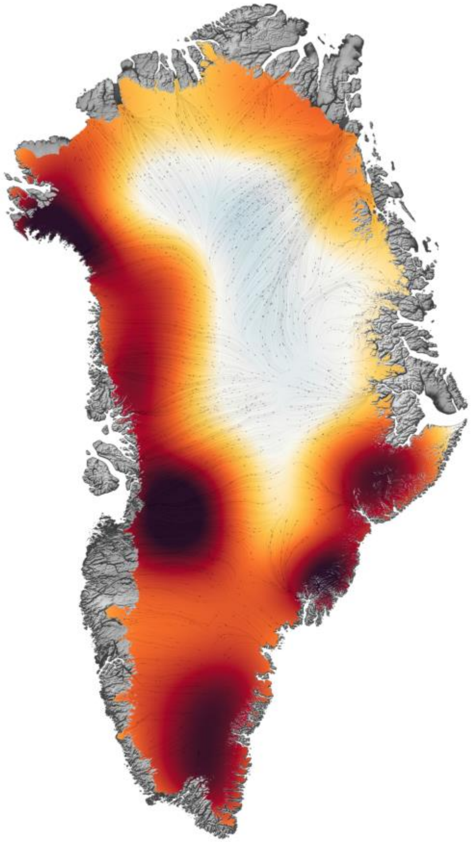
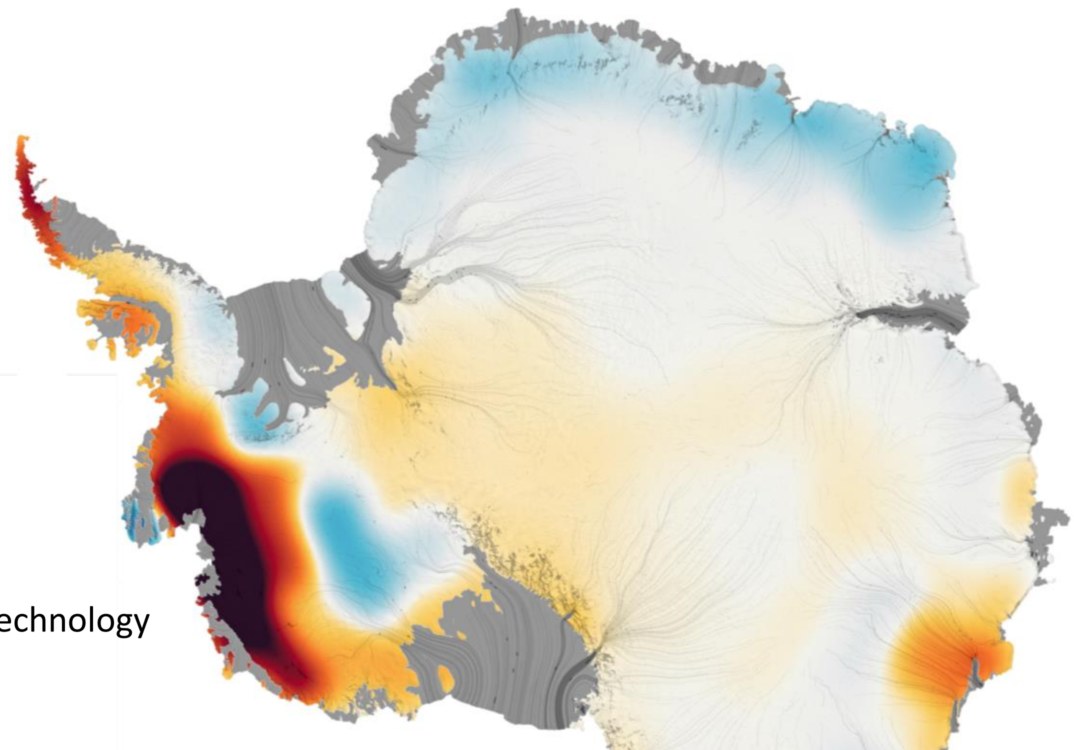
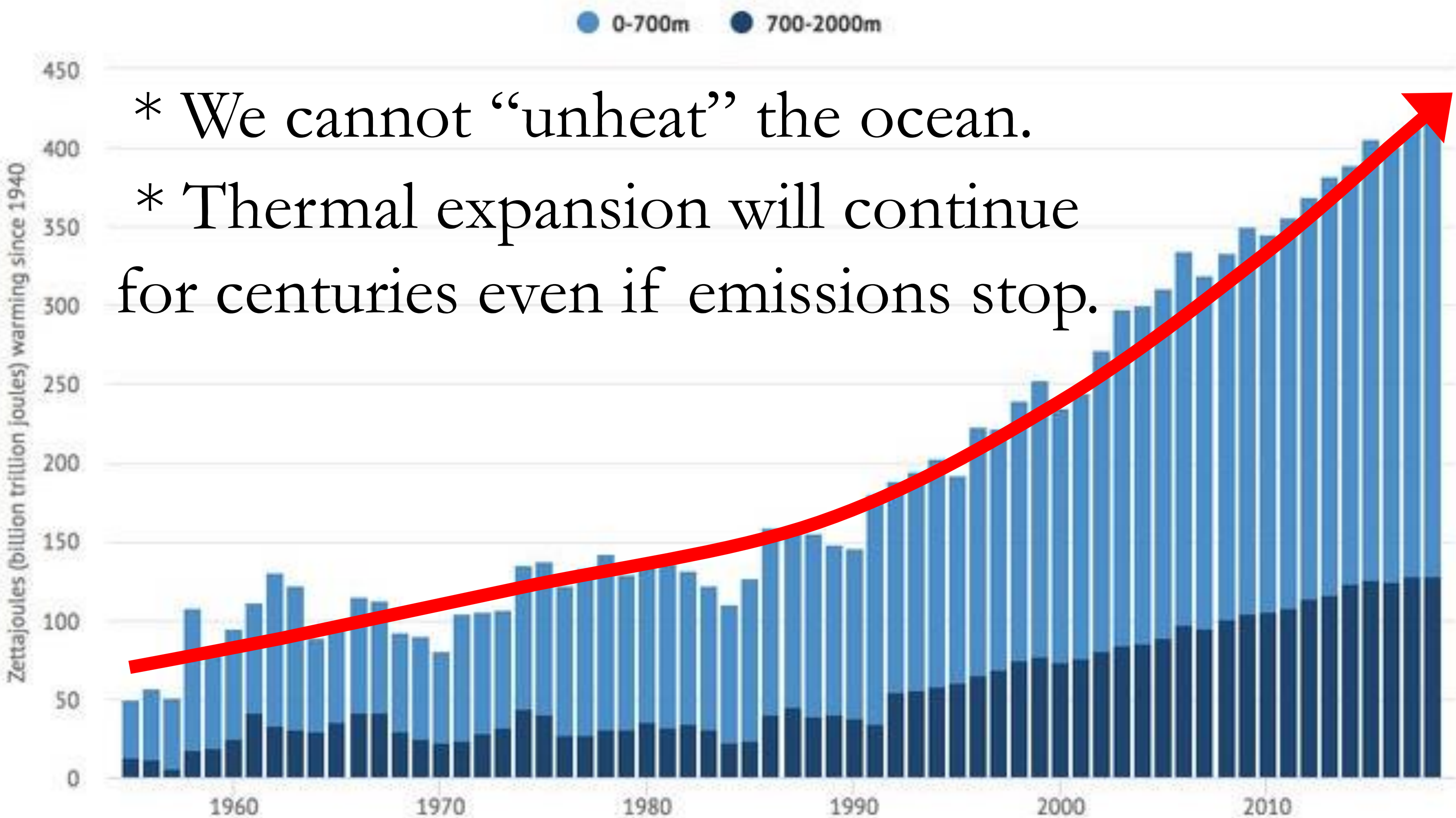


The Sea Level Rise Crisis: An Emergency for Atoll Nations



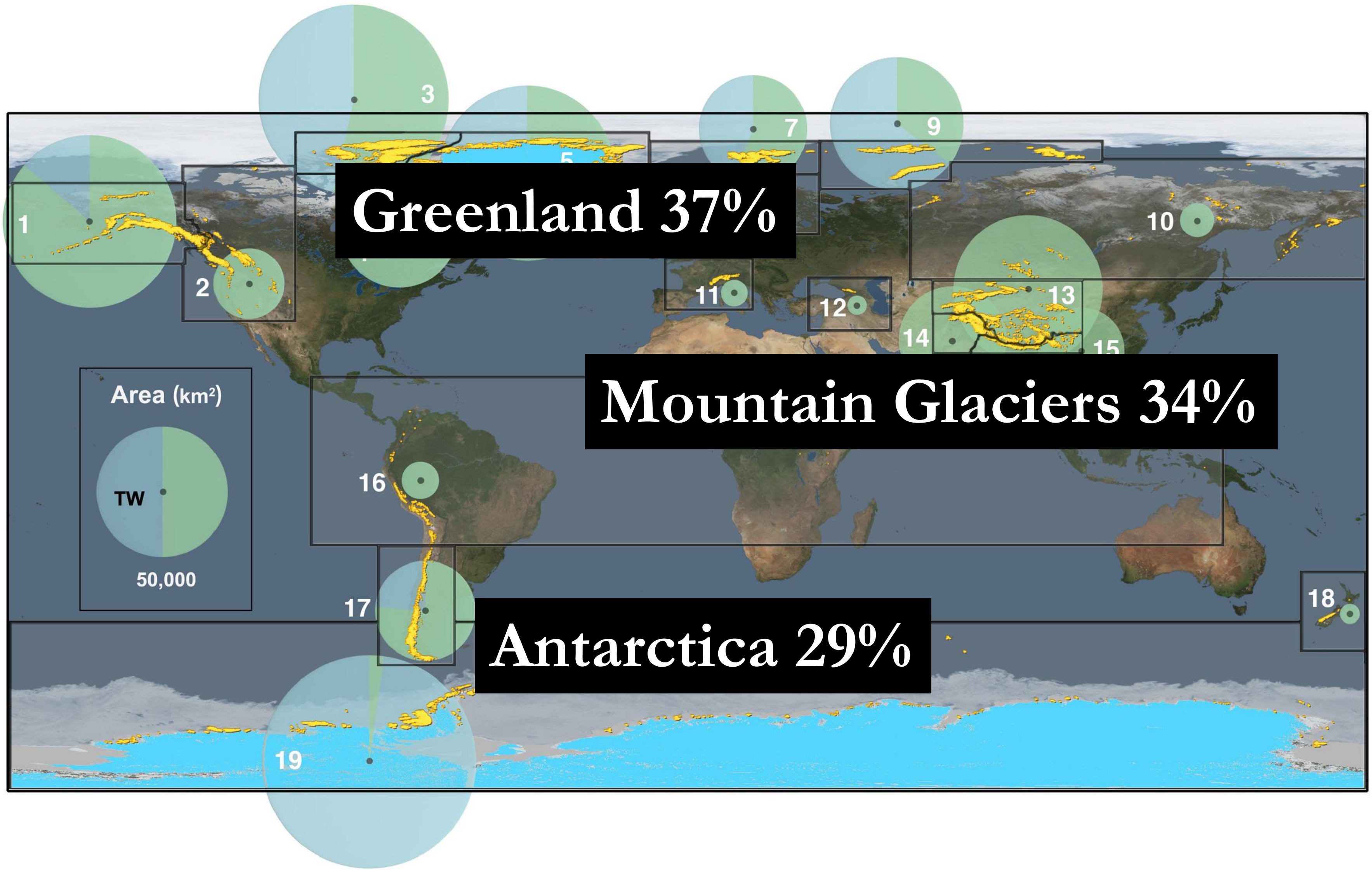
Chip Fletcher, PhD
Professor and Associate Dean
School of Ocean and Earth Science and Technology
University of Hawai'i at Mānoa

The ocean has absorbed 93% of excess heat due to fossil fuel emissions.



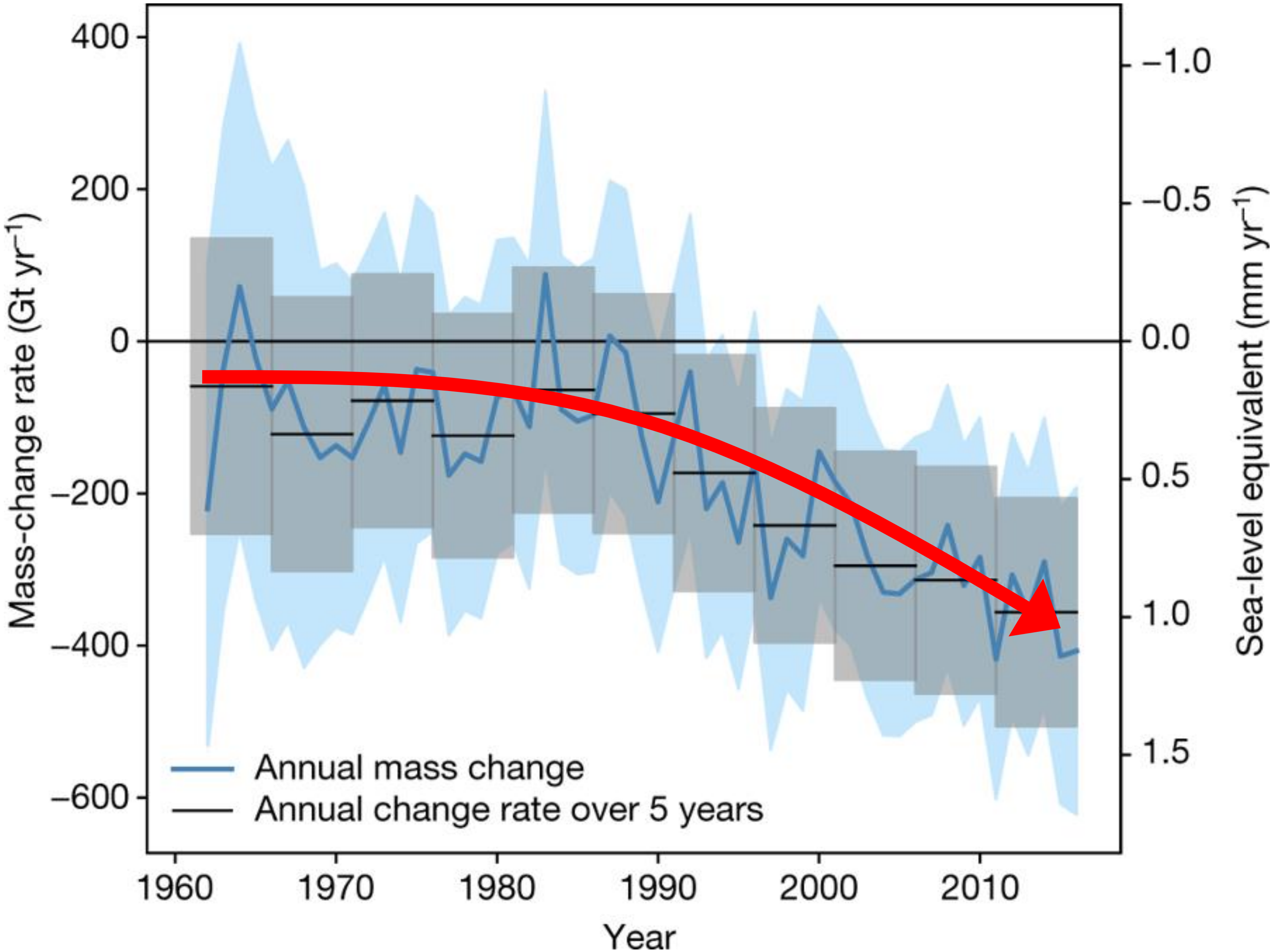
Cheng, L., et al. (2019) How fast are the oceans warming? *Science*, 2019 DOI: 10.1126/science.aav7619; Cheng L. J. Zhu, and J. Abraham, 2015: Global upper ocean heat content estimation: recent progress and the remaining challenges. Atmospheric and Oceanic Science Letters, 8. DOI:10.3878/AOSL20150031. ; Glecker, P.J., et al. (2016) Industrial era global ocean heat uptake doubles in recent decades. Nature Climate change. doi:10.1038/nclimate2915

665 Billion Tons of Ice Melt Each Year



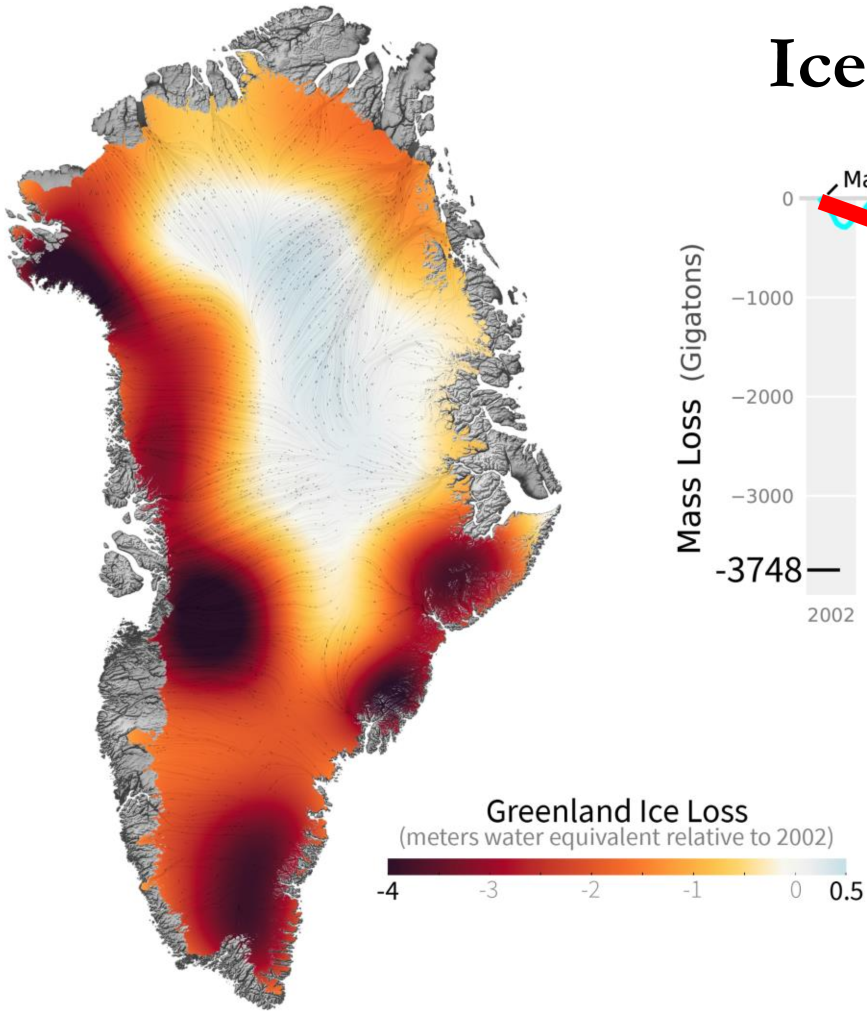
Bamber, J.L., et al (2018) The land ice contribution to sea level during the satellite era, Environ. Res. Lett. 13 https://doi.org/10.1088/1748-9326/aac2f0

Mountain Glaciers lost 10 trillion tons of ice since 1961, raising sea level 3 cm.

