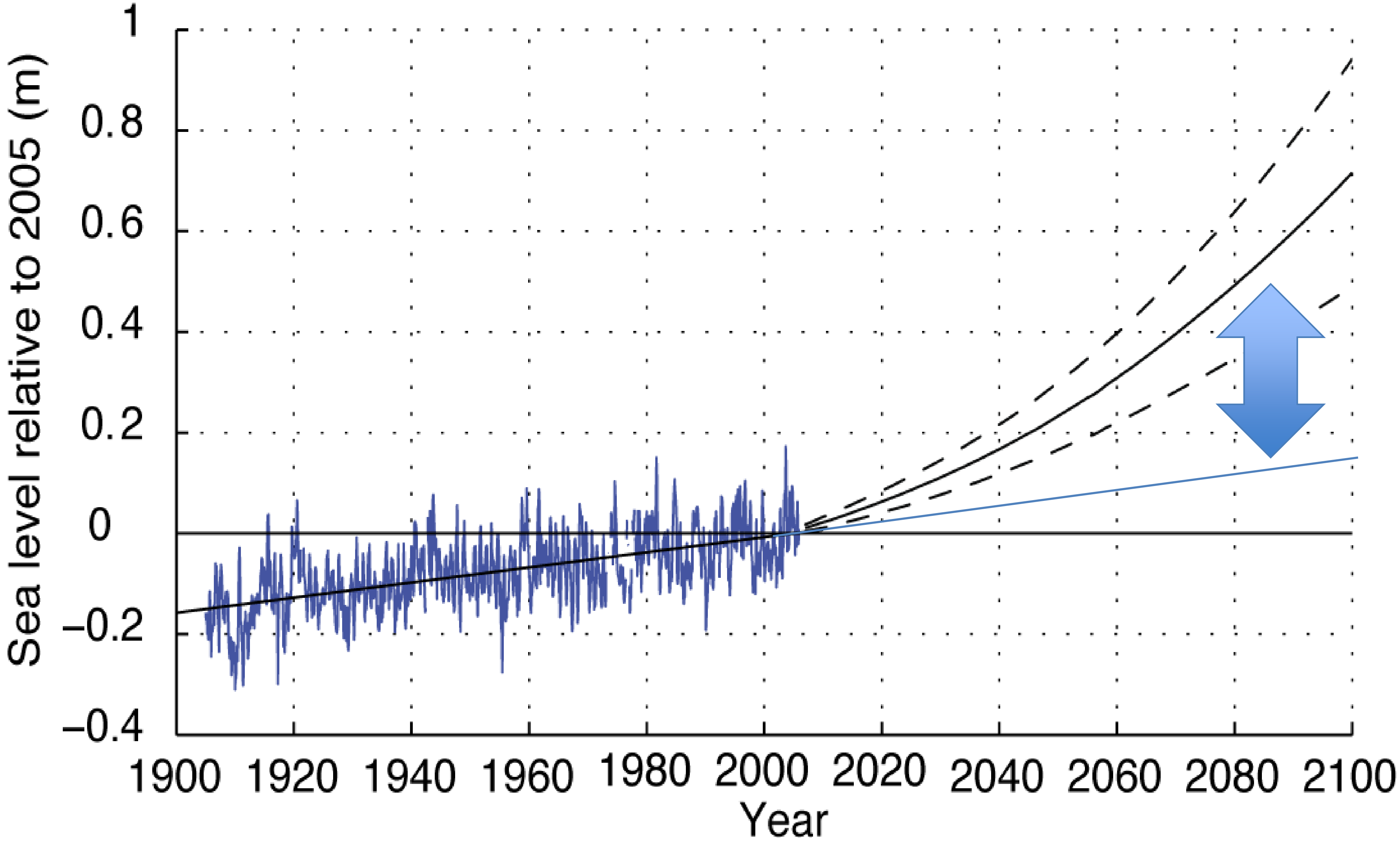
Hawaii coastal database

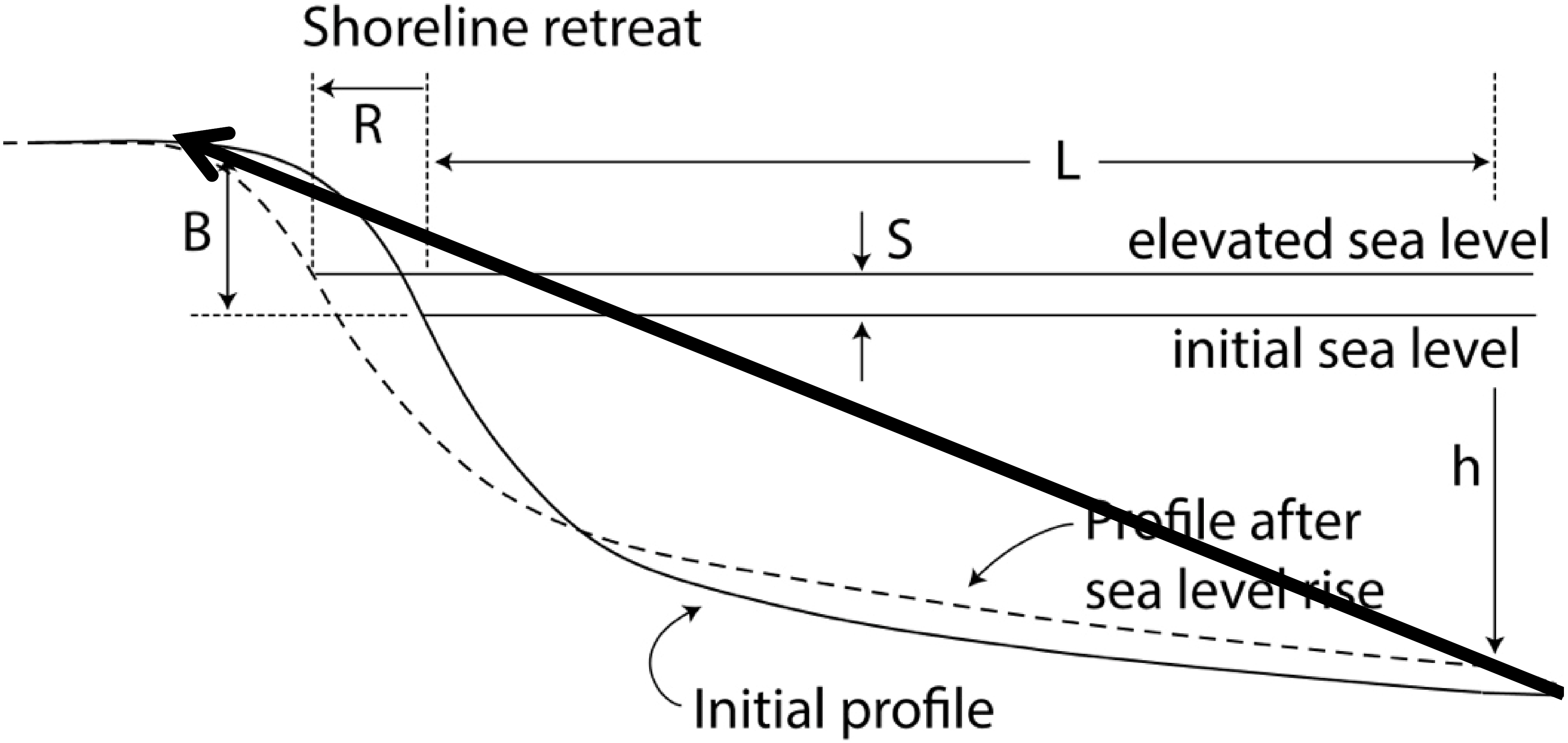


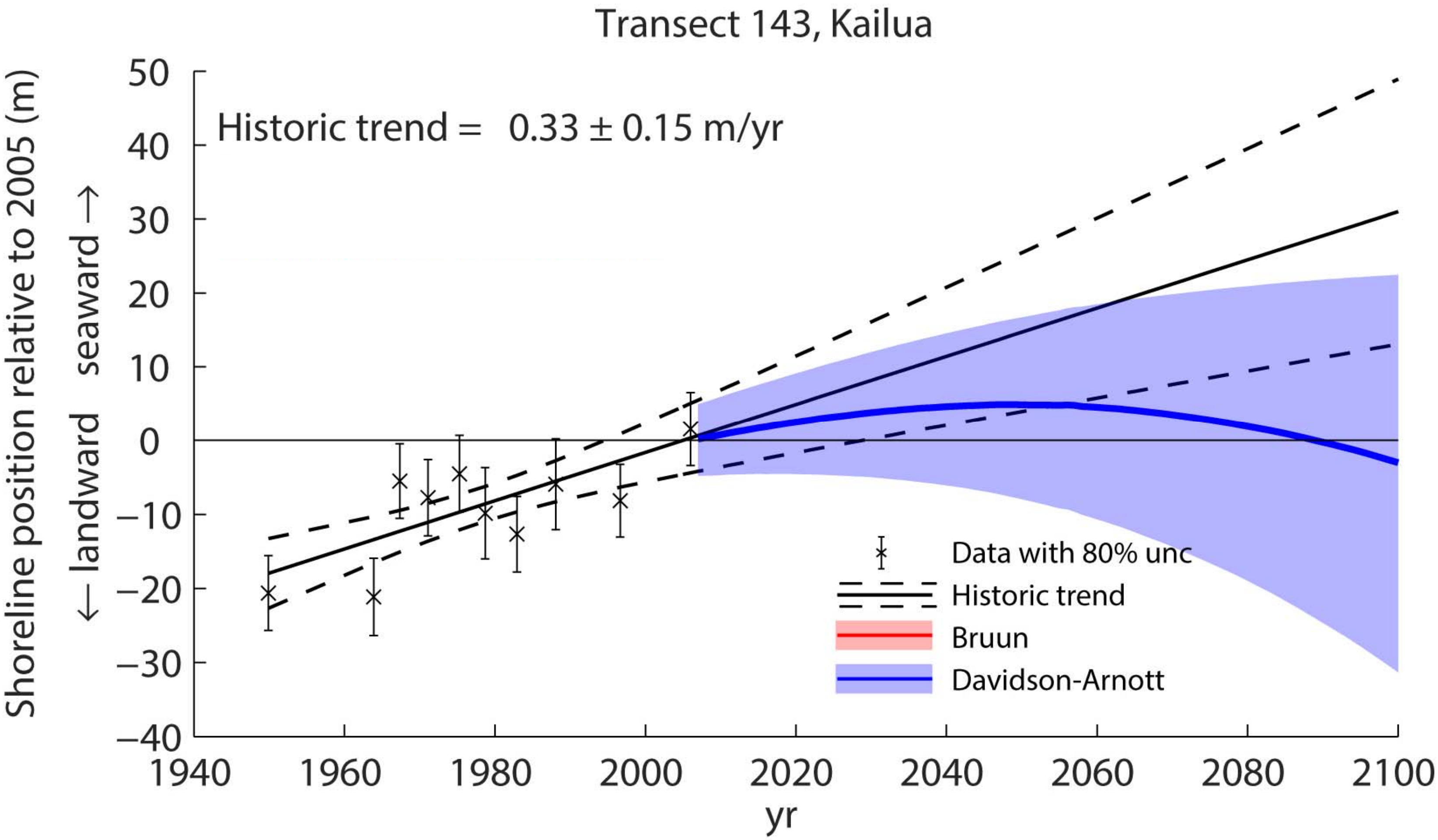

Shoreline Position (m)
20
0
−20
−40
Rate = 0.46 ± 0.25 m/yr
1920
1930
1940
1950
1960
1970
1980
1990
Year
EXPLANATION
Shoreline position with errors
Regression Line

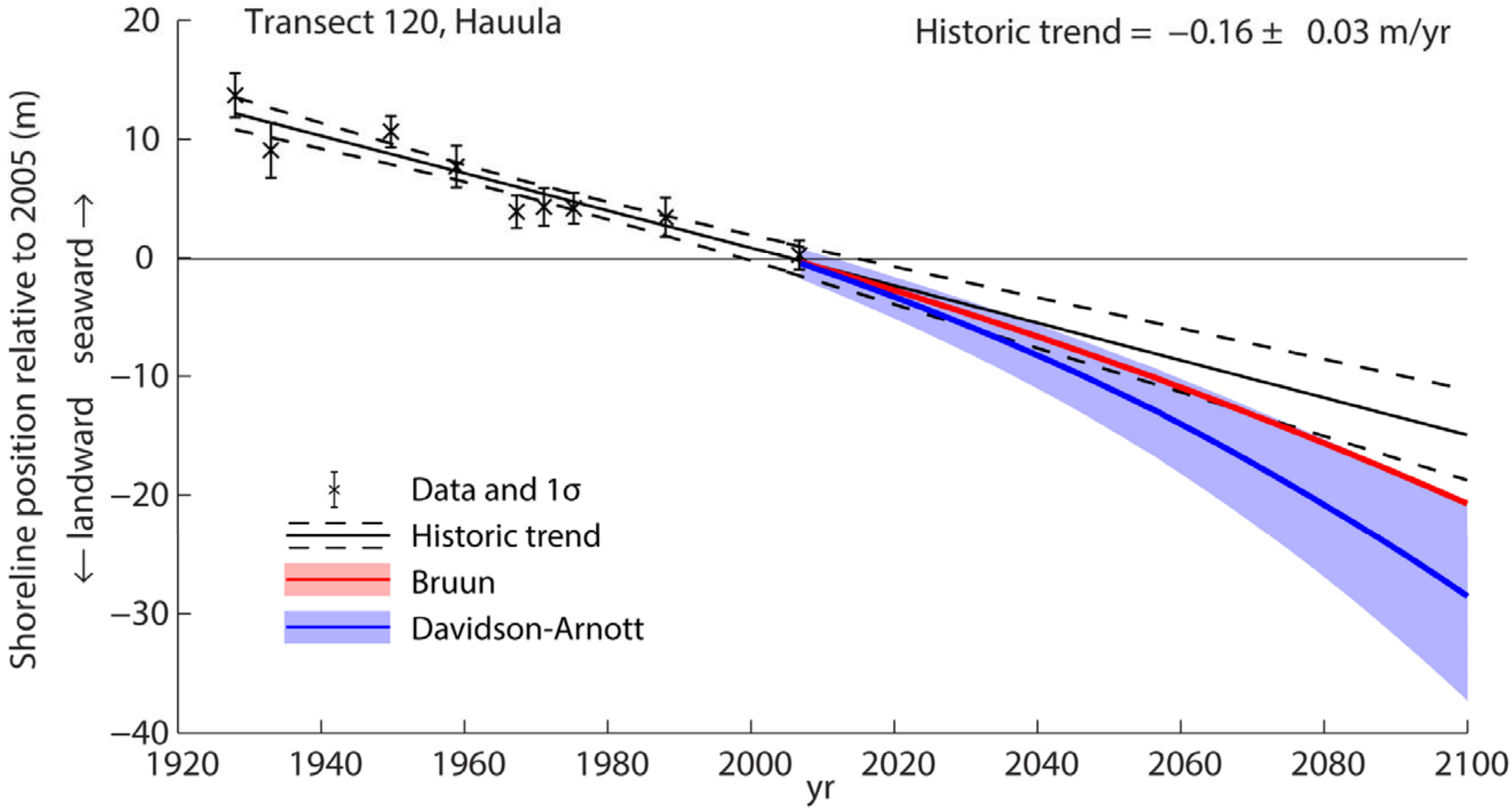

Shoreline Change Trends
🟥 Erosion
🟦 Accretion
Oahu
0
10 km


Transect 143, Kailua
Historic trend = 0.33 ± 0.15 m/yr
Shoreline position relative to 2005 (m)
← landward seaward →
50
40
30
20
10
0
−10
−20
−30
−40
1940
1960
1980
2000
2020
2040
2060
2080
2100
yr
Data with 80% unc
Historic trend


Sea level relative to 2005 (m)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
Year


Shoreline retreat
R
L
B
S
elevated sea level
initial sea level
h
Profile after
sea level rise
Initial profile

 Transect 143, Kailua


Transect 120, Hauula
Historic trend = −0.16 ± 0.03 m/yr
Shoreline position relative to 2005 (m)
← landward seaward →
20
10
0
−10
−20
−30
−40
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
yr
Data and 1σ
Historic trend
Bruun
Davidson-Arnott

Nat Hazards
DOI 10.1007/s11069-015-1698-6

ORIGINAL PAPER

Doubling of coastal erosion under rising sea level by mid-century in Hawaii

Tiffany R. Anderson[1] · **Charles H. Fletcher**[1] ·
Matthew M. Barbee[1] · **L. Neil Frazer**[1] ·
Bradley M. Romine[2]

Received: 28 January 2015 / Accepted: 11 March 2015