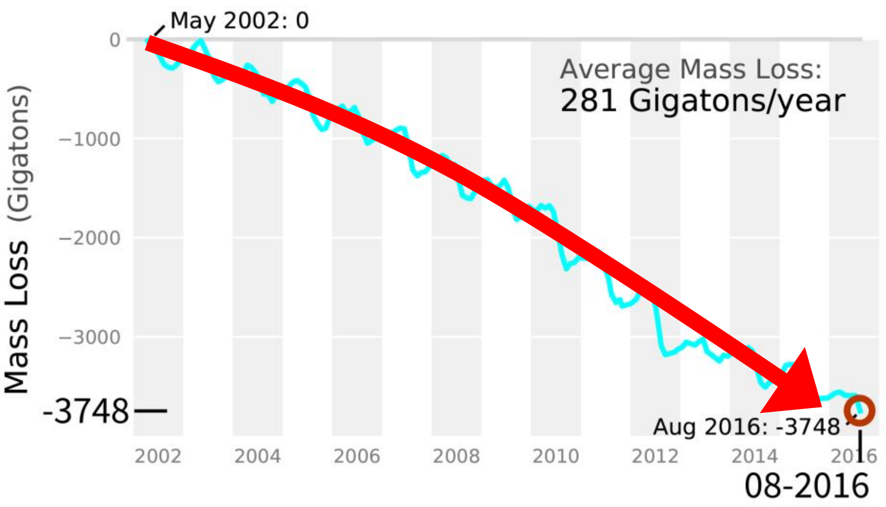


M. Zemp et al. Global glacier mass changes and their contributions to sea-level rise from 1961 to 2016, *Nature* (2019). DOI: 10.1038/s41586-019-1071-0

Greenland faces a 66% chance that melting will become unstoppable at 1.8°C



Ice loss, Gigatons



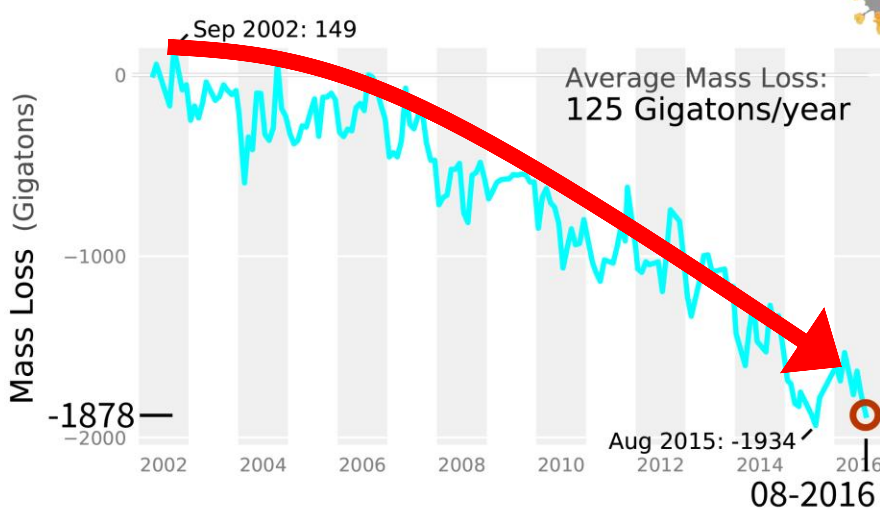
Trusel, et al., 2018 Nonlinear rise in Greenland runoff in response to post-industrial Arctic warming, 104, *Nature*, v564, 6 December: https://doi.org/10.1038/s41586-018-0752-4

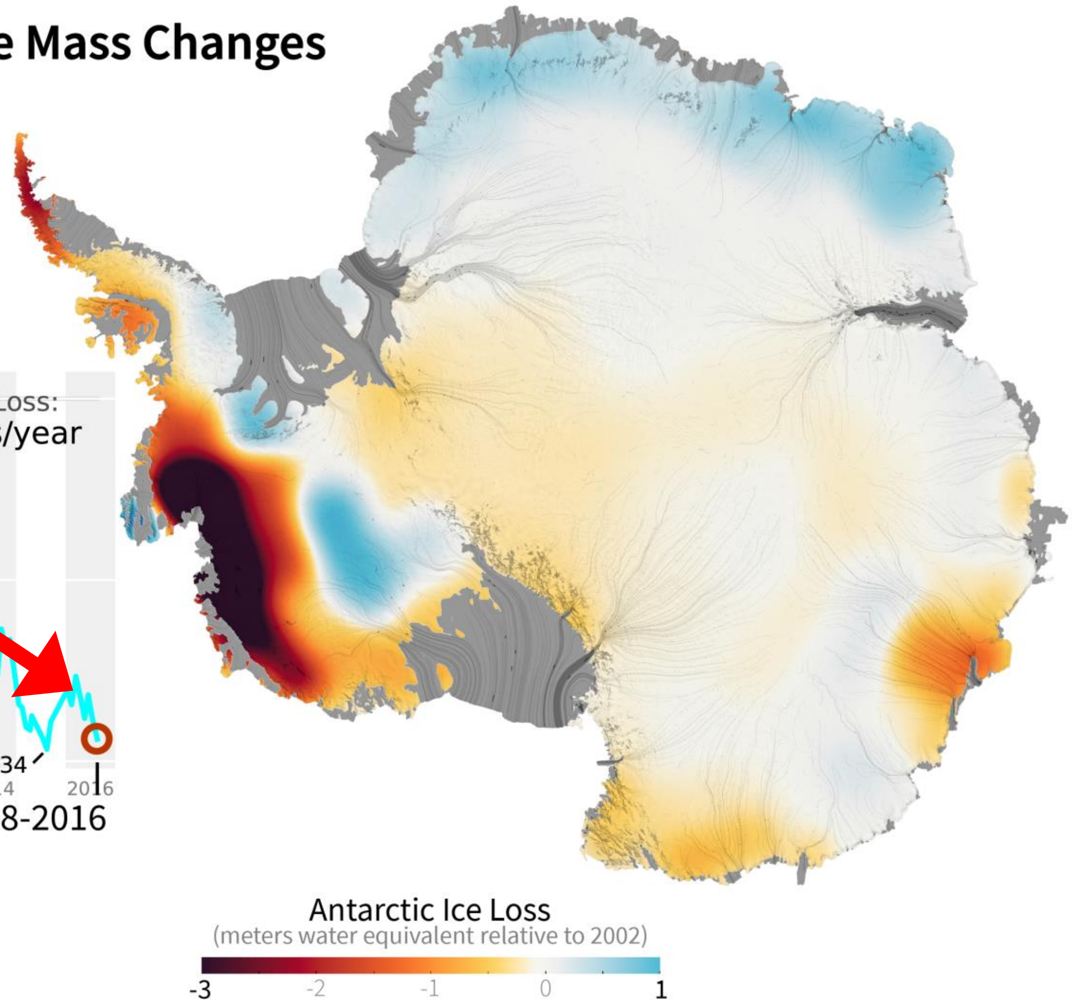
Antarctic ice melt has 'tripled over the past five years'

Is this a long-term accelerating trend, or is this short term variability?

GRACE Observations of Antarctic Ice Mass Changes

Ice loss, Gigatons





The IMBIE team (2018) Mass Balance of the Antarctic Ice Sheet, *Nature*, 558, pages219–222, https://doi.org/10.1038/s41586-018-0179-y

- The Antarctic ice sheet remains the largest single source of uncertainty in projections of future sea-level rise.

- Major adaptation projects require long lead times.

- Atoll communities cannot wait for Antarctic science to clear up.

Ice sheet contributions to future sea-level rise from structured expert judgment

Jonathan L. Bamber[a,1], Michael Oppenheimer[b,c], Robert E. Kopp[d,e], Willy P. Aspinall[f,g], and Roger M. Cooke[h,i]

[a]School of Geographical Sciences, University of Bristol, Bristol BS8 1SS, United Kingdom; [b]Department of Geosciences, Princeton University, Princeton, NJ 08544; [c]The Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ 08544; [d]Department of Earth & Planetary Sciences, Rutgers University, New Brunswick, NJ 08854; [e]Institute of Earth, Ocean, and Atmospheric Sciences, Rutgers University, New Brunswick, NJ 08901; [f]School of Earth Sciences, University of Bristol, Bristol BS8 1RJ, United Kingdom; [g]Aspinall & Associates, Tisbury SP3 6HF, United Kingdom; [h]Land, Water, and Nature, Resources for the Future, Washington, DC 20036; and [i]Department of Mathematics, Delft University of Technology, 2600 GA, Delft, The Netherlands

Edited by Stefan Rahmstorf, Potsdam Institute for Climate Impact Research, Potsdam, Germany, and accepted by Editorial Board Member Hans J. Schellnhuber April 8, 2019 (received for review October 5, 2018)

Despite considerable advances in process understanding, numerical modeling, and the observational record of ice sheet contributions to global mean sea-level rise (SLR) since the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change, severe limitations remain in the predictive capability of ice sheet models. As a consequence, the potential contributions of ice sheets remain the largest source of uncertainty in projecting future SLR. Here, we report the findings of a structured expert judgement study, using unique techniques for modeling correlations between inter- and intra-ice sheet processes and their tail dependences. We find that since the AR5, expert uncertainty has grown, in particular because of uncertain ice dynamic effects. For a +2 °C temperature scenario consistent with the Paris Agreement, we obtain a median estimate of a 26 cm SLR contribution by 2100, with a 95th percentile value of 81 cm. For a +5 °C temperature scenario more consistent with unchecked emissions growth, the corresponding values are 51 and 178 cm, respectively. Inclusion of thermal expansion and glacier contributions results in a global total SLR estimate that exceeds 2 m at the 95th percentile. Our findings support the use of scenarios of 21st century global total SLR exceeding 2 m for planning purposes. Beyond 2100, uncertainty and projected SLR increase rapidly. The 95th percentile ice sheet contribution by 2200, for the +5 °C scenario, is 7.5 m as a result of instabilities coming into play in both West and East Antarctica. Introducing process correlations and tail dependences increases estimates by roughly 15%.

sea-level rise | climate predictions | ice sheets | Greenland | Antarctica

Global mean sea-level rise (SLR), which during the last quarter century has occurred at an accelerating rate (1), averaging about +3 $mm \cdot y^{-1}$, threatens coastal communities and ecosystems worldwide. Adaptation measures accounting for the changing hazard, including building or raising permanent or movable structures such as surge barriers and sea walls, enhancing nature-based defenses such as wetlands, and selective retreat of populations and facilities from areas threatened by episodic flooding or permanent inundation, are being planned or implemented in several countries. Risk assessment for such adaptation efforts requires projections of future SLR, including careful characterization and evaluation of uncertainties (2) and regional projections that account for ocean dynamics, gravitational and rotational effects, and vertical land motion (3). During the nearly 40 y since the first modern, scientific assessments of SLR, understanding of the various causes of this rise has advanced substantially. Improvements during the past decade include closing the historic sea-level budget, attributing global mean SLR to human activities, confirming acceleration of SLR since the nineteenth century and during the satellite altimetry era, and developing analytical frameworks for estimating regional and local mean sea level and extreme water level changes. Nonetheless, long-term SLR projections remain acutely un-

sheets and their responses to future global climate change. This limitation is especially troubling, given that the ice sheet influence on SLR has been increasing since the 1990s (4) and has overtaken mountain glaciers to become the largest barystatic (mass) contribution to SLR (5). In addition, for any given future climate scenario, the ice sheets constitute the component with the largest uncertainties by a substantial margin, especially beyond 2050 (6).

Advances since the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (7) include improved process understanding and representation in deterministic ice sheet models (8, 9), probabilistic projections calibrated against these models and the observational record (10), and new semiempirical models, based on the historical relationship between temperature and sea-level changes. Each of these approaches has limitations that stem from factors including poorly understood processes, poorly constrained boundary conditions, and a short (~25 y) satellite observation record of ice sheets that does not capture the time scales of internal variability in the ice sheet climate system. As a consequence, it is unclear to what extent recent observed ice sheet changes (11) are a result of internal variability (ice sheet weather) or external forcing (ice sheet climate).

Significance

Future sea level rise (SLR) poses serious threats to the viability of coastal communities, but continues to be challenging to project using deterministic modeling approaches. Nonetheless, adaptation strategies urgently require quantification of future SLR uncertainties, particularly upper-end estimates. Structured expert judgement (SEJ) has proved a valuable approach for similar problems. Our findings, using SEJ, produce probability distributions with long upper tails that are influenced by interdependencies between processes and ice sheets. We find that a global total SLR exceeding 2 m by 2100 lies within the 90% uncertainty bounds for a high emission scenario. This is more than twice the upper value put forward by the Intergovernmental Panel on Climate Change in the Fifth Assessment Report.

Author contributions: J.L.B., M.O., and R.E.K. designed research; J.L.B., M.O., R.E.K., W.P.A., and R.M.C. performed research; W.P.A. and R.M.C. analyzed data; and J.L.B. and M.O. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission. S.R. is a guest editor invited by the Editorial Board.

Data deposition: The data sets and workshop materials are available from the University of Bristol permanent repository, https://data.bris.ac.uk/data/dataset/23k1jbtan6sjv2huakf63cqgav.

[1]To whom correspondence may be addressed. Email: j.bamber@bristol.ac.uk.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.

A survey of global experts found a 10% chance of sea level exceeding 2 m by 2100.

On our current emissions path, sea level will exceed 7.5 m by 2200 and 9.7 m by 2300.

If every 10th airplane crashed into the sea, you would decide to never fly.

10% probability is a compelling reason to make a no regrets decision to save a nation.

J. L. Bamber, et al. (2019 Ice sheet contributions to future sea-level rise from structured expert judgment. *Proceedings of the National Academy of Sciences*, May 20, 2019; DOI: 10.1073/pnas.1817205116

Sea Level Rise has <u>Accelerated</u>

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NEW RESEARCH IN Physical Sciences Social Sciences

Climate-change–driven accelerated sea-level rise detected in the altimeter era

R. S. Nerem, B. D. Beckley, J. T. Fasullo, B. D. Hamlington, D. Masters, and G. T. Mitchum

PNAS published ahead of print February 12, 2018 https://doi.org/10.1073/pnas.1717312115

Edited by Anny Cazenave, Centre National d'Etudes Spatiales, Toulouse, France, and approved January 9, 2018 (received for review October 2, 2017)

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Significance

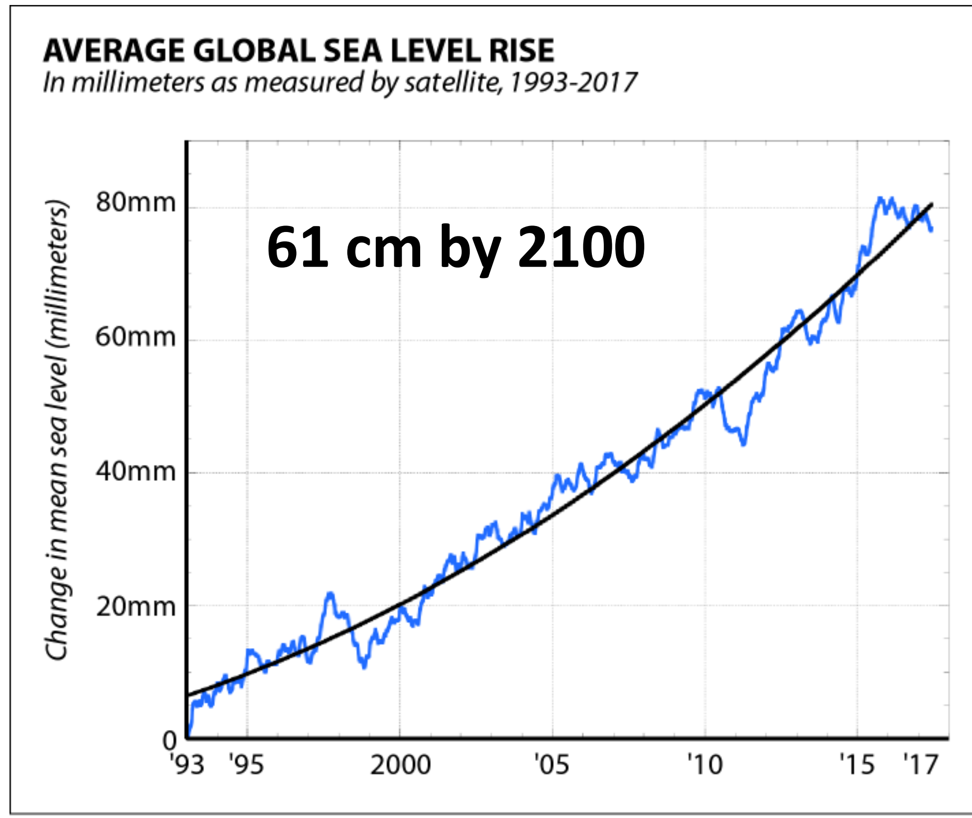
Satellite altimetry has shown that global mean sea level has been rising at a rate of ~3 ± 0.4 mm/y since 1993. Using the altimeter record coupled with careful consideration of interannual and decadal variability as well as potential instrument errors, we show that this rate is accelerating at 0.084 ± 0.025 mm/y^2, which agrees well with climate model projections. If sea level continues to change at this rate and acceleration, sea-level rise by 2100 (~65 cm) will be more than double the amount if the rate was constant at 3 mm/y.

Abstract

Using a 25-y time series of precision satellite altimeter data from TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3, we estimate the climate-change–driven acceleration of global mean sea level over the last 25 y to be 0.084 ± 0.025 mm/y^2. Coupled with the average climate-change–driven rate of sea level rise over these same 25 y of 2.9 mm/y, simple extrapolation of the quadratic implies global mean sea level could rise 65 ± 12 cm by 2100 compared with 2005, roughly in agreement with the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) model projections.

sea level acceleration climate change satellite altimetry

Satellite altimeter data collected since 1993 have measured a rise in global mean sea level



SOURCE: Steve Nerem/University of Colorado, Boulder InsideClimate News

Sea Level Rise has been accelerating since the 1960's

nature climate change

ARTICLES

https://doi.org/10.1038/s41558-019-0531-8

Persistent acceleration in global sea-level rise since the 1960s

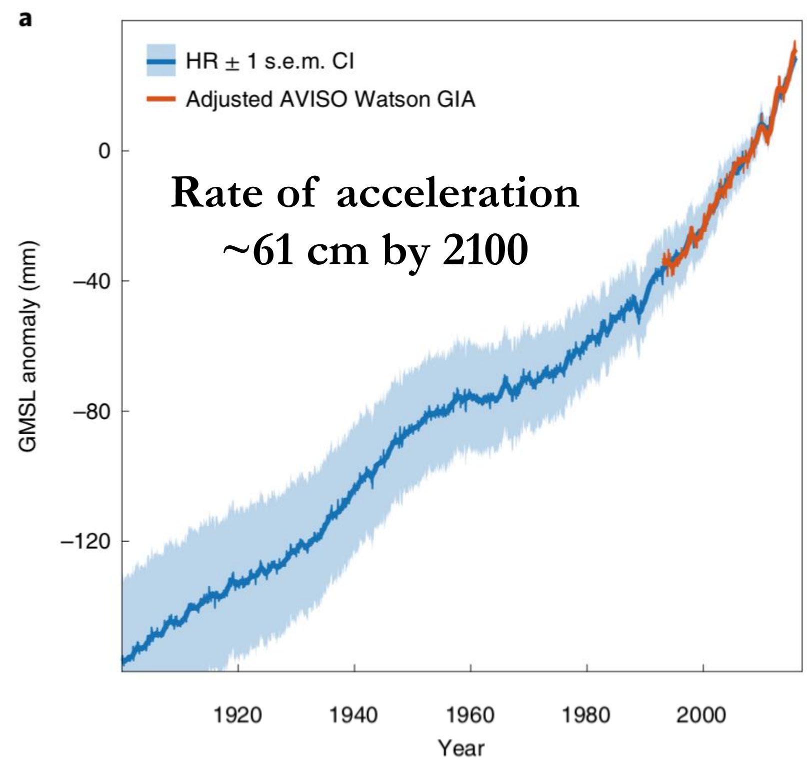
Sönke Dangendorf[1,2]*, Carling Hay[3], Francisco M. Calafat[4], Marta Marcos[5], Christopher G. Piecuch[6], Kevin Berk[7] and Jürgen Jensen[1]

Previous studies reconstructed twentieth-century global mean sea level (GMSL) from sparse tide-gauge records to understand whether the recent high rates obtained from satellite altimetry are part of a longer-term acceleration. However, these analyses used techniques that can only accurately capture either the trend or the variability in GMSL, but not both. Here we present an improved hybrid sea-level reconstruction during 1900–2015 that combines previous techniques at time scales where they perform best. We find a persistent acceleration in GMSL since the 1960s and demonstrate that this is largely (~76%) associated with sea-level changes in the Indo-Pacific and South Atlantic. We show that the initiation of the acceleration in the 1960s is tightly linked to an intensification and a basin-scale equatorward shift of Southern Hemispheric westerlies, leading to increased ocean heat uptake, and hence greater rates of GMSL rise, through changes in the circulation of the Southern Ocean.

Understanding twentieth-century global and regional sea-level changes is of paramount importance, as they reflect both natural and anthropogenic changes occurring in the Earth's climate system (through changes in land-ice and ocean heat uptake) and affect the livelihood of hundreds of millions of people in the world's coastal regions. Satellite altimetry shows that GMSL has been rising at an average rate of about 3.1 ± 0.3 mm yr^{-1} since 1993, whereas complementary observations from profiling floats (observing density changes in the upper 2,000 m of the ocean) and gravimetric satellites (measuring mass changes from space) have enabled the attribution of the GMSL signal to its density and mass contributions with an accuracy of ~0.3 mm yr^{-1} since about 2005 (ref. [1]). Recent altimetry-based studies also report that the pace of GMSL has been accelerating since 1993 (refs. [2–4]), which is consistent with independent estimates of increasing mass contributions from Greenland and Antarctica over the last two decades[5,6]. However, when this acceleration started and what processes contributed the most to it remains unclear, as satellite altimetry only covers the short period since 1993. A complementary source of sea-level information comes from the network of tide gauges. Although confined to the coast and containing data gaps, tide-gauge records in some places date back to the Industrial Revolution. Synthesizing the tide-gauge record with satellite altimetry requires statistical techniques that allow for sparse data coverage and the treatment of systematic differences between the two observing systems[7–9].

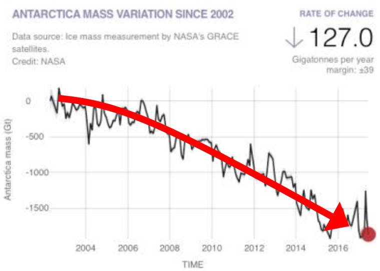
Several approaches have been developed to reconstruct the geometry of past sea-level change with similar spatial coverage as satellite altimetry and spanning the same period as the tide-gauge record[10–12]. These can roughly be divided into two types of approaches: probabilistic techniques based on the Kalman Smoother (KS) or Gaussian Process Regression[12–14], which fit known spatial patterns of individual sea-level contributors[15], also known as fingerprints, to tide-gauge records, and Reduced Space Optimal Interpolation (RSOI) techniques, which reconstruct the temporal amplitudes of a truncated set of empirical orthogonal functions (EOFs) calculated from satellite altimetry using tide-gauge data[10,11,16]. Probabilistic techniques provide robust and smooth reconstructions of long-term changes in sea level (including more realistic modelling of uncertainties) even if only a few tide gauges are available[12–14], but in their current set-up they fail in realistically reconstructing the interannual variability[17]. RSOI reconstructions, on the other hand, are generally capable of reconstructing interannual to decadal sea-level changes[18–20], although they have their limitations in accurately estimating long-term trends[14]. Consequently, while both groups of techniques have their individual advantages, neither is (as currently configured) able to reconstruct the full spectrum of global and regional sea-level change[18]. This conundrum contributes to the large differences between individual reconstructions before the 1970s[21,22] and therefore hampers placing the recent acceleration into the historical context of the twentieth century.

Our aim here is to combine low-frequency sea-level information from the KS[12] with high-frequency information from RSOI reconstructions to generate a hybrid reconstruction (HR) of global and regional sea-level during 1900–2015, which uses the techniques only at those time scales where they perform best. This is achieved by taking the low-frequency signal of the KS reconstruction (smoothed with a cut-off period of 15 years) at individual sites as a trend correction for each tide-gauge record. The residuals (with spectral power remaining at periods below 15 years) are then used in an iterative RSOI reconstruction with similarly detrended satellite altimetry data (see also Supplementary Fig. 1). The latter step also includes a gap-filling algorithm based on stepwise regression models with surface wind stress, sea-level pressure (SLP), sea surface temperature (SST), and neighbouring sites as predictors for minimizing gap-induced biases in the RSOI reconstruction (see Methods). Combining the low-frequency KS field with the high-frequency residual RSOI reconstruction provides a novel HR including high latitudes in the Arctic Ocean and around Antarctica. The HR of GMSL presented is based on the assimilation of 479 carefully selected tide-gauge records (see Methods).



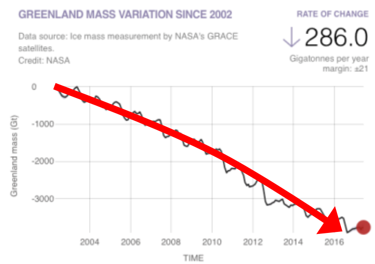
Dangendorf, S. et al. (2019) Persistent acceleration in global sea-level rise since the 1960s, Nature Climate Change: http://dx.doi.org/10.1038/s41558-019-0531-8. R. S. Nerem el al., "Climate-change–driven accelerated sea-level rise detected in the altimeter era," *PNAS* (2018). www.pnas.org/cgi/doi/10.1073/pnas.1717312115

Present rates of melting and thermal expansion add up to 1 m by 2100



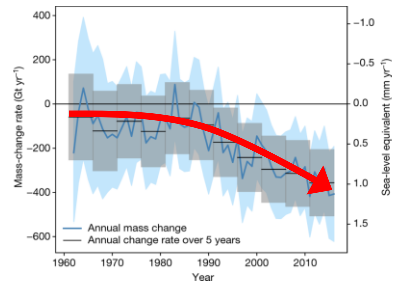
Antarctic ice loss

+



Greenland ice loss

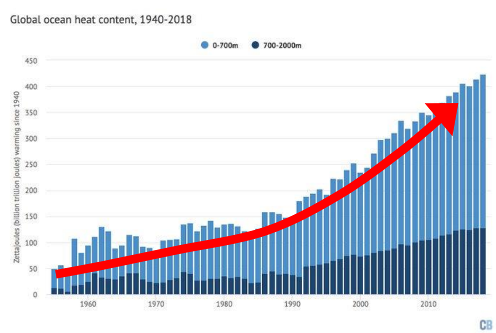
+



Mountain glacier ice loss

= 0.8 m

0.8 m +



Thermal expansion

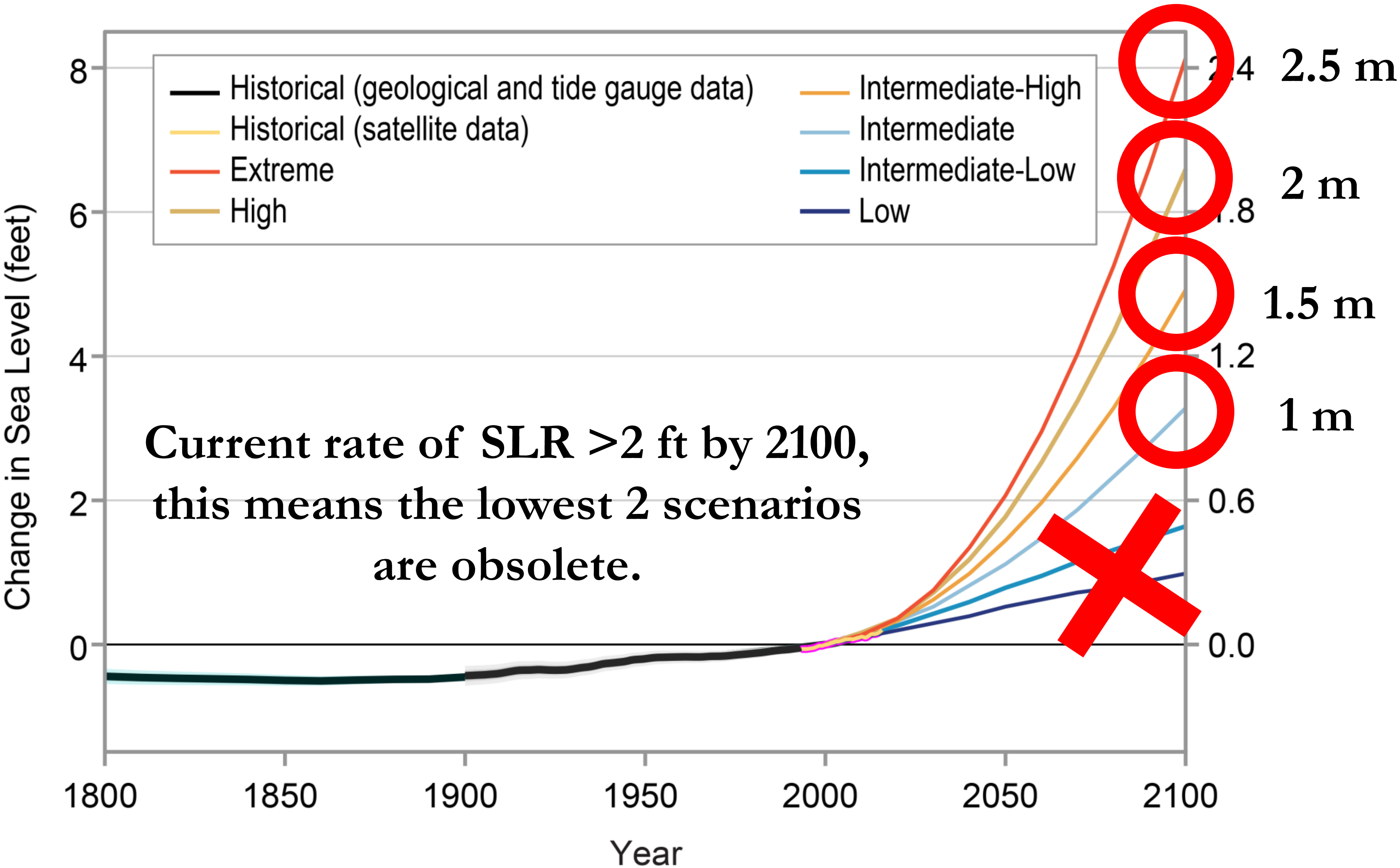
= 1 m by 2100

This only reflects past and current warming. We are still emitting GHG's and there is more warming to come.

E. Rignot (2019) pers. comm.: http://sites.nationalacademies.org/SSB/SSB_191179

Hawai‘i is not waiting for further proof that SLR threatens our communities.