Abstract Chronic erosion in Hawaii causes beach loss, damages homes and infrastructure, and endangers critical habitat. These problems will likely worsen with increased sea level rise (SLR). We forecast future coastal change by combining historical shoreline trends with projected accelerations in SLR (IPCC RCP8.5) using the Davidson-Arnott profile model. The resulting erosion hazard zones are overlain on aerial photos and other GIS layers to provide a tool for identifying assets exposed to future coastal erosion. We estimate rates and distances of shoreline change for ten study sites across the Hawaiian Islands. Excluding one beach (Kailua) historically dominated by accretion, approximately 92 and 96 % of the shorelines studied are projected to retreat by 2050 and 2100, respectively. Most projections (~80 %) range between 1–24 m of landward movement by 2050 (relative to 2005) and 4–60 m by 2100, except at Kailua which is projected to begin receding around 2050. Compared to projections based only on historical extrapolation, those that include accelerated SLR have an average 5.4 ± 0.4 m (±standard deviation of the average) of additional shoreline recession by 2050 and 18.7 ± 1.5 m of additional recession by 2100. Due to increasing SLR, the average shoreline recession by 2050 is nearly twice the historical extrapolation, and by 2100 it is nearly 2.5 times the historical extrapolation. Our approach accounts for accretion and long-term sediment processes (based on historical trends) in projecting future shoreline position. However, it does not incorporate potential future changes in nearshore hydrodynamics associated with accelerated SLR.