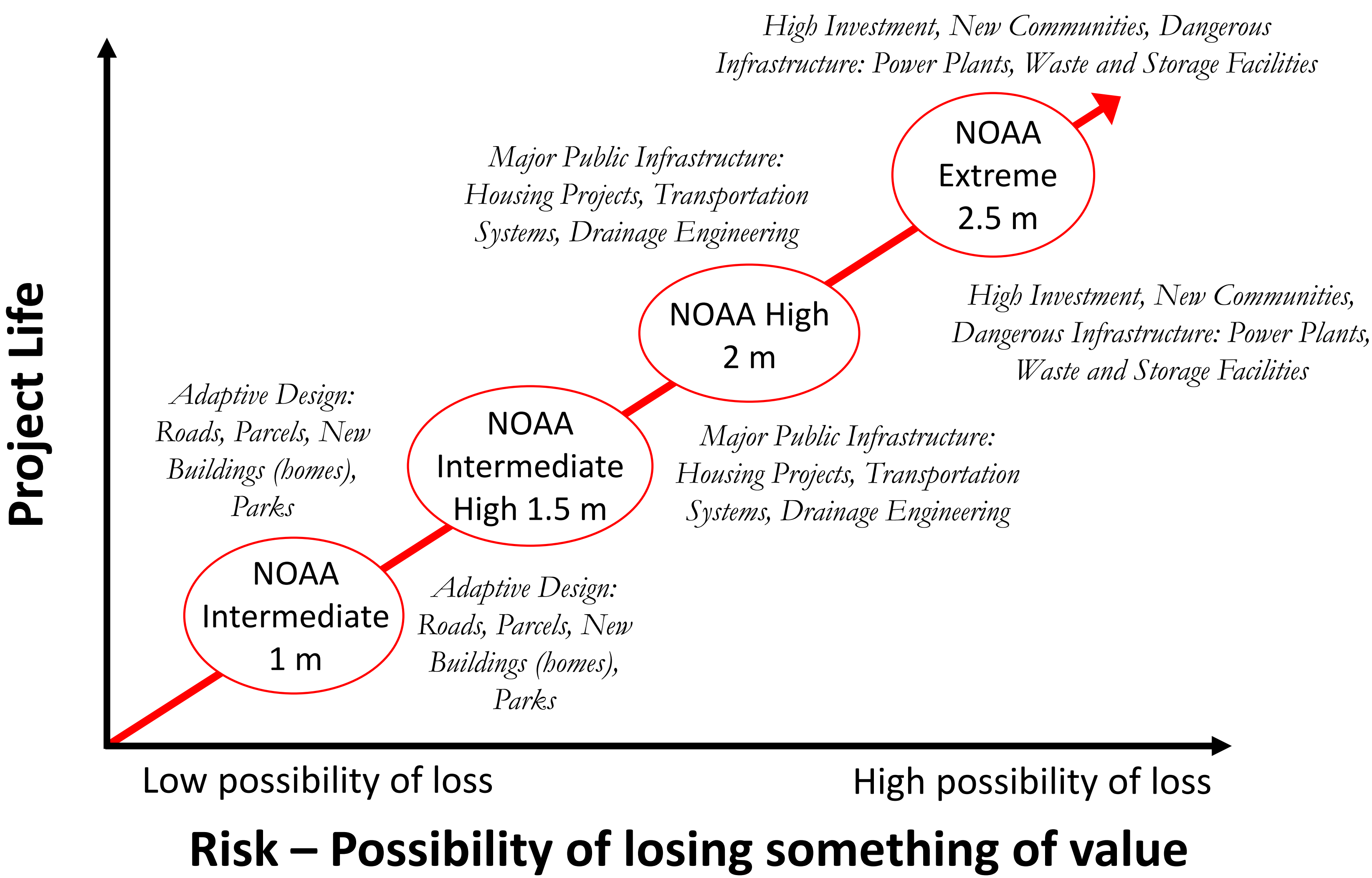
NOAA & 4th NCA SLR Scenarios



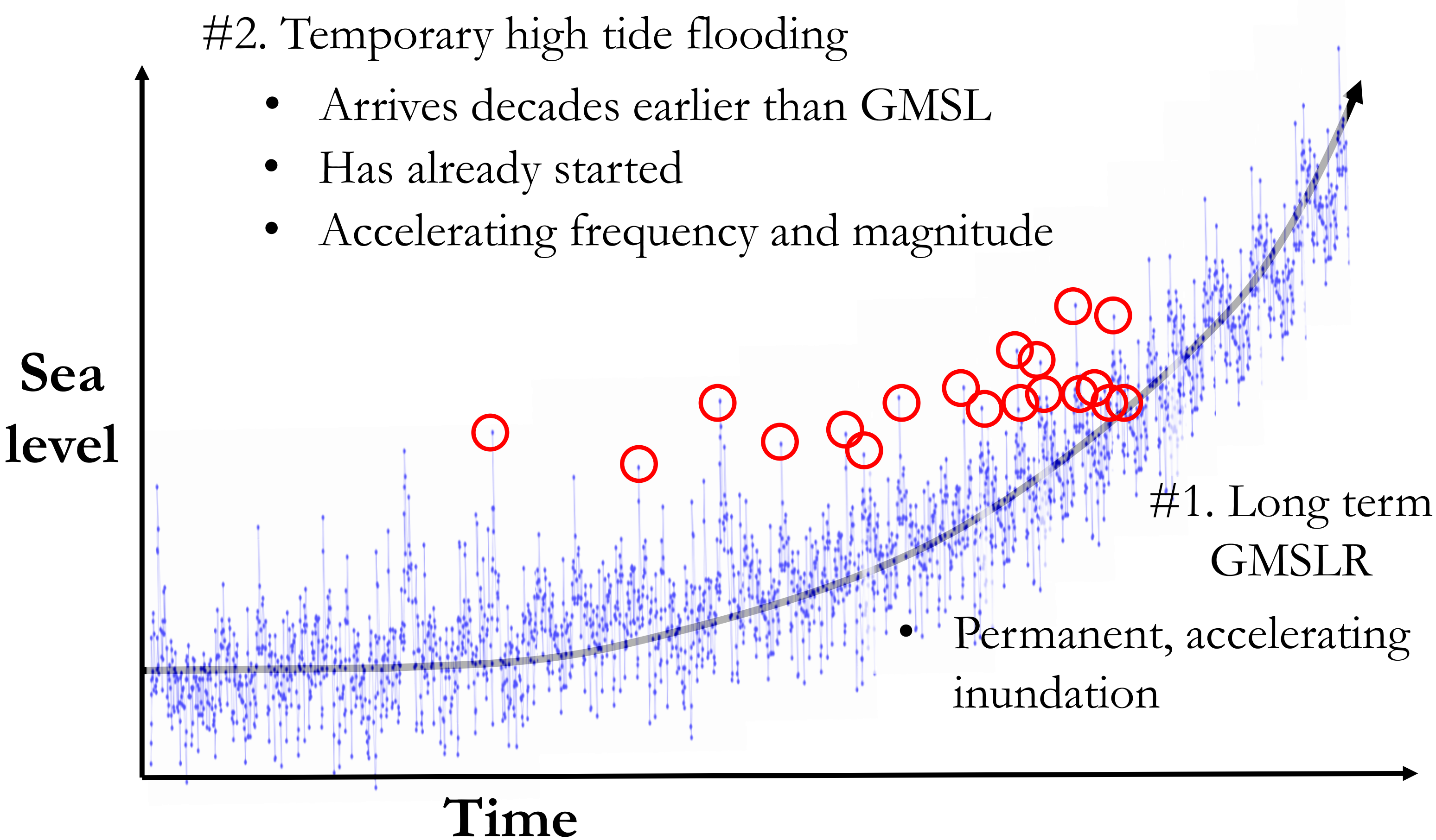
Sweet, W.V., et al. 2017 Sea level rise. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I*[Wuebbles, D.J., et al. (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 333-363, https://science2017.globalchange.gov/chapter/12/

SLR Scenario Planning

decision-making under conditions of uncertainty



SLR Flooding: Nuisance and Permanent

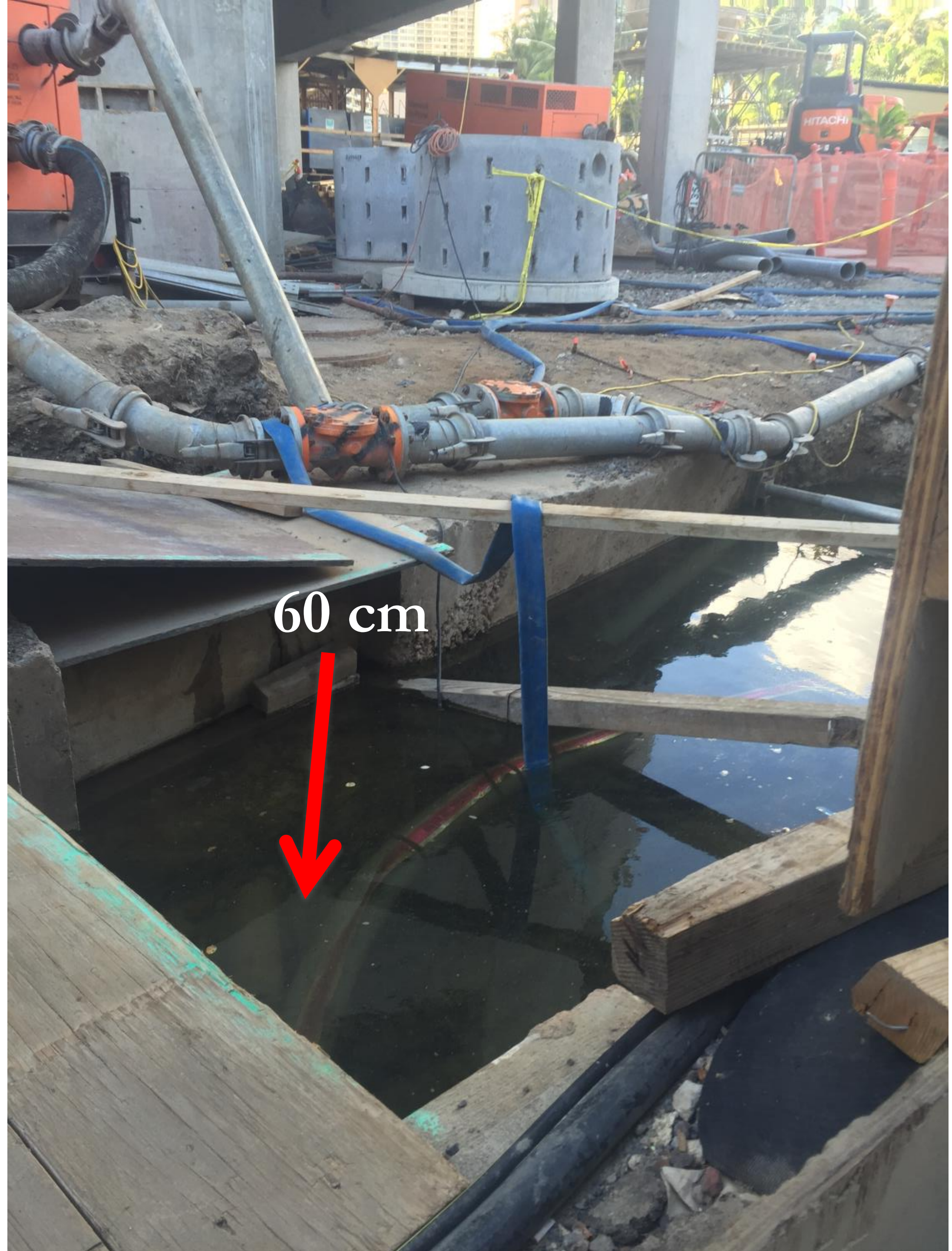


High tide flooding is occurring with greater frequency

Storm Drain Backflow

At high tide the water table is only 60 cm below the ground surface in Waikiki

Groundwater Inundation



Heavy rains at high tide cause urban flooding

Coastal Erosion and Beach Loss

Department of Transportation

- 140 miles
- 120 bridges
- 10-15% all roads
- $15B total

Model targets per IPCC AR5

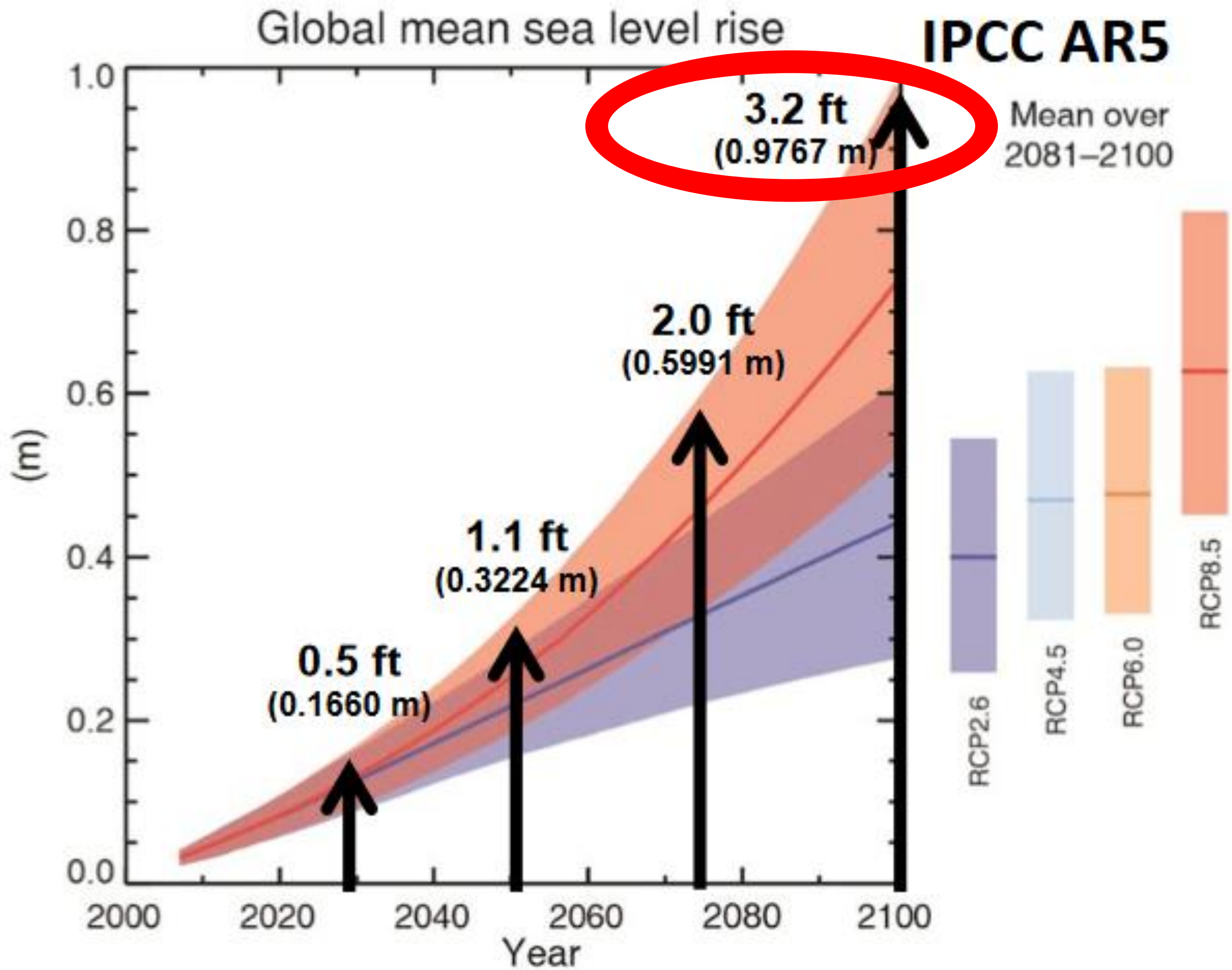


Figure 1. Projected GMSL rise under different greenhouse gas emissions scenarios from the IPCC AR5 Report.

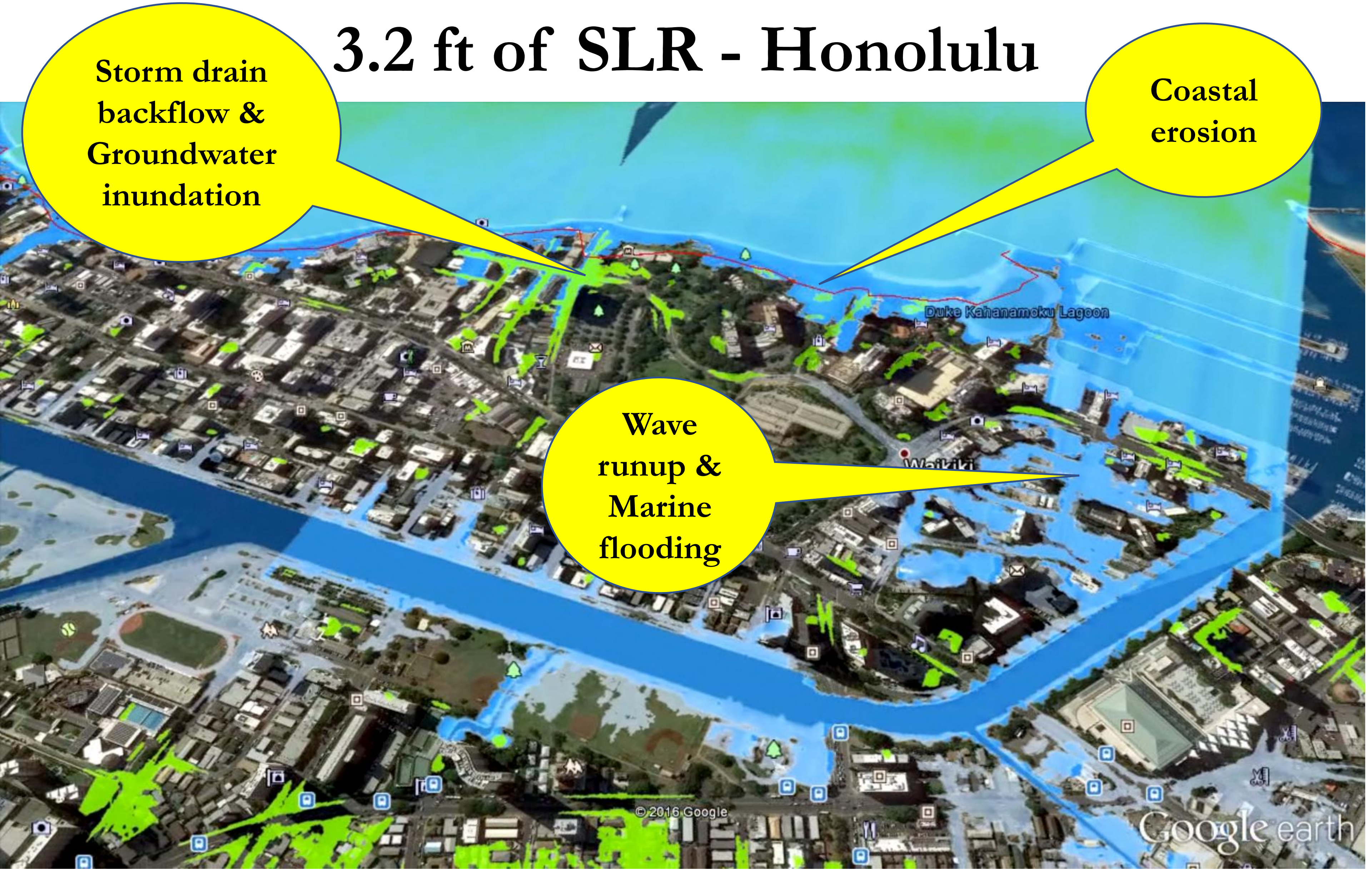
https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

Summer wave run-up 60 cm

Summer wave run-up 98 cm


Sunset Beach 98 cm SLR
Paumalū Gulch
Rocky Point
Sunset Beach Park
Kamehameha Hwy
Girl Scout Camp Rd
Annual wave Run-up
Erosion
'Ehukai Beach Park
Kālunawaika'ala Stream
Banzai Rocks
Sunset Beach Neighborhood Park
Pukea Rd
Opae Rd

3.2 ft of SLR - Honolulu



Article | OPEN | Publi

Modeling ... reveals up ... compared ... methods

Tiffany R. Anderson ✉, (... no &
Jade M.S. M. S. Delevau

Scientific Reports **8**, Arti

https://www.nat

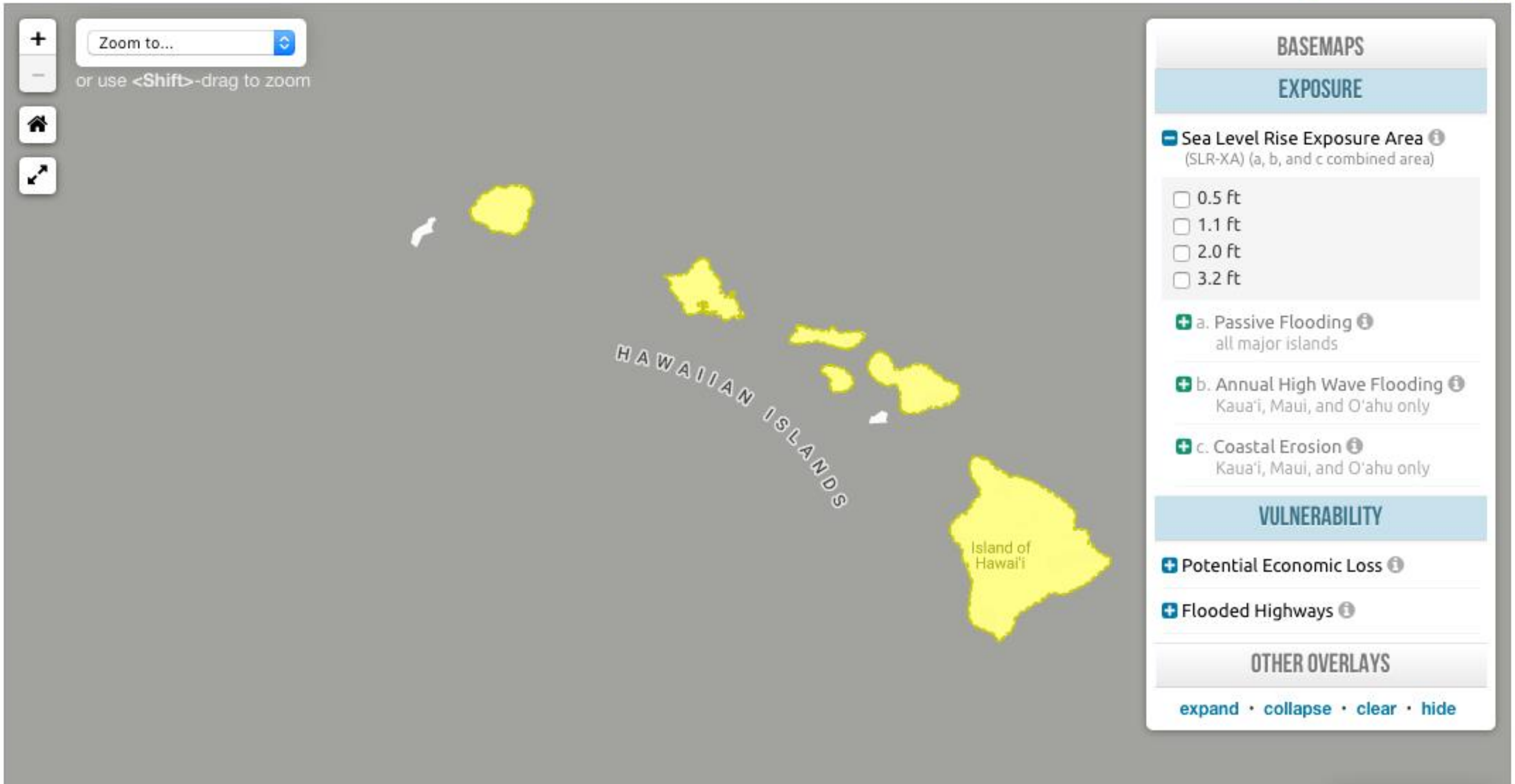
Abstract

Planning community resilience to sea level rise (SLR) requires information about where, when, and how SLR hazards will impact the coastal zone. We augment passive flood mapping (the so-called “bathtub” approach) by simulating physical processes posing recurrent threats to coastal infrastructure, communities, and ecosystems in Hawai‘i (including tidally-forced direct marine and groundwater flooding, seasonal wave inundation, and chronic coastal erosion). We find that the “bathtub” approach, alone, ignores 35–54 percent of the total land area exposed to one or more of these hazards, depending on location and SLR scenario. We conclude that modeling dynamic processes, including waves and erosion, is essential to robust SLR vulnerability assessment. Results also indicate that as sea level rises,

Hawai´i Sea Level Rise Vulnerability and Adaptation Report

Sea Level Rise : Hawai‘i Sea Level Rise Viewer

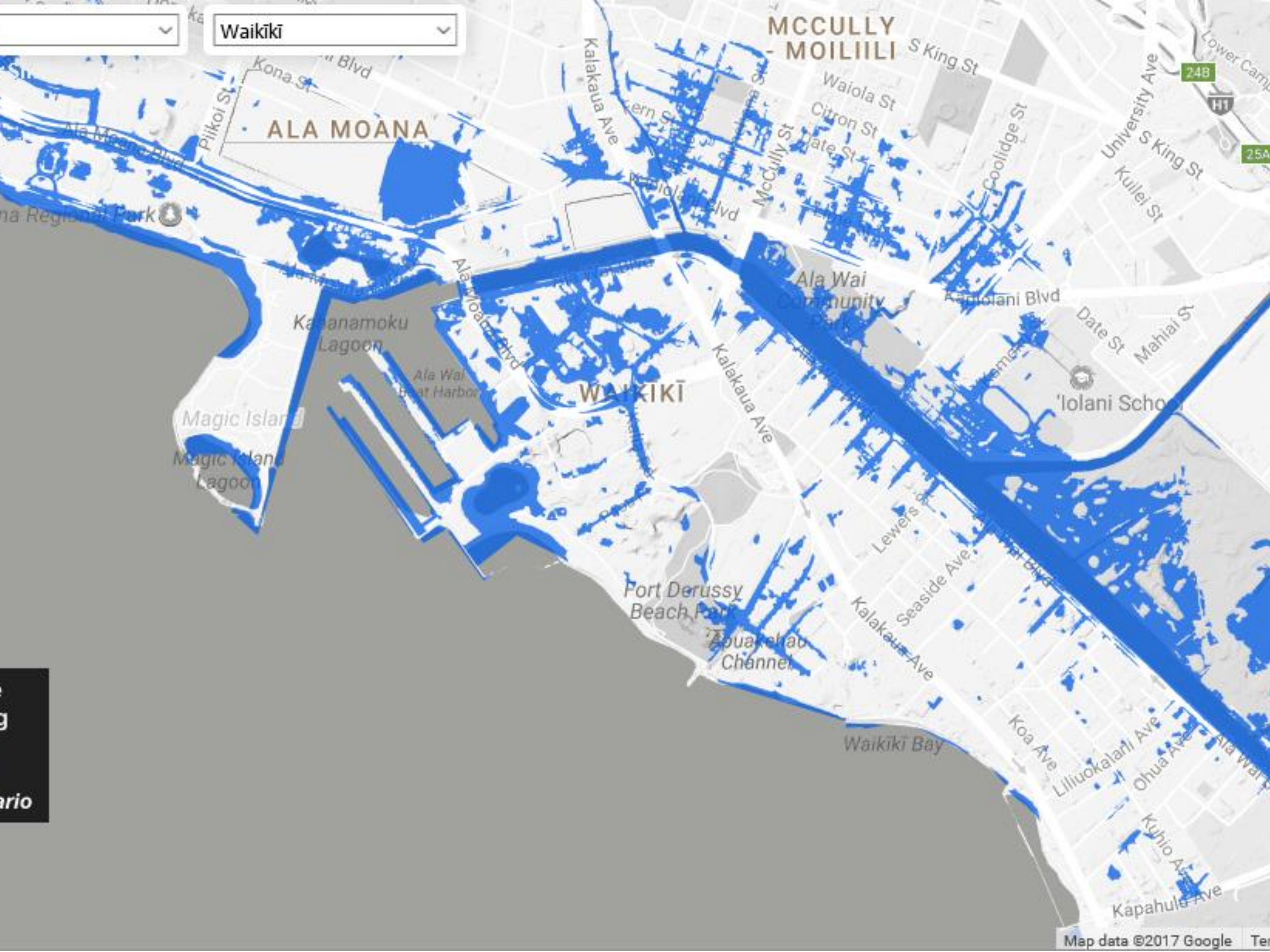
view full-screen map



The 3.2SLR-XA
King Tide Flooding & Permanent Inundation


Kapiolani Blvd
MOILIILI
S King St
Kalakaua Ave
University Ave
H1
Pikoi St
ALA MOANA
Ala Moana Blvd
McCully St
S King St
Palolo Stream
Ala Moana Regional Park
Kapiolani Blvd
Ala Moana Beach Park
Walalae Ave
Kapiolani Blvd
Ala Moana Blvd
Ala Wai Community Park
Kapiolani Blvd
Kahanamoku Lagoon
'Iolani School
Ala Wai Boat Harbor
Ala Wai Blvd
Ala Wai Canal Fishery Management Area
Ala Moana Blvd
Magic Island
Magic Island Lagoon
WAIKIKI
Ala Wai Blvd
Kapahulu Ave
6th Ave
Fort Derussy Beach Park
Kalakaua Ave
Apuakehau Channel
Waikiki Bay
Ala Wai Blvd
© 2019 Google
Kapahulu Ave
Paki Ave
Monsarrat Ave
Monsarrat Ave
Waikiki Marine Life Conservation District
Kalakaua Ave
Paki Ave
Kapi'olani Regional Park
Kapua Entrance
Kaluahole

MOILIILI
S King St
Kapiolani Blvd
Kalakaua Ave
ALA MOANA
Piikoi St
Ala Moana Blvd
McCully St
University Ave
S King St
Pālolo Stream
H1
Waialae Ave
Kapiolani Blvd
Ala Moana Regional Park
Ala Moana Beach Park
Kahanamoku Lagoon
Ala Wai Community Park
Kapiolani Blvd
Iolani School
Magic Island
Magic Island Lagoon
Ala Moana Blvd
Ala Wai Blvd
Ala Wai Canal Fishery Management Area
WAIKIKI
Kapahulu Ave
6th Ave
Fort Derussy Beach Park
Kalakaua Ave
Waikiki Bay
Ala Wai Blvd
© 2019 Google
Kapahulu Ave
Paki Ave
Monsarrat Ave
Monsarrat Ave
Waikiki Marine Life Conservation District
Kalakaua Ave
Paki Ave
Kapiolani Regional Park
Kapua Entrance
Kaluahole
75%



Waikīkī
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WAIKĪKĪ
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Waiola St
Citron St
Date St
Kona St
Piikoi St
Kalakaua Ave
McCully St
Coolidge St
University Ave
Kuilei St
Kapiolani Blvd
Ala Moana Blvd
Ala Wai Community Park
Kahanamoku Lagoon
Ala Wai Boat Harbor
Magic Island
Magic Island Lagoon
Date St
Mahiai St
'Iolani School
Lewers St
Seaside Ave
Port Derussy Beach Park
'Apuakehau Channel
Waikīkī Bay
Koa Ave
Liliuokalani Ave
Ohua Ave
Kuhio Ave
Kapahulu Ave
24B
H1
25A
Map data ©2017 Google

HAWAII NEWS

Honolulu Climate Change Commission holds first meeting

By Gordon Y.K. Pang · Feb. 8, 2018

DENNIS ODA / DODA@STARADVERTISER.COM

Shown at the first meeting of the Climate Change Commission at Honolulu Hale on Wednesday are Chairwoman Makena Coffman, left, corporation counsel Courtney K. Sue-Ako, Victoria Keener and Bettina Mehnert. Not pictured but also on the committee are Rosanna Alegado and Vice Chairman Charles "Chip" Fletcher.

City and County of Honolulu Office of Climate Change, Sustainability and Resiliency

Climate Change Commission

ABOUT THE COMMISSION

MEETING AGENDAS AND MINUTES

GUIDANCE AND PUBLICATIONS

SUBSCRIBE TO MEETING AGENDAS AND MINUTES

CONTACT THE COMMISSION

Climate Change Commission Guidance and Publications

Below are links to the Climate Change Commission reports, guidance, research papers, and related publications.

CLIMATE CHANGE BRIEF

Th[illegible] regional, and global impacts of climate change as documented by the peer-reviewed scientific literature and credible empirical data sources. It provides a benchmark for the commission, attesting to the Climate Change Commission's concerns, underpinning the Commission's decisions and recommendations, and serving to

SEA LEVEL RISE GUIDANCE

Th[illegible] in the Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report (2017), Sweet et al. (2017), USGCRP (2017), Sweet et al. (2018), and other scientific literature to provide specific policy and planning guidance on responding to sea level rise by the City.

HAWAII NEWS NOW

NEWS LIVE WEATHER SPORTS CONFLICT ON MAUNA KEA HI NOW

Honolulu mayor says Oahu must prepare for 3-foot sea level rise by mid-century

Honolulu Mayor Kirk Caldwell says the city needs to prepare for rising sea levels. (Image: Barbara Dittrich)

By Austin Westfall | July 17, 2018 at 8:43 PM HST - Updated September 19 at 6:46 PM

HONOLULU (HawaiiNewsNow) - Honolulu Mayor Kirk Caldwell is directing all city departments to address, minimize the risks from, and adapt to the impacts of climate change and sea level rise.

"Climate change is the biggest challenge of our time," Caldwell said in a statement on Facebook on Monday. "Whether it be changing the building code, whether it be looking at allowing more housing to be built close to the shore, and everything else in between."

The mayor gave the directive in a press conference Monday after receiving sea level rise guidelines from the the Honolulu Climate Change Commission, which is led by the University of Hawaii.