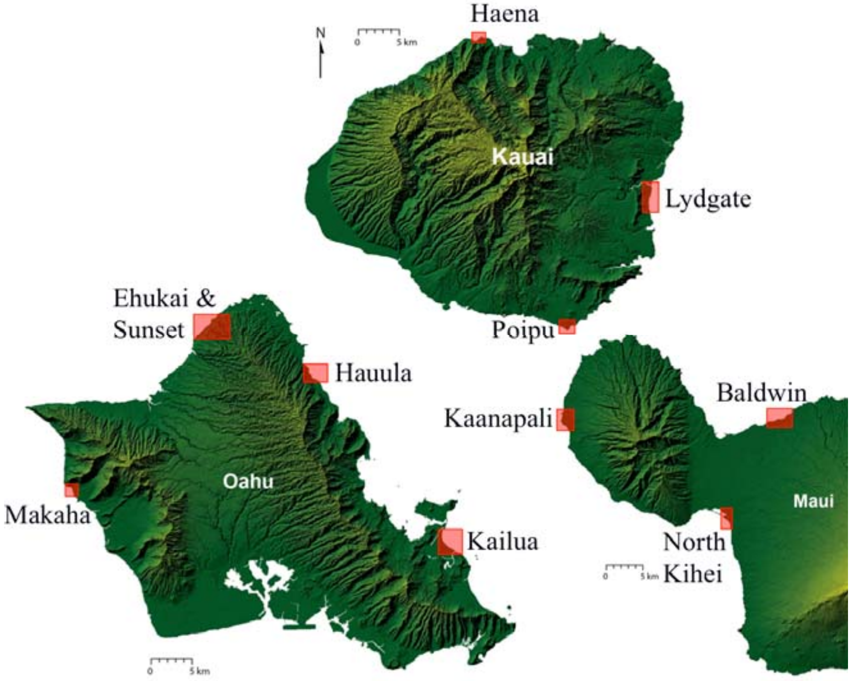
Electronic supplementary material The online version of this article (doi:10.1007/s11069-015-1698-6) contains supplementary material, which is available to authorized users.

✉ Tiffany R. Anderson
tranders@hawaii.edu

[1] Department of Geology and Geophysics, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, 1680 East-West Road, POST Room 721, Honolulu, HI 96822, USA

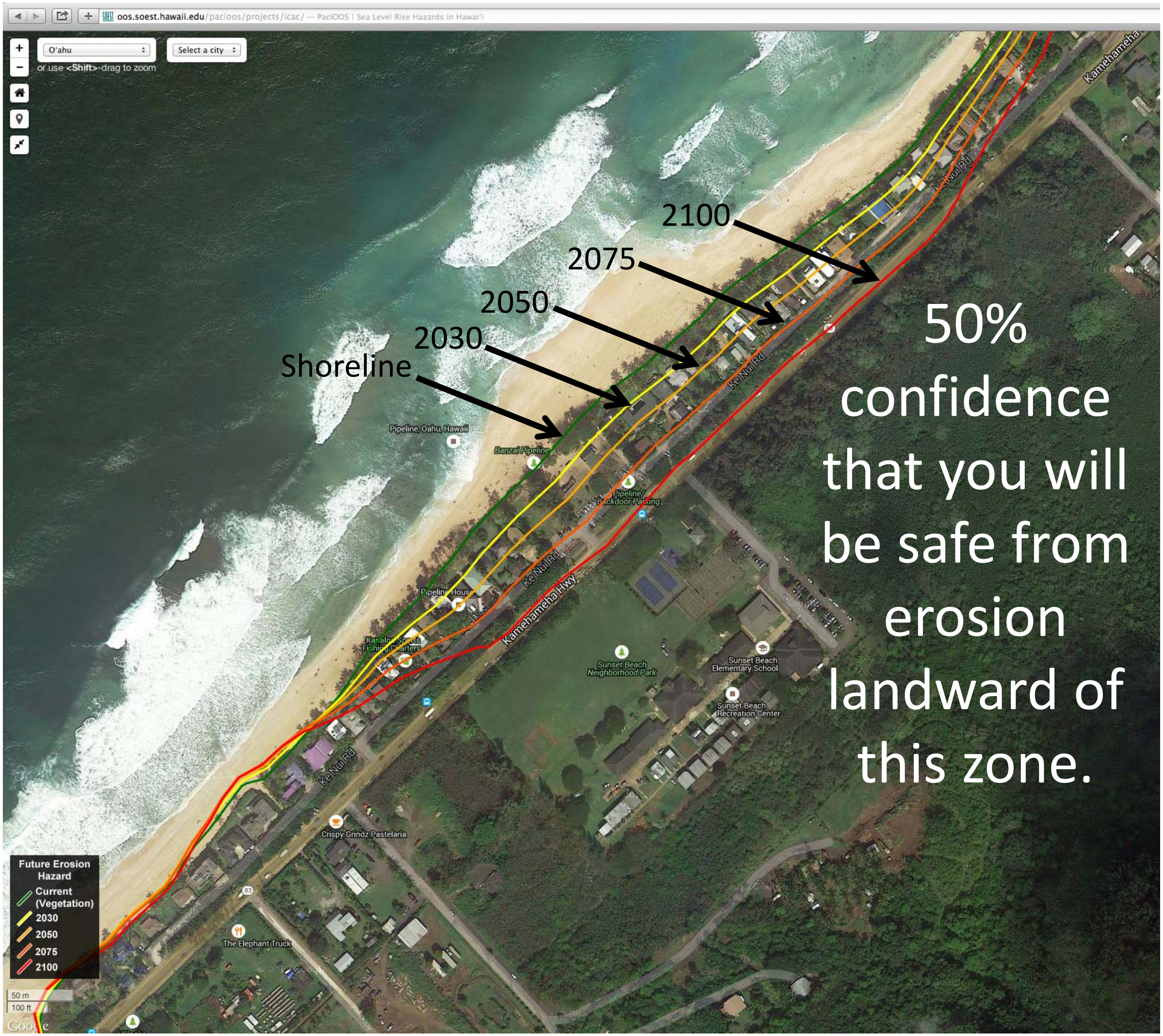
[2] University of Hawaii Sea Grant College Program c/o Department of Land and Natural Resources, Office of Conservation and Coastal Lands, 1151 Punchbowl Street, Room 131, Honolulu, HI 96813, USA

Springer

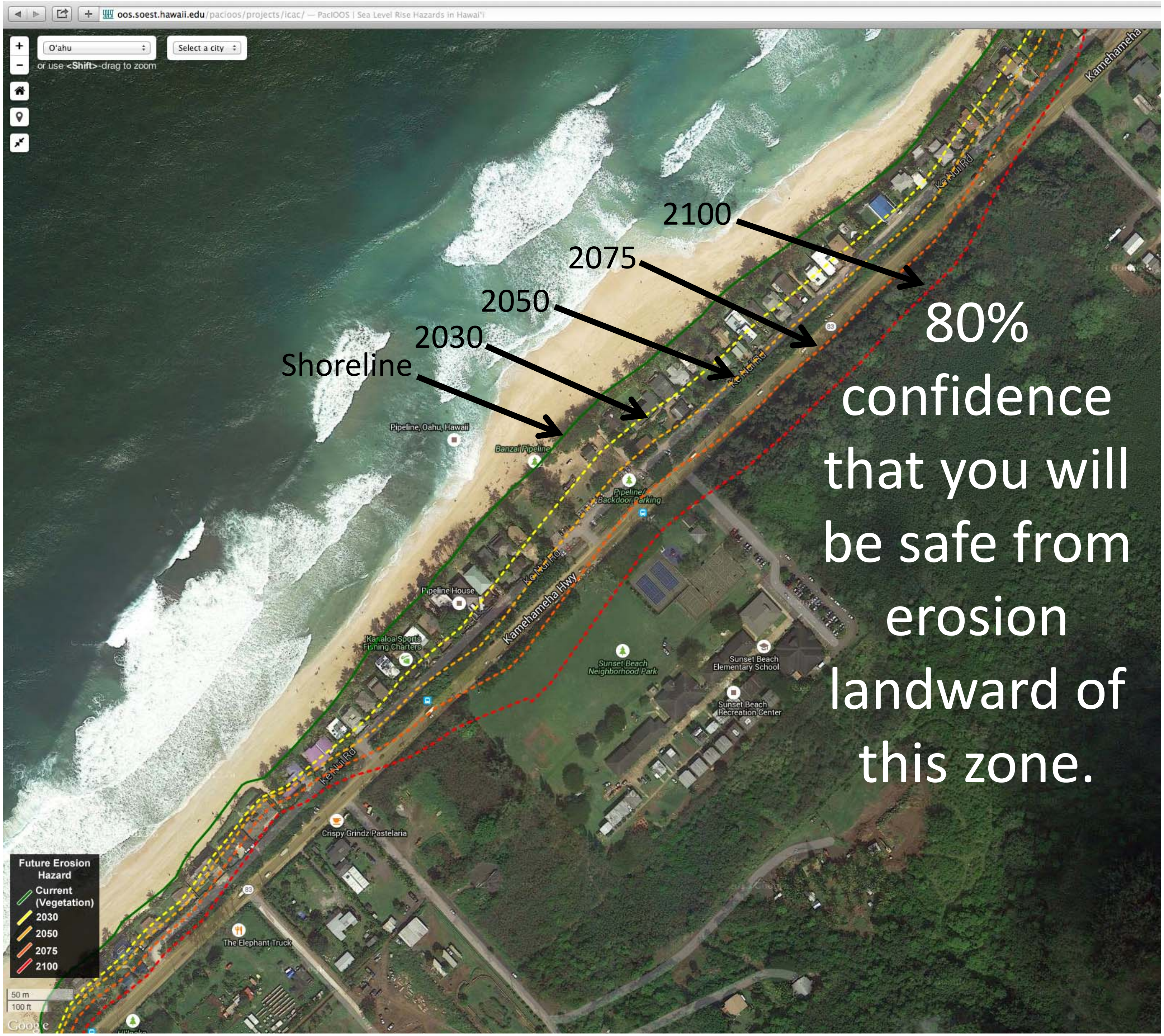


Approximately 92 and 96 % of the shorelines studied are projected to retreat by 2050 and 2100

80% of projections range from 1–80 ft of erosion by 2050 and 13 – 200 ft by 2100



50% confidence that you will be safe from erosion landward of this zone.