"The city should be planning for high tide flooding associated with 3.2 feet of sea level rise by mid-century," the school said in a news release.

The commission says Oahu is the most vulnerable Hawaiian island when it comes to flood risk. The report says nearly 4,000 structures on Oahu, most of which are homes or businesses, will be chronically flooded with the three-foot sea level rise. Furthermore, about 18 miles of the island's coastal roads will become impassable, jeopardizing access to many communities.

"And, because of continued high global carbon emissions, take into consideration 6 feet of sea level rise in later decades of the century, especially for critical infrastructure with long expected lifespans and low-risk tolerance," the school said.

PLAN FOR:

- 3.2 ft of SLR by end of century
- High tide flooding in the 3.2 ft SLR-XA by mid-century
- 6 ft of SLR for projects with low tolerance for risk

PRIMARY URBAN CENTER
DEVELOPMENT PLAN

HOME ABOUT RESOURCES CONVERSA

Honolulu Sea-Level Rise "Pop-Ups"

UPCOMING EVENTS

Sea Level Rise Pop-Ups (Third Round)

DPP will be out and about in the community in late August and September 2019, with a focus on climate change and sea level rise impacts for urban Honolulu. Come and learn about the conditions and forecasts for the area and provide your input on strategies to address this critical issue!

View the Pop-Up Schedule Flyer!

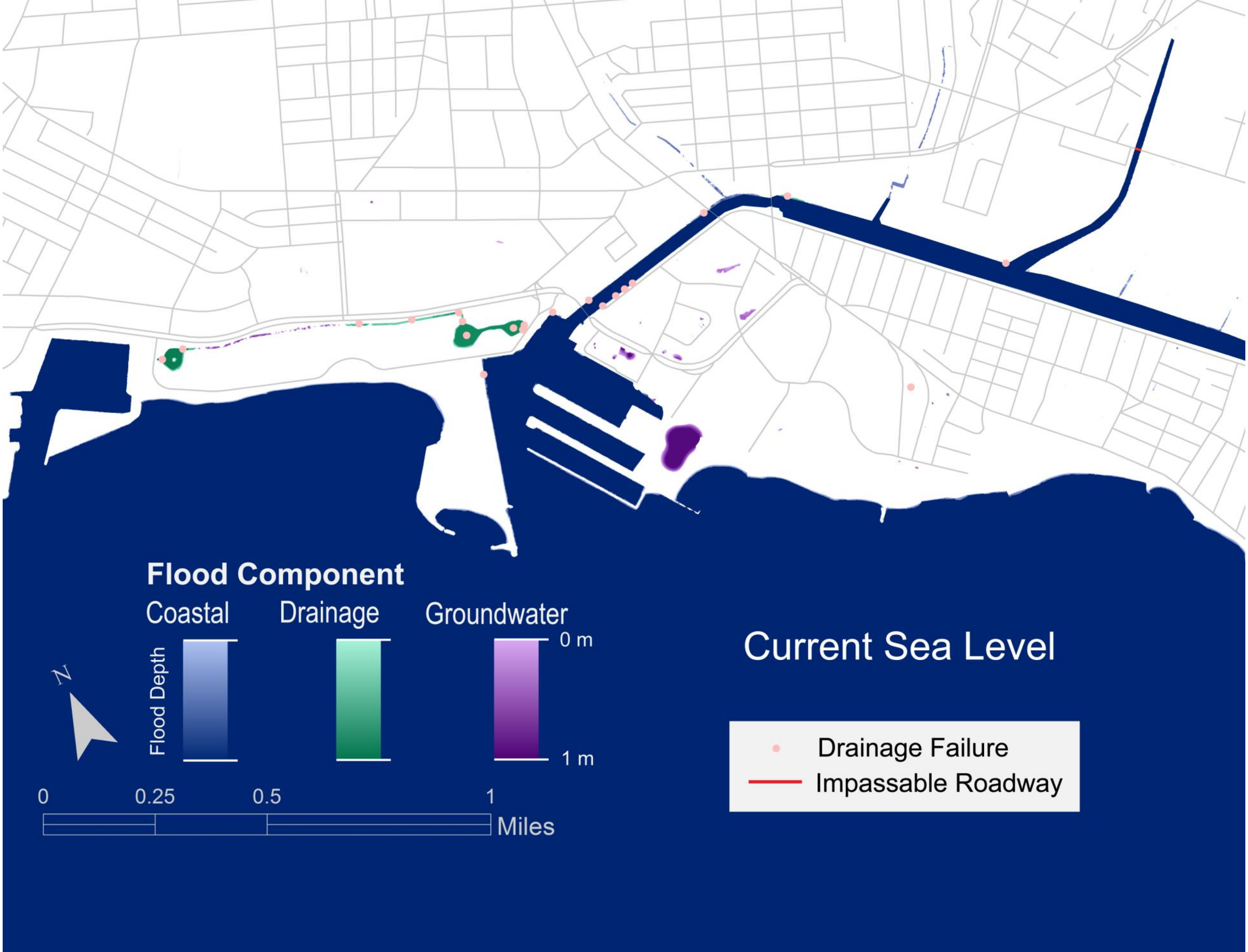
Pop-Up Schedule

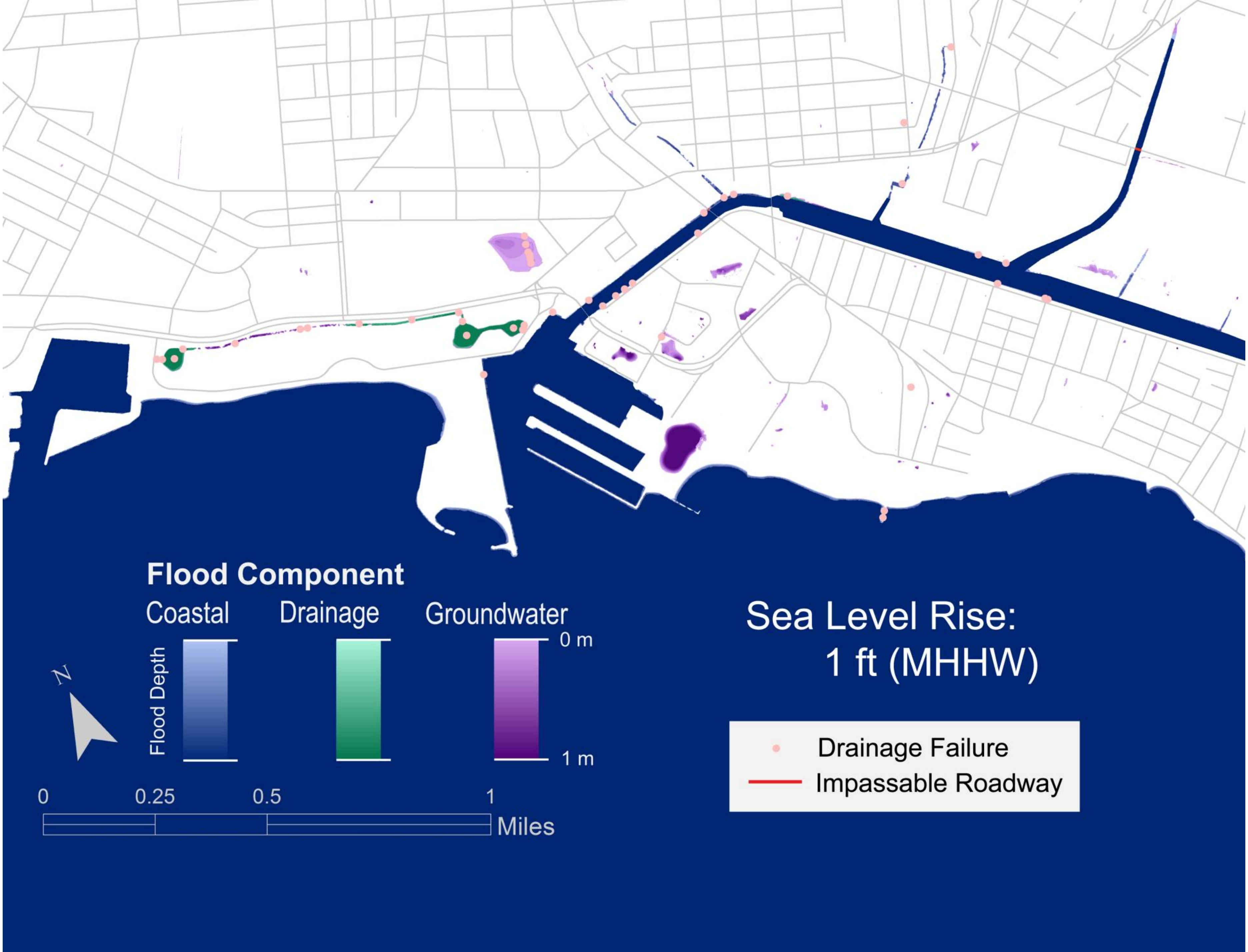
Pop-Up #1: Kamehameha Shopping Center, Times Supermarket
1620 N School Street
Monday, August 26th, 11:00am - 1:00pm

Pop-Up #2: University of Hawai`i, Welcome Back Fair
Campus Center, 2465 Campus Road
Tuesday, August 27th, 9:00am - 1:00pm

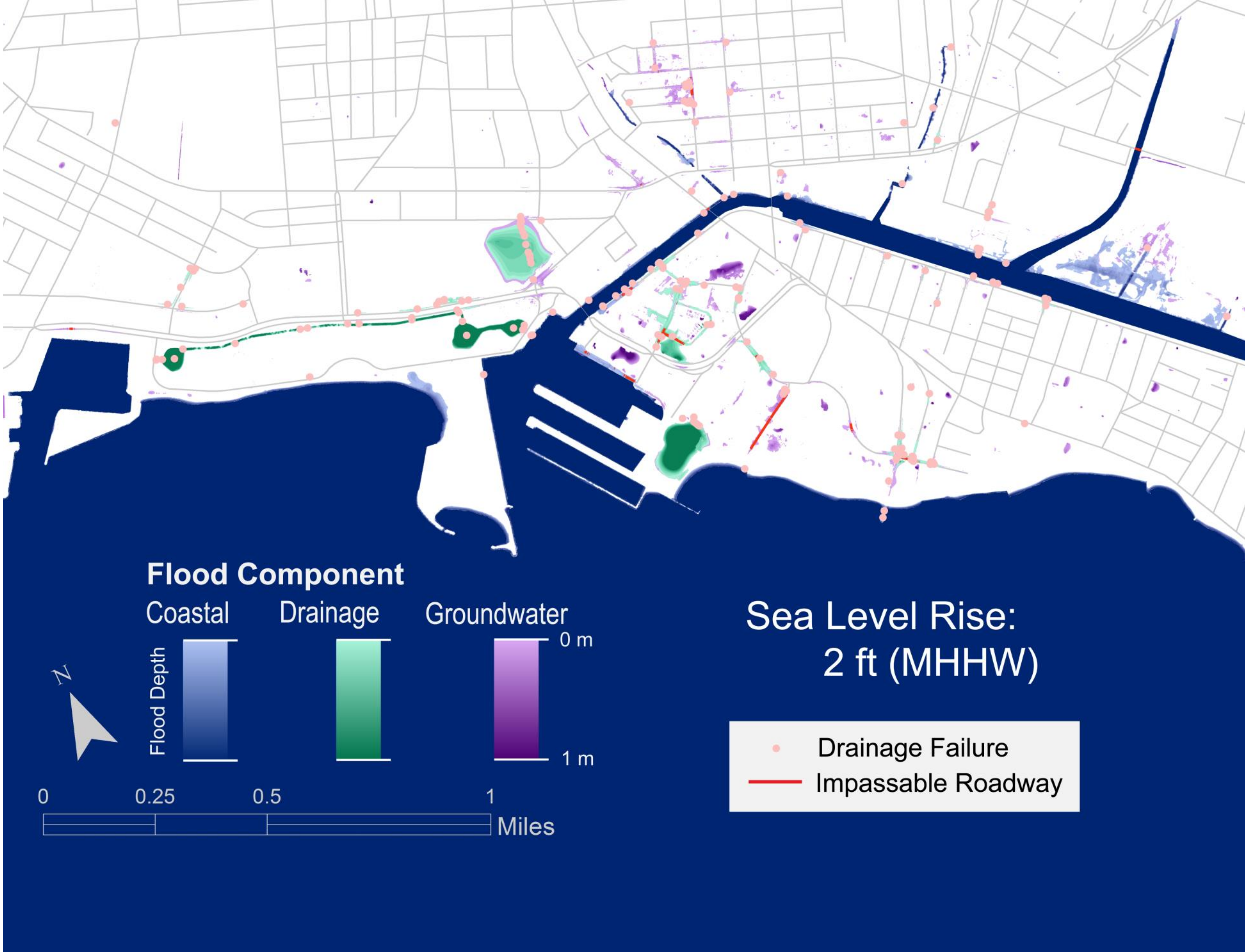
Pop-Up #3: Lanakila Multipurpose Senior Center
1640 Lanakila Road
Thursday, August 29th, 8:30am - 11:30am

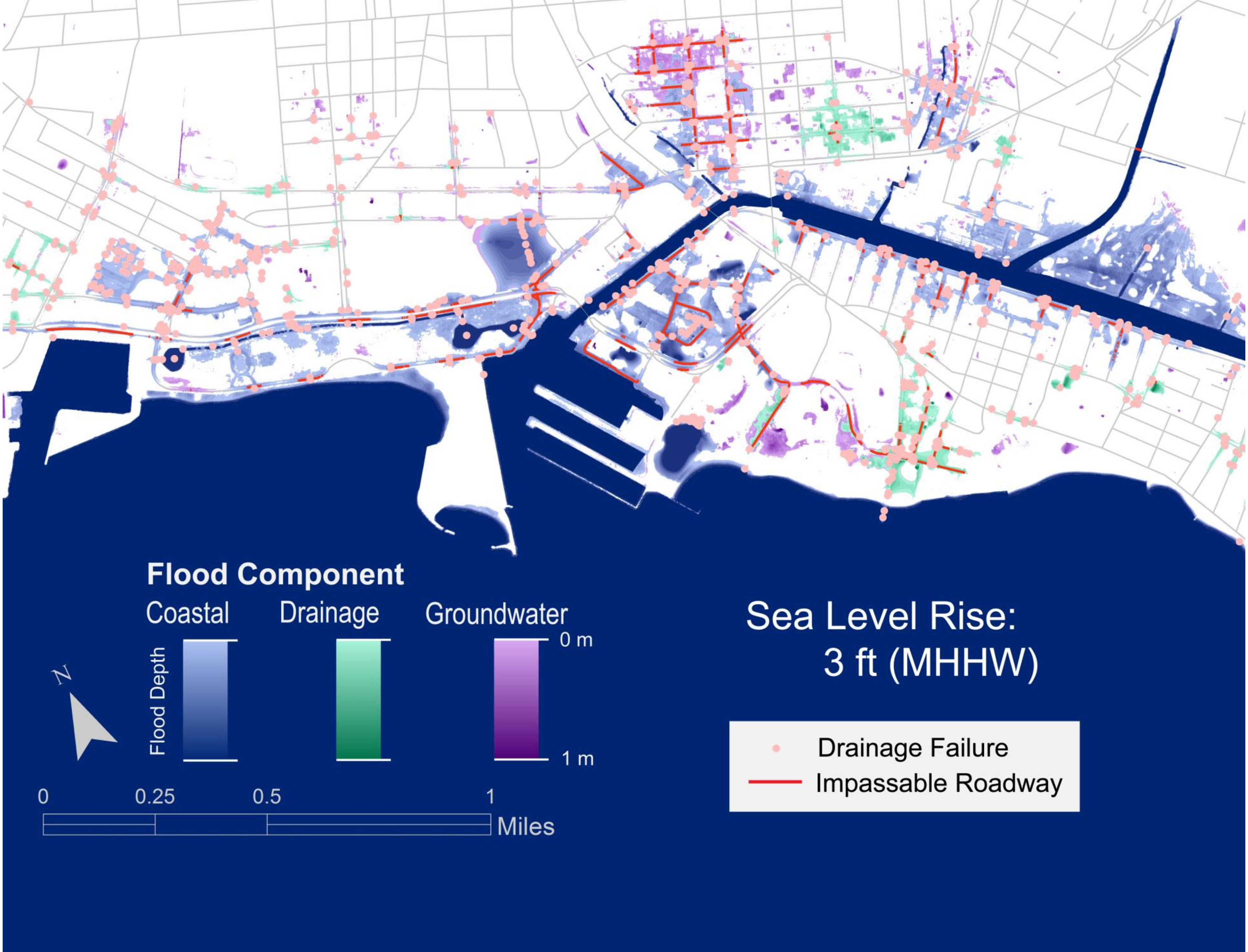
Pop-Up #4: Pearlridge Center, Farmer's Market
98-1005 Moanalua Road