Shoreline

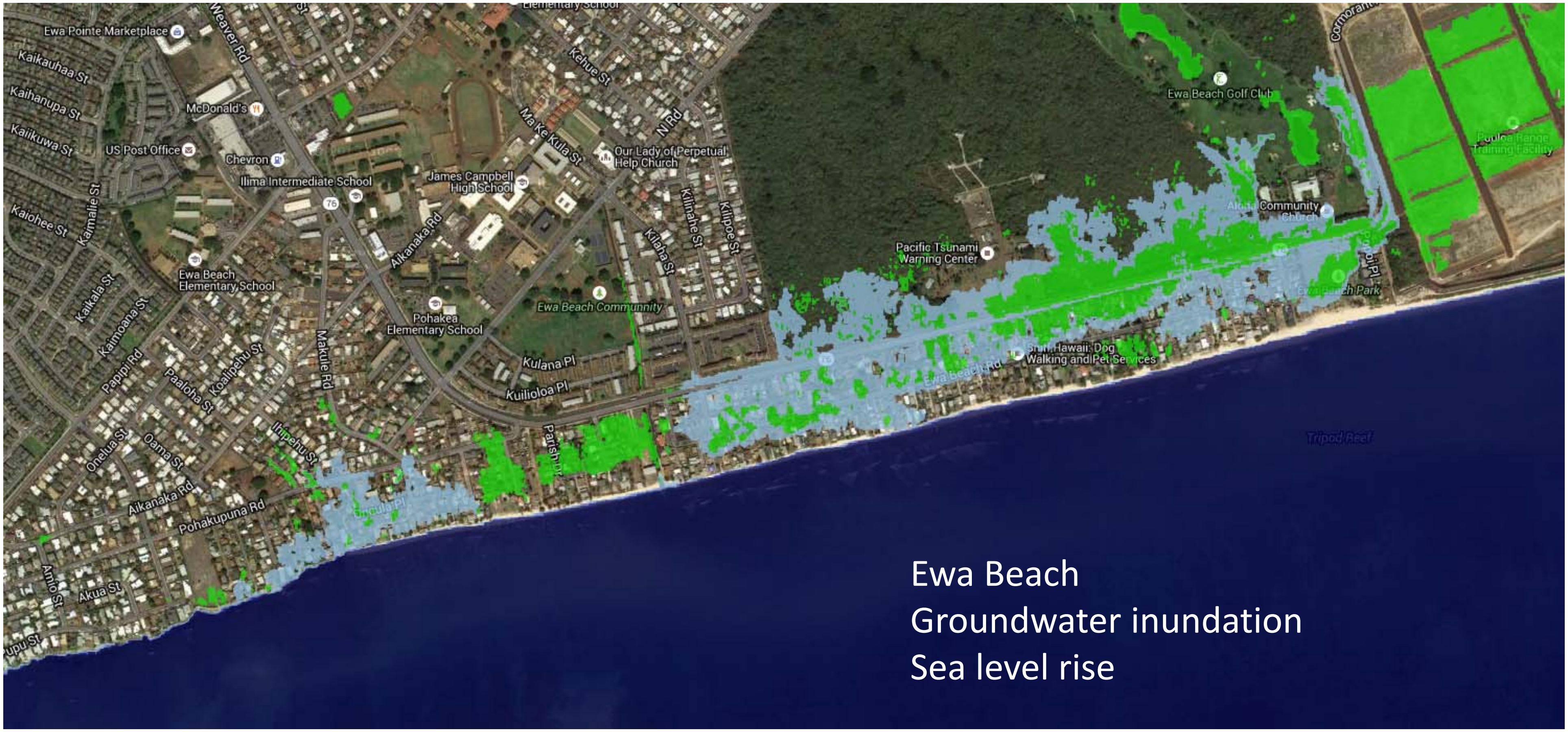
2030

2050

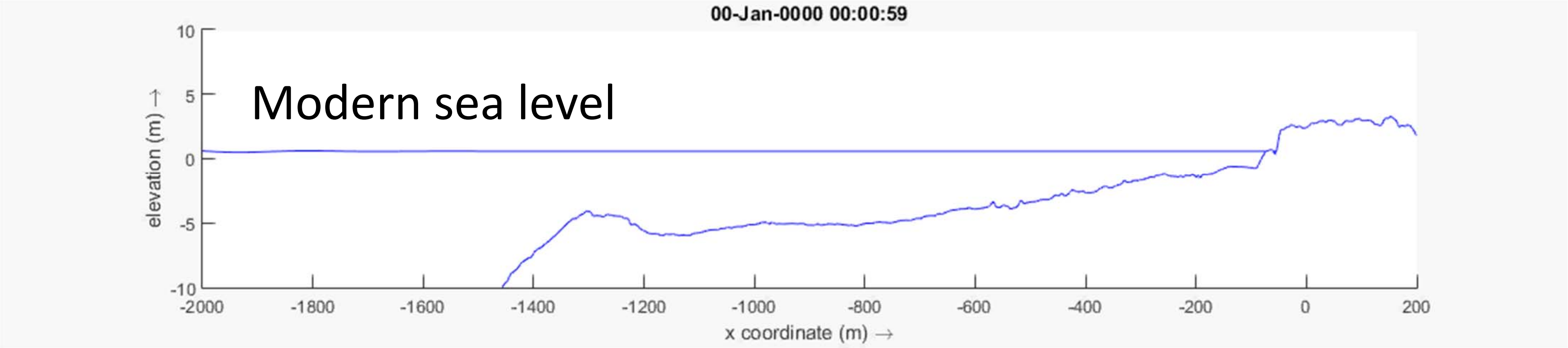
2075

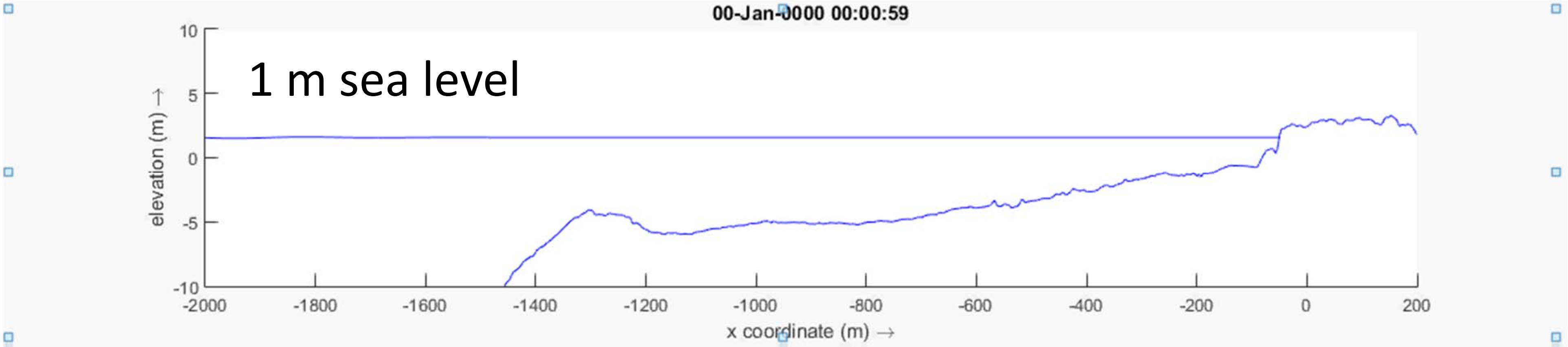
2100

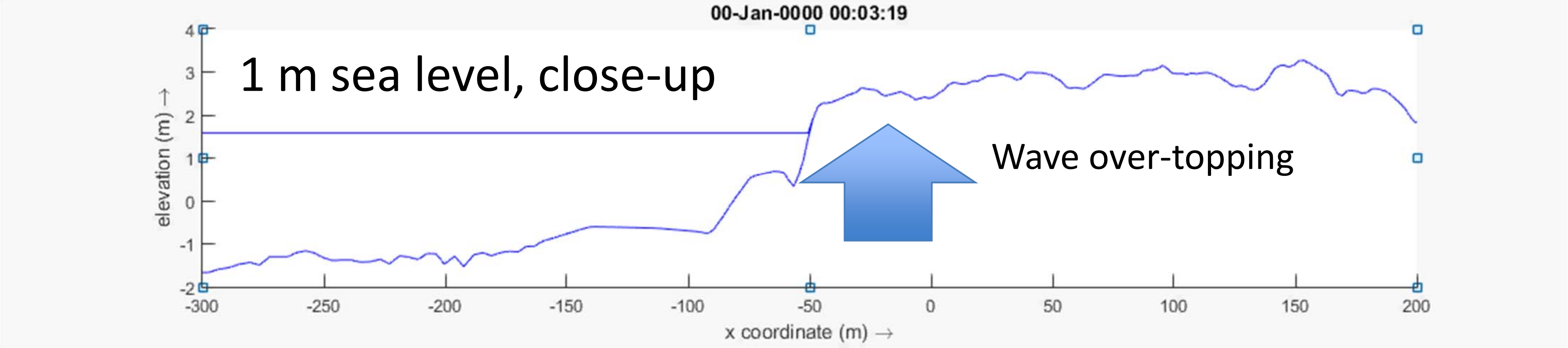
80% confidence that you will be safe from erosion landward of this zone.



Ewa Beach
Groundwater inundation
Sea level rise

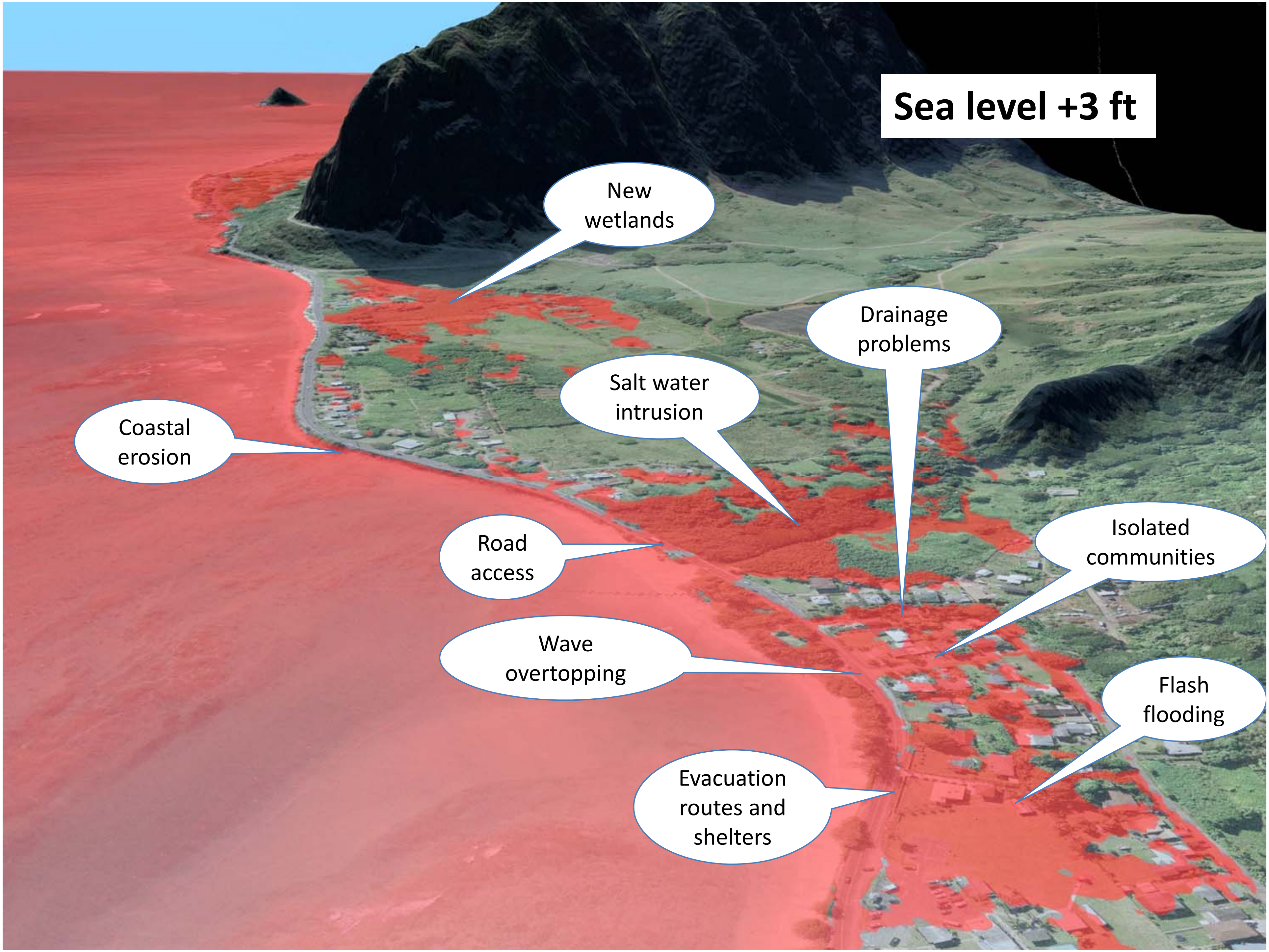

00-Jan-0000 00:00:59
Modern sea level
elevation (m) →
10
5
0
-5
-10
-2000
-1800
-1600
-1400
-1200
-1000
-800
-600
-400
-200
0
200
x coordinate (m) →


00-Jan-0000 00:00:59
1 m sea level
elevation (m) →
10
5
0
-5
-10
-2000
-1800
-1600
-1400
-1200
-1000
-800
-600
-400
-200
0
200
x coordinate (m) →


00-Jan-0000 00:03:19
1 m sea level, close-up
Wave over-topping
elevation (m) →
4
3
2
1
0
-1
-2
-300
-250
-200
-150
-100
-50
0
50
100
150
200
x coordinate (m) →


×10^6
2.3567
2.3567
2.3566
2.3566
2.3565
2.3565
2.3564
2.3564
2.3563
2.3563
2.3562
Northing (m)
6.014
6.015
6.016
6.017
6.018
6.019
6.02
6.021
×10^5
Easting (m)


×10^6
2.3567
2.3567
2.3566
2.3566
2.3565
2.3565
2.3564
2.3564
2.3563
2.3563
2.3562
Northing (m)
6.014
6.015
6.016
6.017
6.018
6.019
6.02
6.021
×10^5
Easting (m)


Sea level +3 ft
New wetlands
Drainage problems
Salt water intrusion
Coastal erosion
Isolated communities
Road access
Wave overtopping
Flash flooding
Evacuation routes and shelters

What are the options?

Fortify (keep the water out)

What are the options?

Retreat (move to higher ground)

What are the options?

Adapt (live with water)

What are the options?

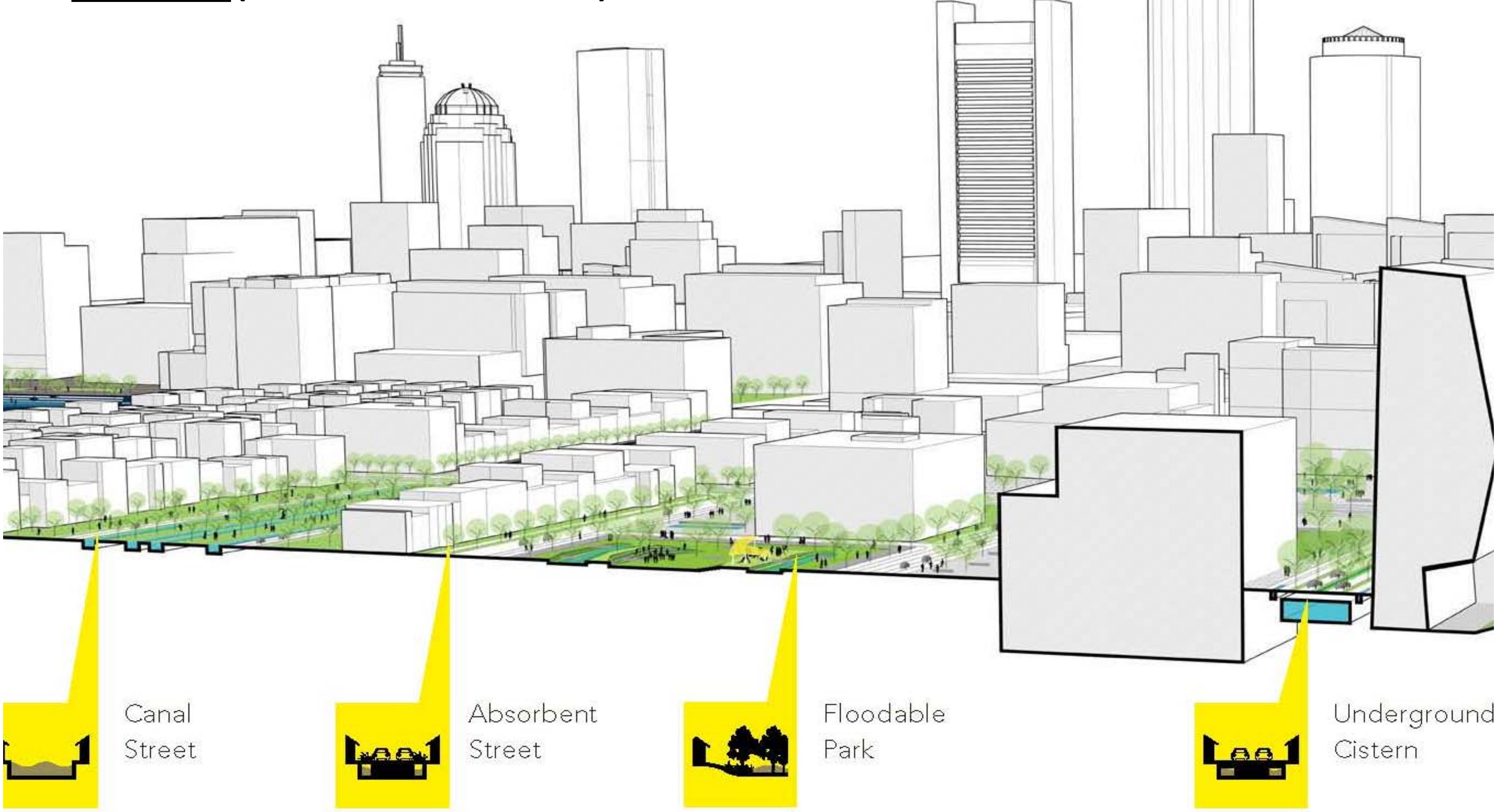
Adapt (live with water)

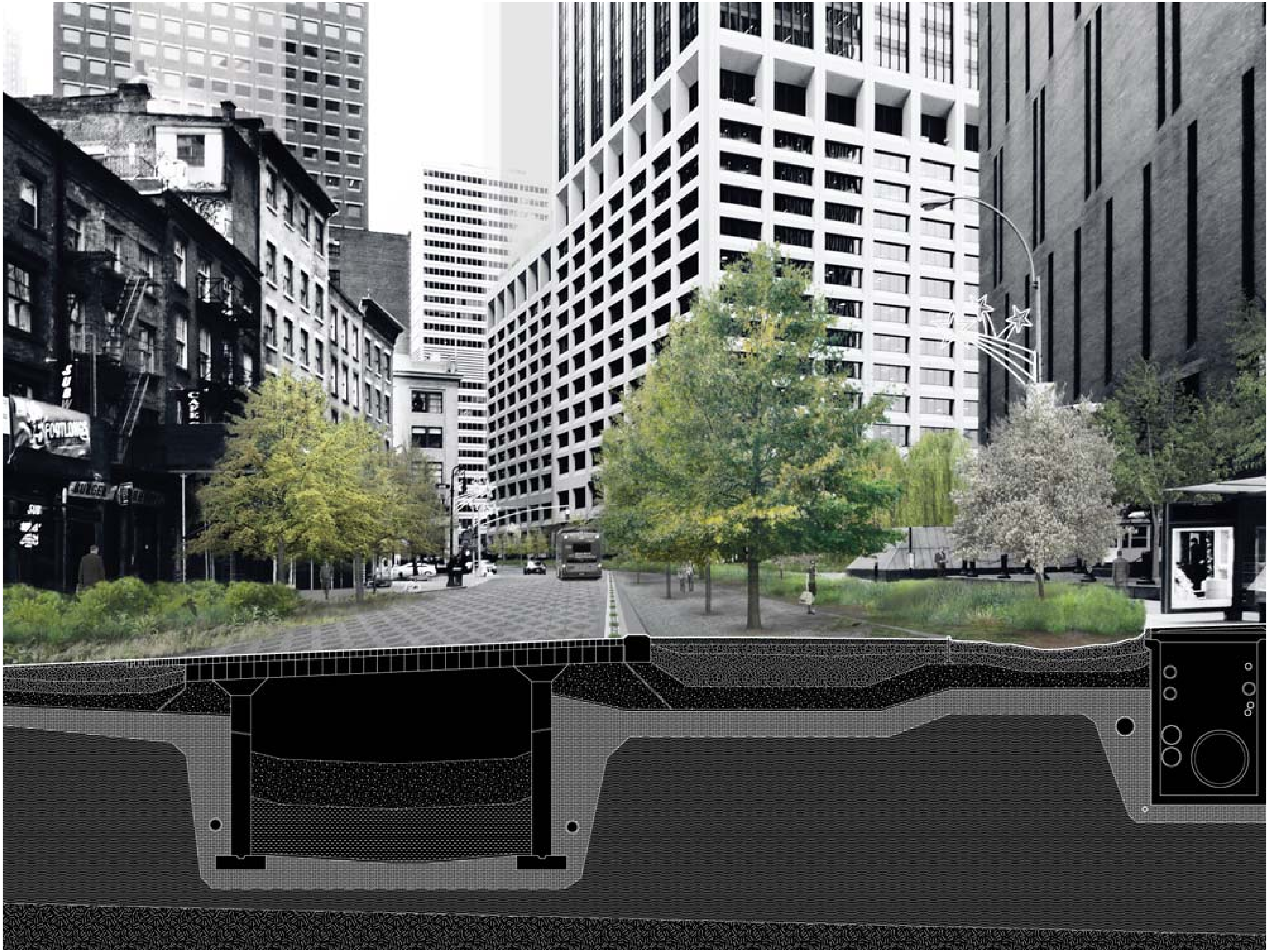
What are the options?