Flood Component
Coastal
Drainage
Groundwater
Flood Depth
0 m
1 m
N
0
0.25
0.5
1
Miles
Current Sea Level
Drainage Failure
Impassable Roadway

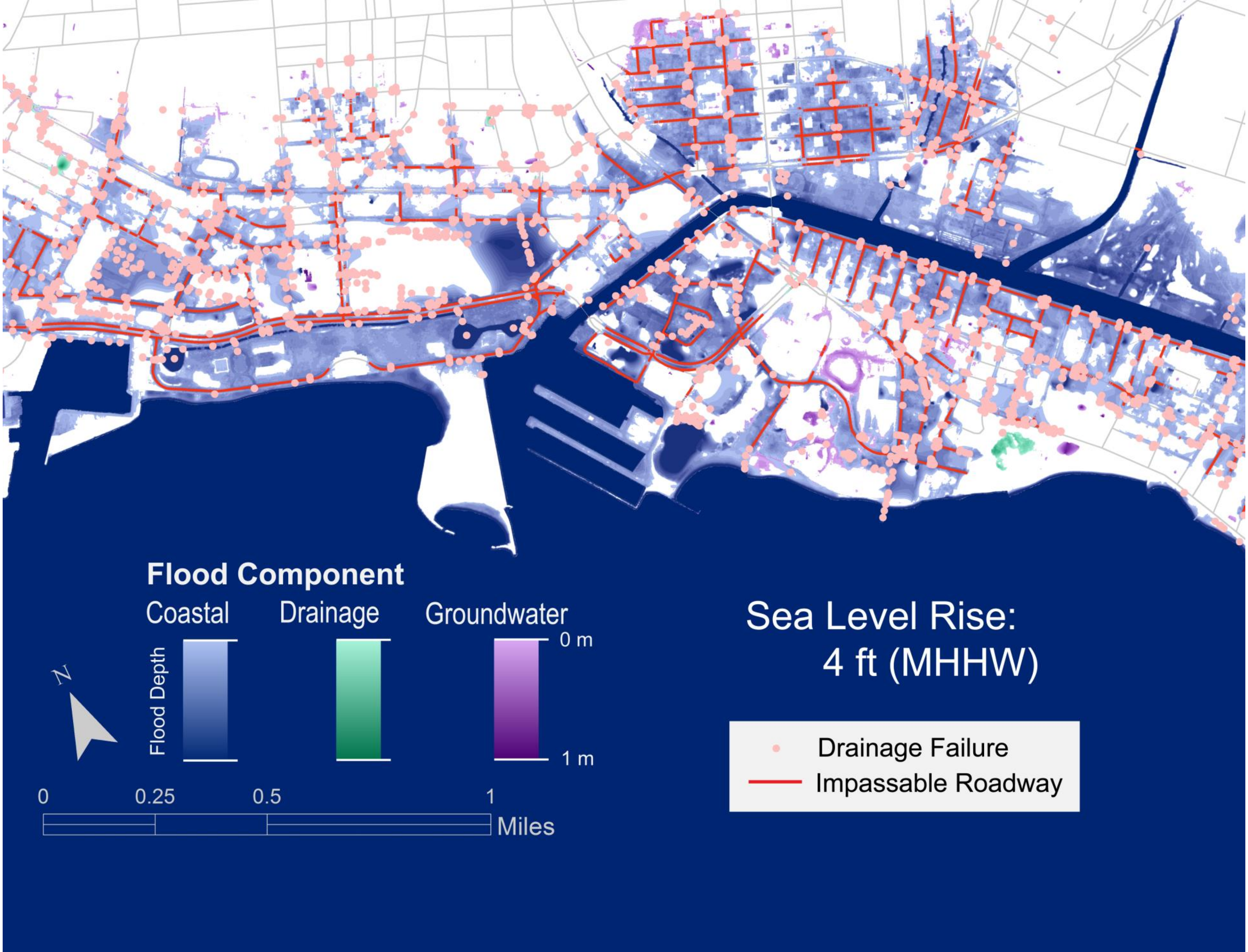


Flood Component
Coastal
Drainage
Groundwater
Flood Depth
0 m
1 m
N
0
0.25
0.5
1
Miles
Sea Level Rise:
1 ft (MHHW)
Drainage Failure
Impassable Roadway

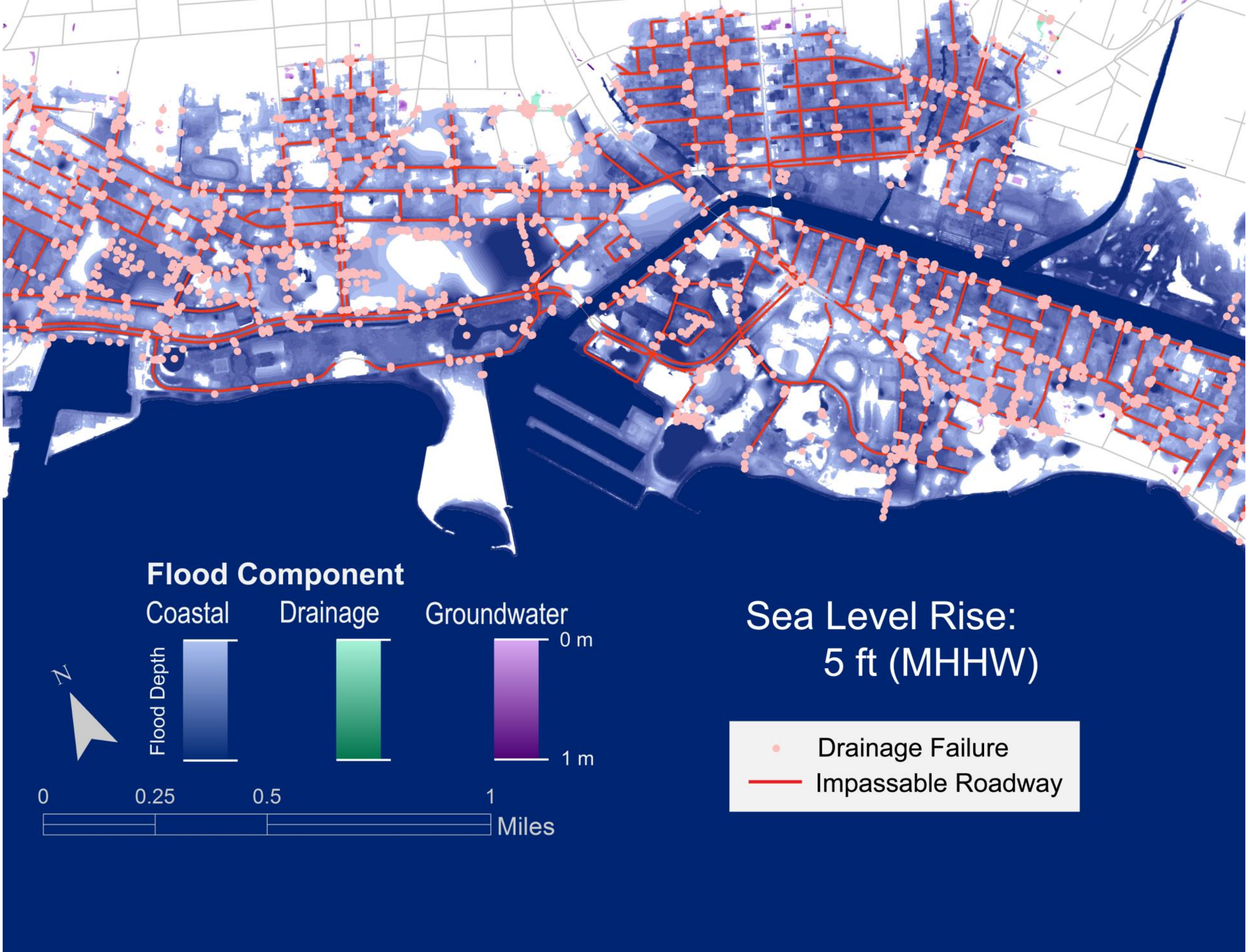

Flood Component
Coastal
Drainage
Groundwater
Flood Depth
0 m
1 m
N
0
0.25
0.5
1
Miles
Sea Level Rise:
2 ft (MHHW)
Drainage Failure
Impassable Roadway



Flood Component
Coastal
Drainage
Groundwater
Flood Depth
0 m
1 m
N
0
0.25
0.5
1
Miles
Sea Level Rise:
3 ft (MHHW)
Drainage Failure
Impassable Roadway



Flood Component
Coastal
Drainage
Groundwater
Flood Depth
0 m
1 m
N
0
0.25
0.5
1
Miles
Sea Level Rise:
4 ft (MHHW)
Drainage Failure
Impassable Roadway

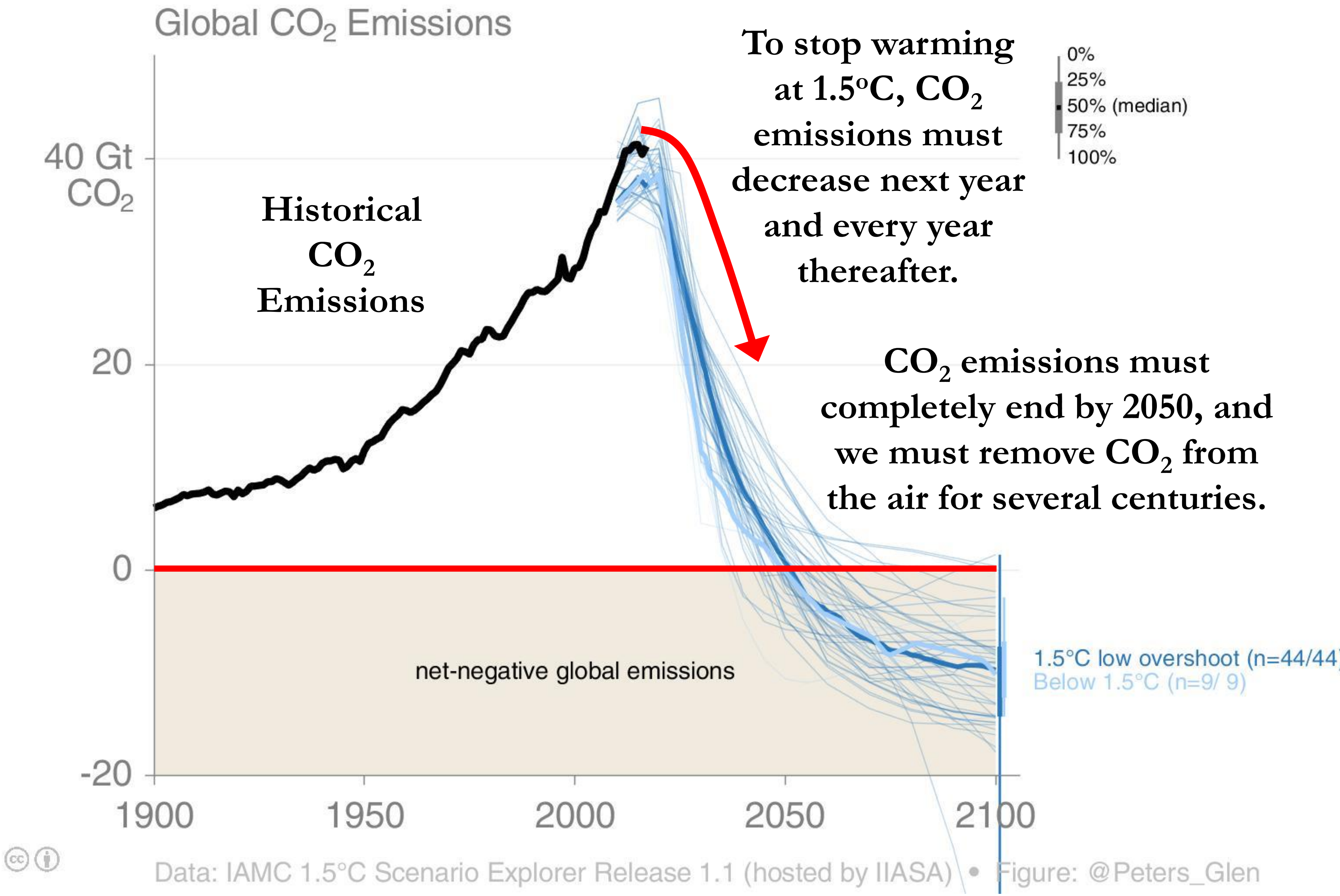


Flood Component
Coastal
Drainage
Groundwater
Flood Depth
0 m
1 m
N
0
0.25
0.5
1
Miles
Sea Level Rise:
5 ft (MHHW)
Drainage Failure
Impassable Roadway

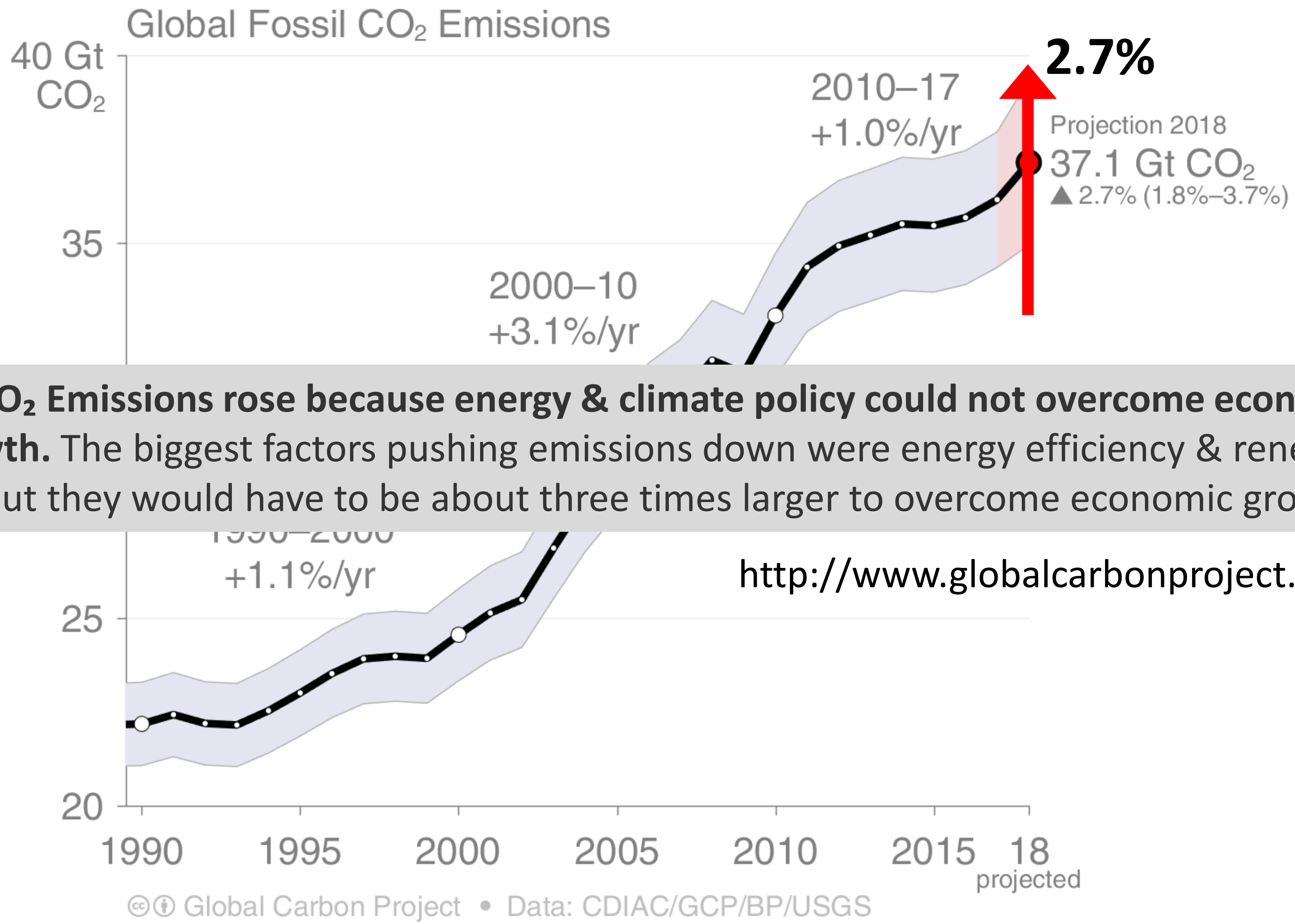
It is important to acknowledge the reality of global efforts to control the climate crisis.

Conventional approaches to mitigating climate change are not working

- Progress is falling well short of the Paris Agreement.
  - < 1/3 of needed reductions,
  - < 1% population in full compliance
- Solutions by sector are geographically and temporally irregular.
- Solutions must simultaneously
  - 1) End carbon emissions,
  - 2) Sequester 1 trillion tons of CO_2, and
  - 3) Adapt to centuries of growing weather disasters.
- Any one of these costs more than we can afford.