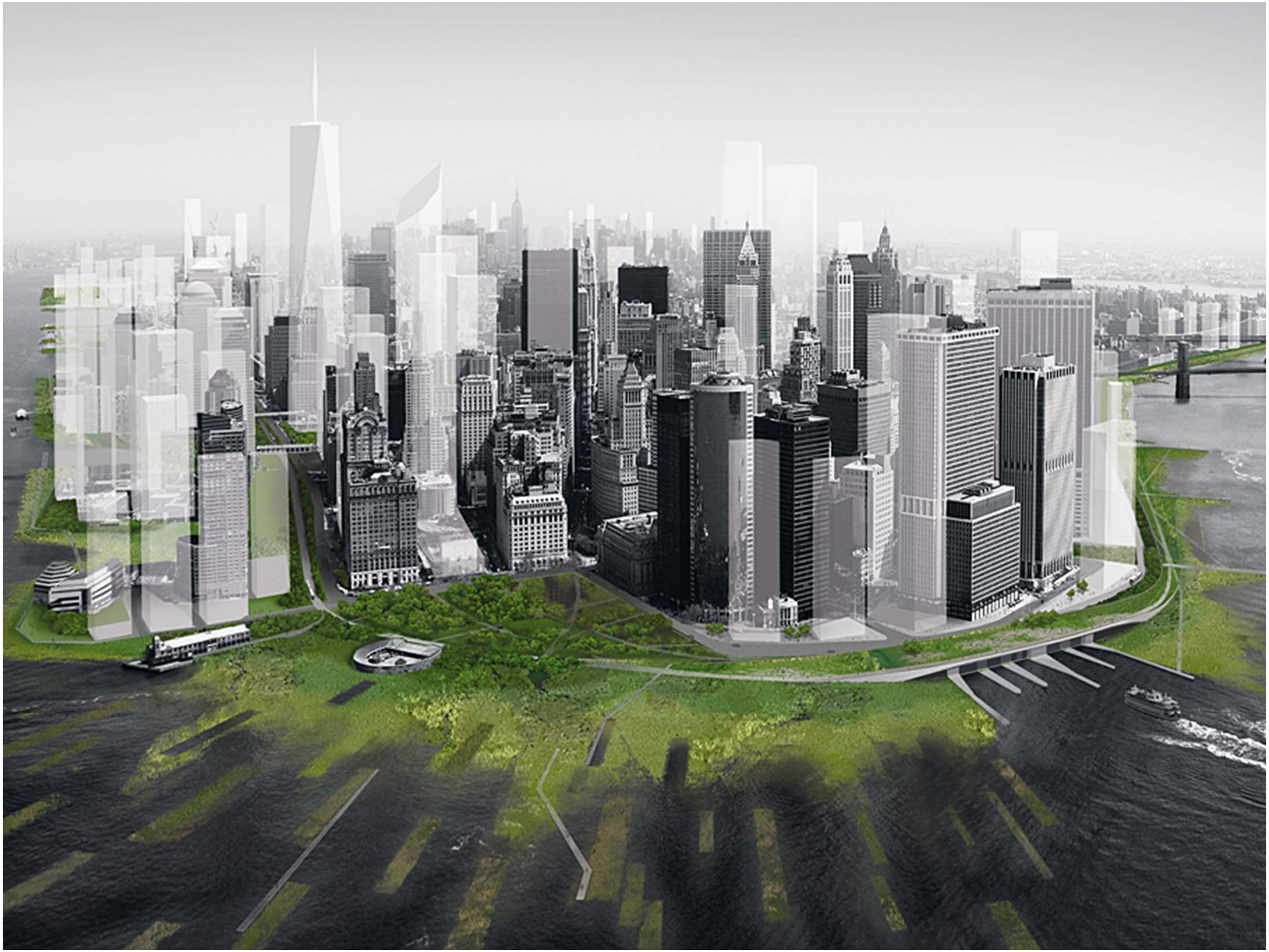
Adapt (live with water)

What are the options?

Adapt (live with water)

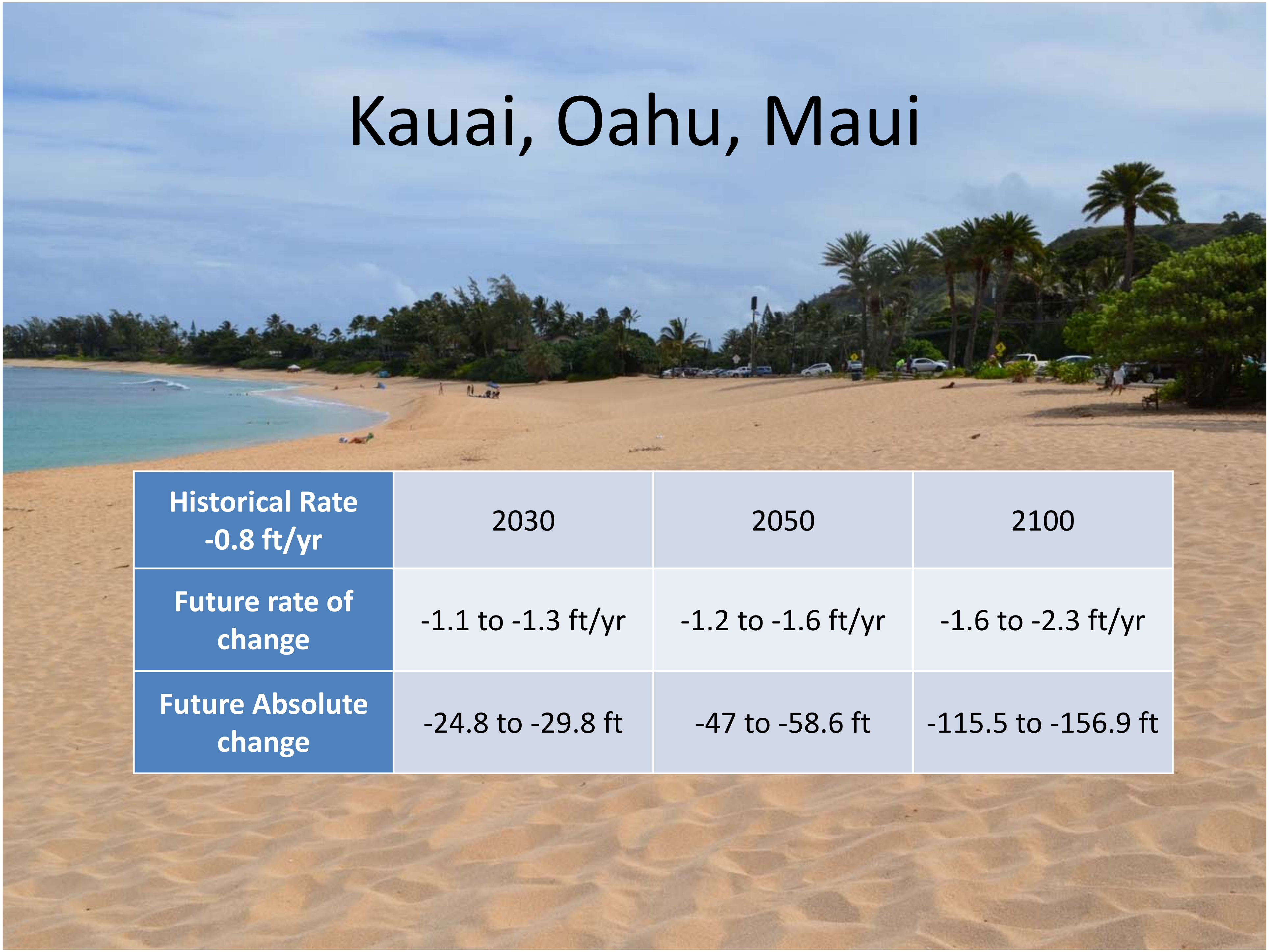



FOOTLONGS
BURGER
SUB

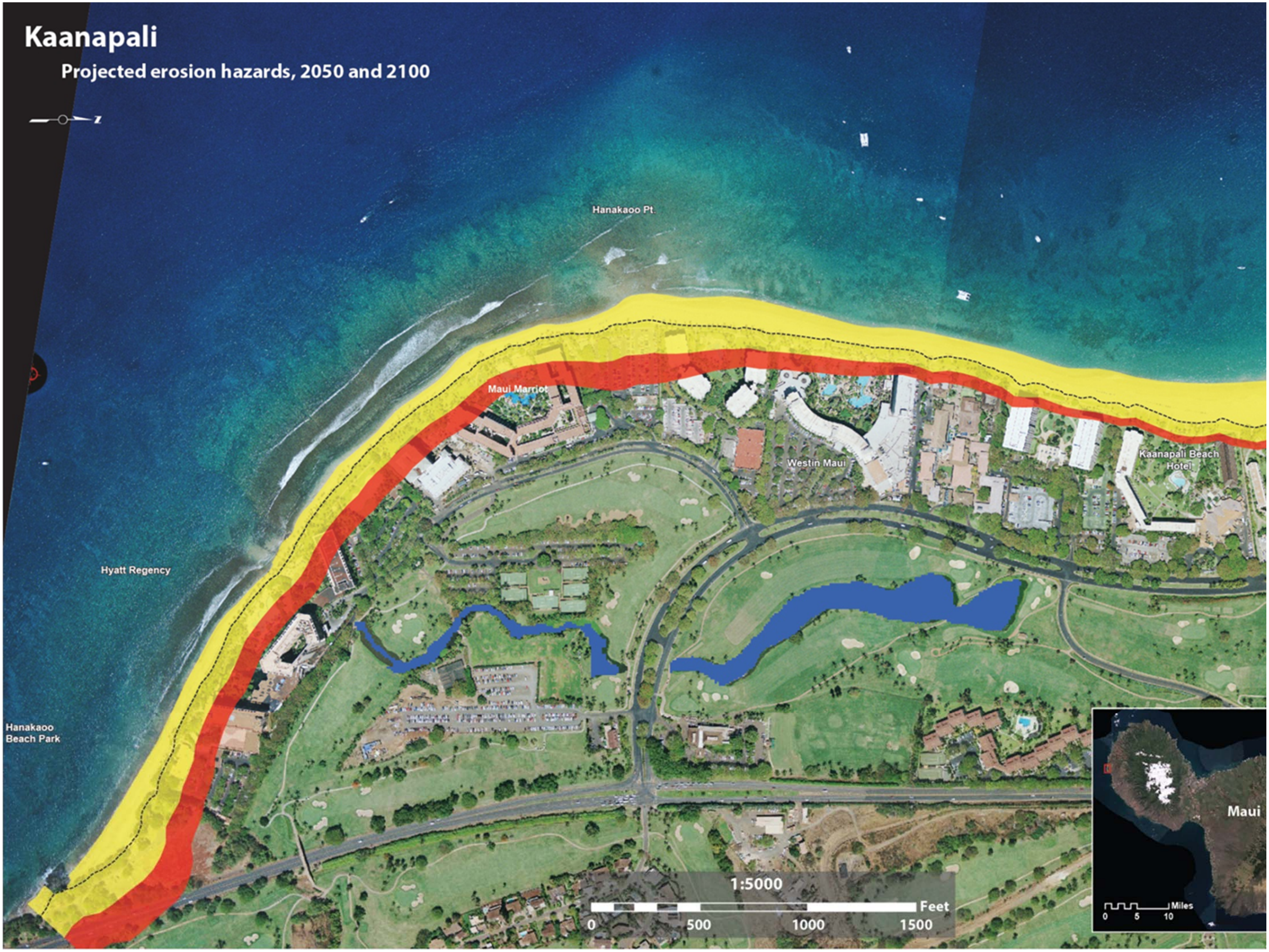


Thank you

Kauai, Oahu, Maui



Historical Rate -0.8 ft/yr	2030	2050	2100
Future rate of change	-1.1 to -1.3 ft/yr	-1.2 to -1.6 ft/yr	-1.6 to -2.3 ft/yr
Future Absolute change	-24.8 to -29.8 ft	-47 to -58.6 ft	-115.5 to -156.9 ft

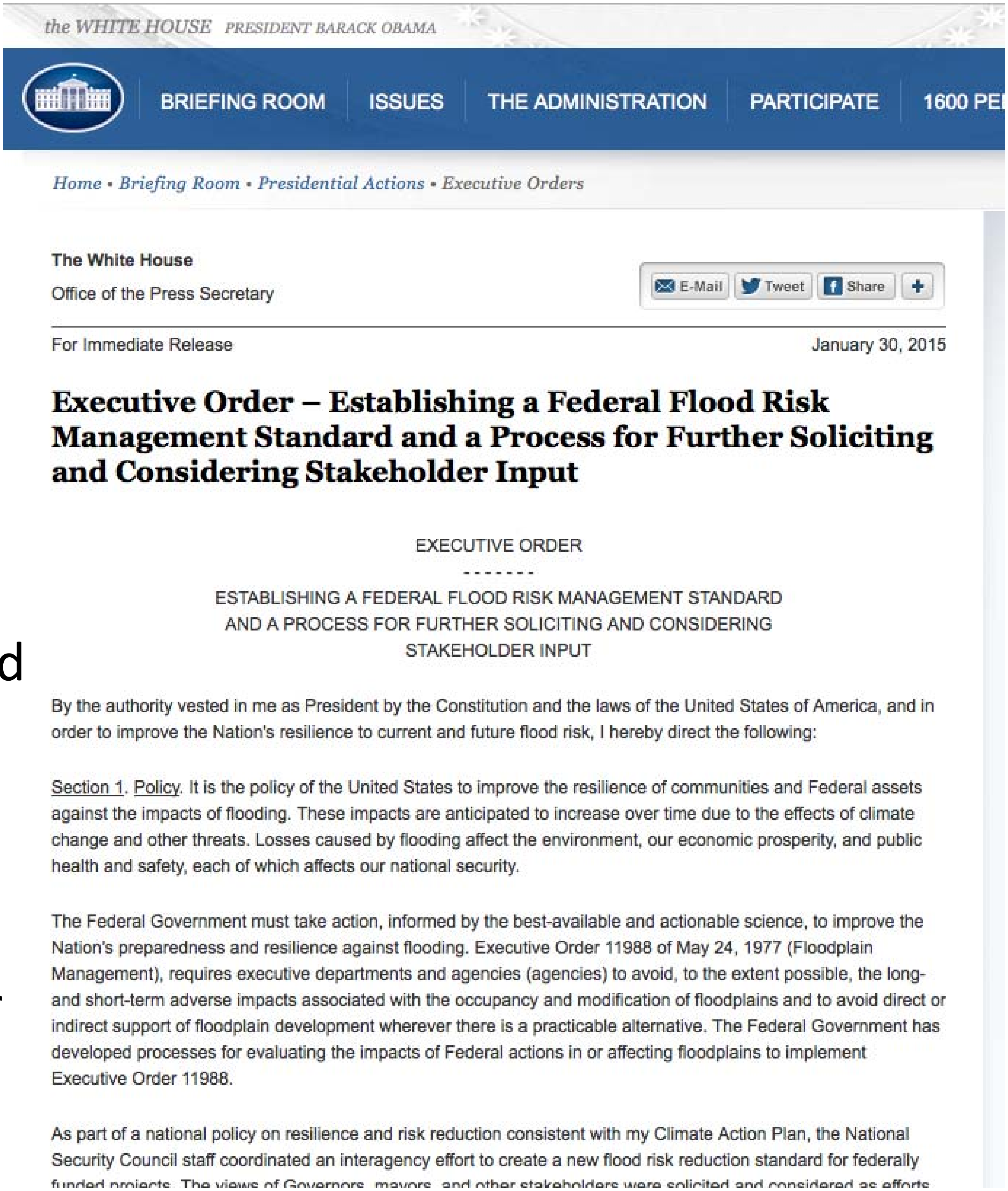


Kaanapali

Projected erosion hazards, 2050 and 2100

Federal agencies plan for rising seas

- Use data and methods “informed by best-available, actionable climate science”;
- Build 2 ft above the 100-year flood elevation for standard projects, and 3 ft above for critical buildings (hospitals and evacuation centers);
- Build to the 500-year flood elevation.



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The White House

Office of the Press Secretary

For Immediate Release

January 30, 2015

Executive Order – Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input

EXECUTIVE ORDER

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ESTABLISHING A FEDERAL FLOOD RISK MANAGEMENT STANDARD
AND A PROCESS FOR FURTHER SOLICITING AND CONSIDERING
STAKEHOLDER INPUT

By the authority vested in me as President by the Constitution and the laws of the United States of America, and in order to improve the Nation's resilience to current and future flood risk, I hereby direct the following:

Section 1. Policy. It is the policy of the United States to improve the resilience of communities and Federal assets against the impacts of flooding. These impacts are anticipated to increase over time due to the effects of climate change and other threats. Losses caused by flooding affect the environment, our economic prosperity, and public health and safety, each of which affects our national security.

The Federal Government must take action, informed by the best-available and actionable science, to improve the Nation's preparedness and resilience against flooding. Executive Order 11988 of May 24, 1977 (Floodplain Management), requires executive departments and agencies (agencies) to avoid, to the extent possible, the long- and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct or indirect support of floodplain development wherever there is a practicable alternative. The Federal Government has developed processes for evaluating the impacts of Federal actions in or affecting floodplains to implement Executive Order 11988.

As part of a national policy on resilience and risk reduction consistent with my Climate Action Plan, the National Security Council staff coordinated an interagency effort to create a new flood risk reduction standard for federally funded projects. The views of Governors, mayors, and other stakeholders were solicited and considered as efforts