Global CO_2 Emissions
To stop warming at 1.5°C, CO_2 emissions must decrease next year and every year thereafter.
0%
25%
50% (median)
75%
100%
40 Gt CO_2
20
0
-20
Historical CO_2 Emissions
CO_2 emissions must completely end by 2050, and we must remove CO_2 from the air for several centuries.
net-negative global emissions
1.5°C low overshoot (n=44/44)
Below 1.5°C (n=9/ 9)
1900
1950
2000
2050
2100
Data: IAMC 1.5°C Scenario Explorer Release 1.1 (hosted by IIASA) • Figure: @Peters_Glen

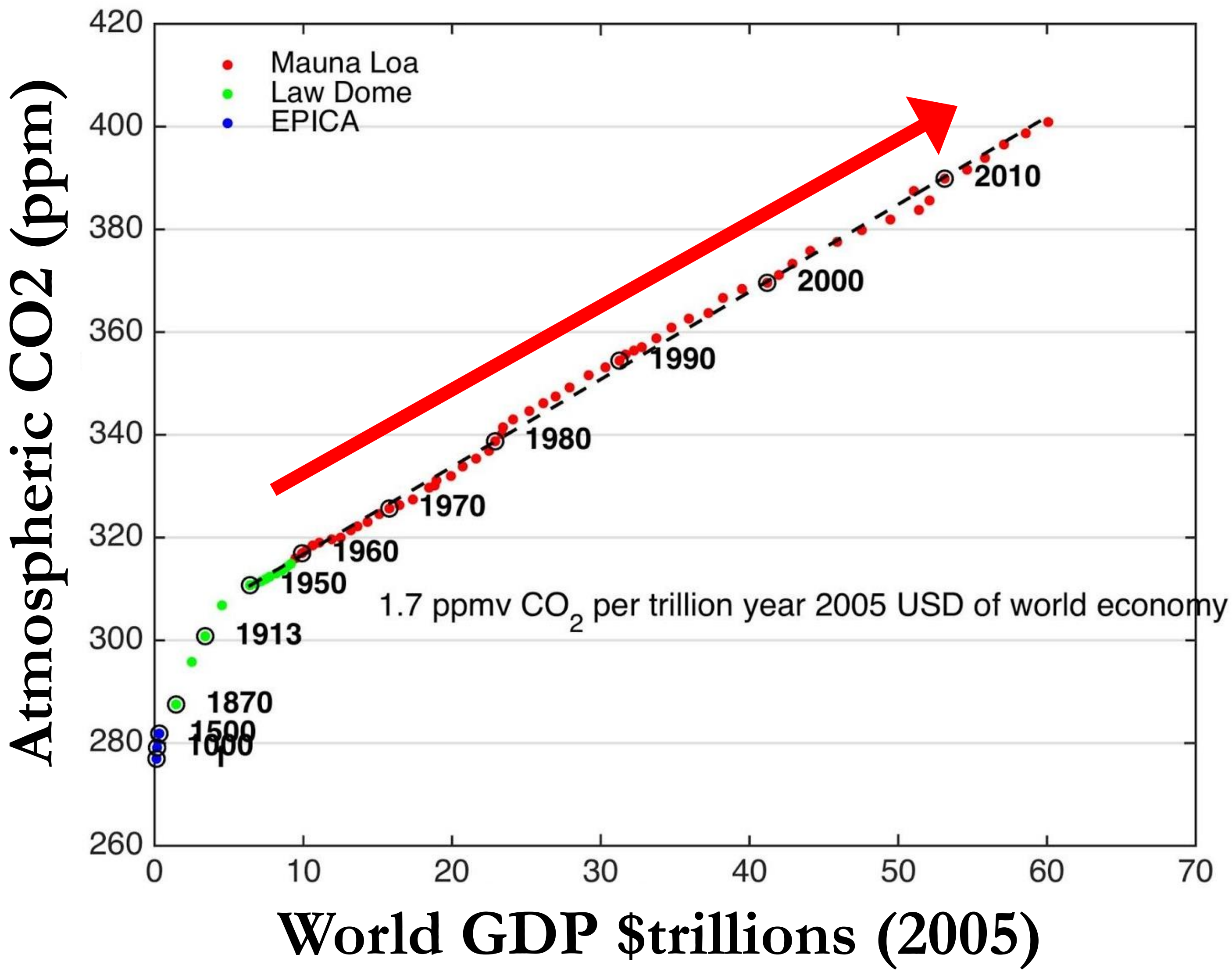
CO_2 emissions are rising at record levels



CO_2 Emissions rose because energy & climate policy could not overcome economic growth. The biggest factors pushing emissions down were energy efficiency & renewables, but they would have to be about three times larger to overcome economic growth.

http://www.globalcarbonproject.org

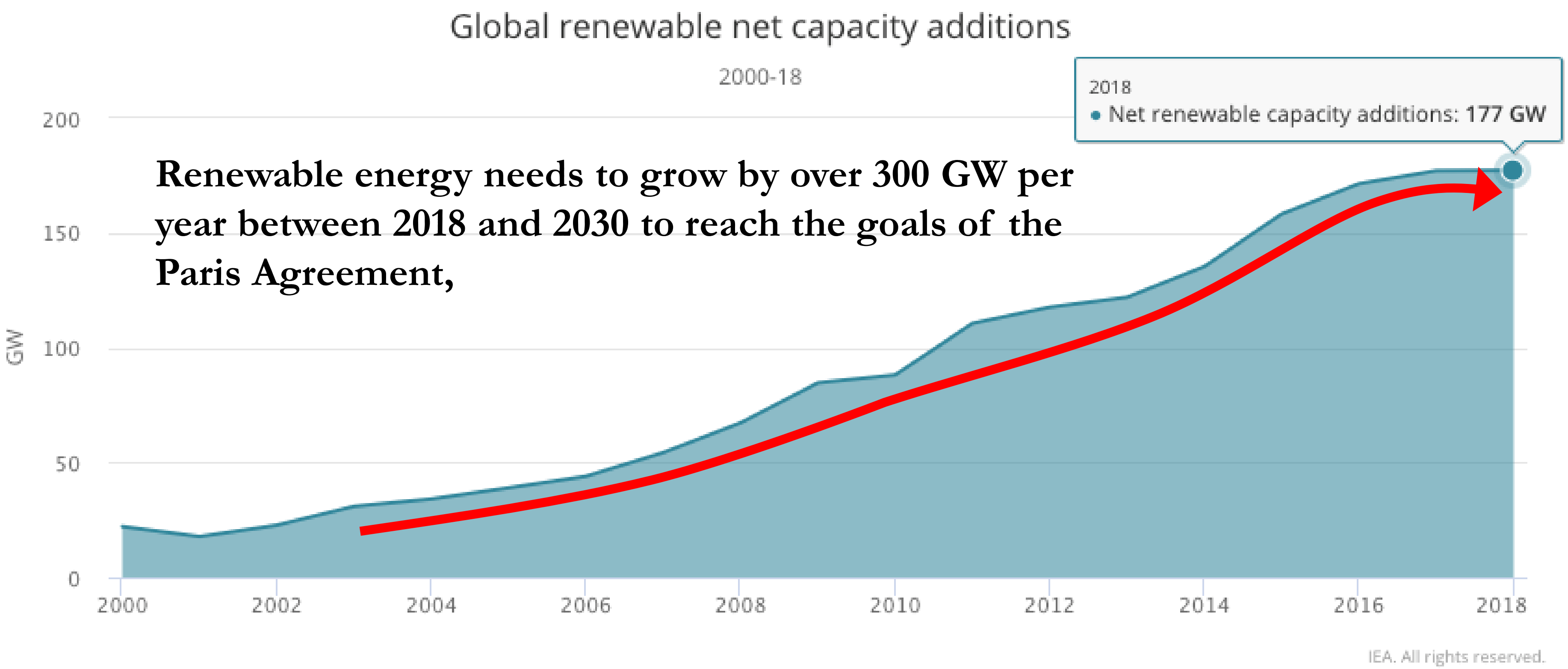
Emissions Follow World GDP, +130% by 2050



Price Waterhouse Consultants (PwC) https://www.pwc.com/gx/en/issues/economy/the-world-in-2050.html

Tim Garrett - https://twitter.com/nephologue/status/1051218794679390209 Garrett, T. J.: No way out? The double-bind in seeking global prosperity alongside mitigated climate change, Earth Syst. Dynam., 3, 1-17, https://doi.org/10.5194/esd-3-1-2012, 2012.

Last year was the first time since 2001 that growth in renewable power failed to increase

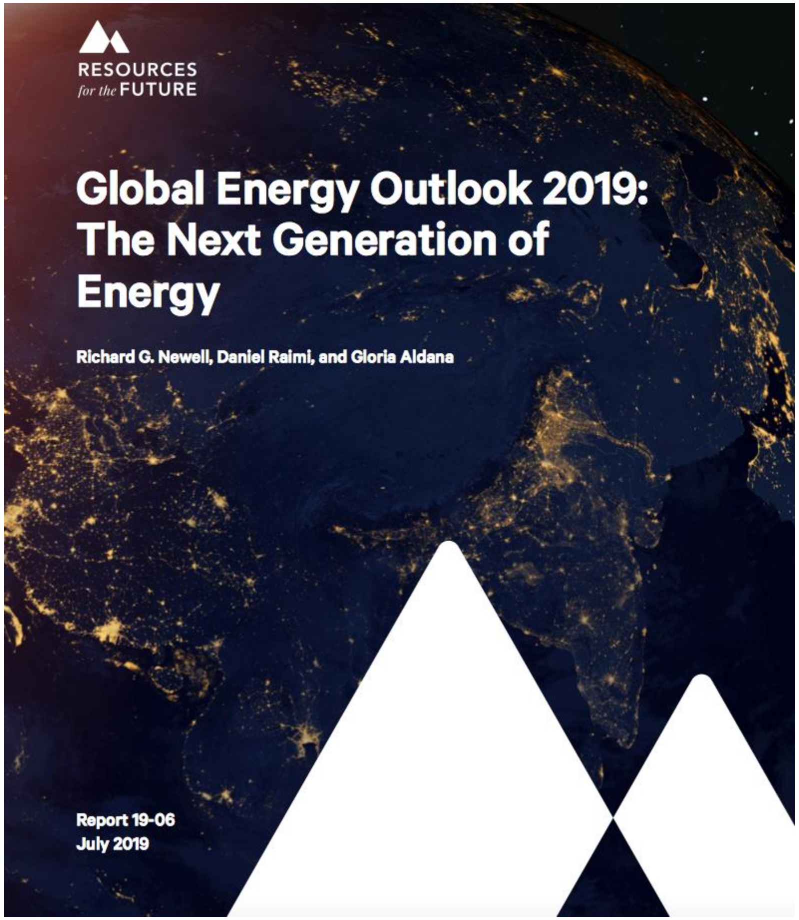


https://www.iea.org/newsroom/news/2019/may/renewable-capacity-growth-worldwide-stalled-in-2018-after-two-decades-of-strong-e.html

- Energy demand set to grow >25% by 2040
- Renewables make up only two-thirds of new capacity
- Oil consumption grows due to rising demand for petrochemicals, trucking, aviation, energy
- CO_2 emissions continue to increase to mid-century

https://www.iea.org/weo/

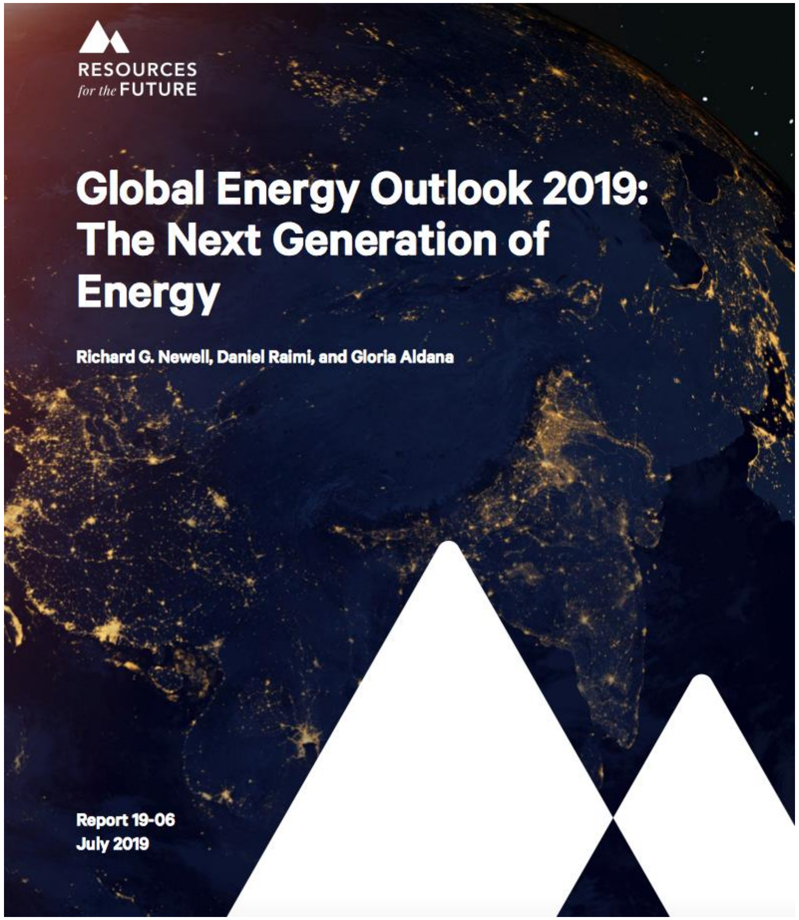
Outlook – Emissions continue to grow



- Without ambitious climate policies—global energy consumption will grow 20–30% or more through 2040 and beyond, led largely by fossil fuels.
- This is driven by population and economic growth in the global "East," while energy consumption in the "West" remains roughly flat.
- The global economy becomes more energy efficient over time, though carbon dioxide emissions continue to grow unless there is a shift in current policy and technology trends.

Global Energy Outlook 2019, The Next Generation of energy: https://media.rff.org/documents/GEO_Report_7-19-19.pdf

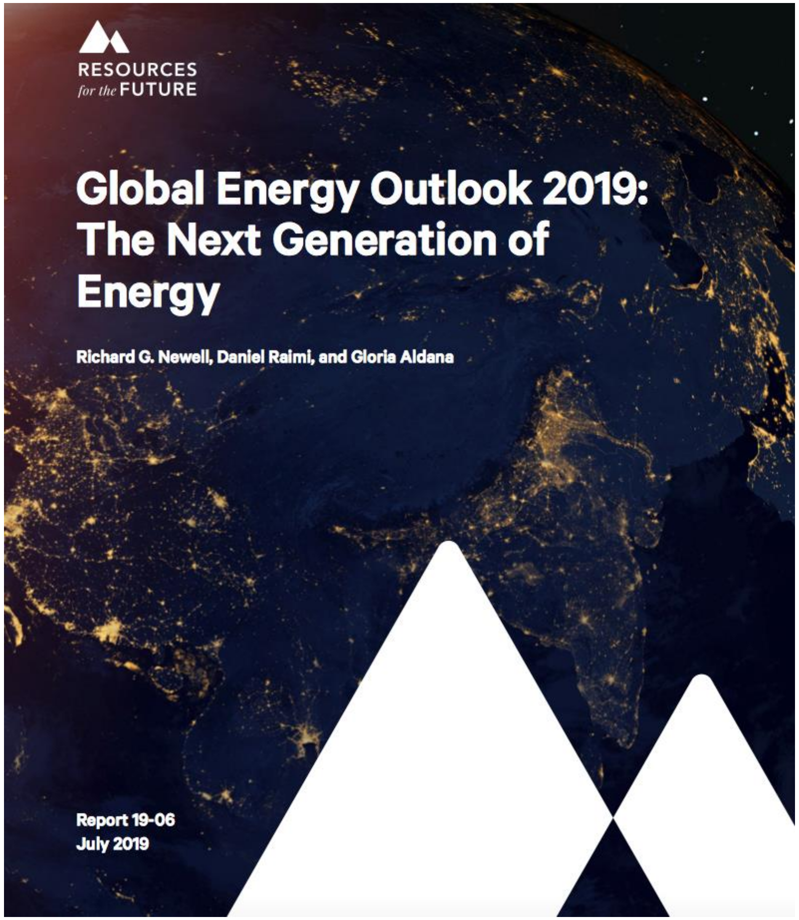
Outlook – Emissions continue to grow



- Renewable energy grows rapidly, though it primarily adds to, rather than displaces, fossil fuels.
- Electric vehicles play an important role in the future of transportation. But their effect is to restrain the growth of, rather than lead to a decline in, global oil demand over the next two decades
- In 2018, 23 commercial-scale **carbon capture and storage (CCS)** projects were in operation or under construction around the world, capturing 40 million metric tons of CO2 annually. *This is* $1/1000^{th}$ *of annual emissions.*

Global Energy Outlook 2019, The Next Generation of energy: https://media.rff.org/documents/GEO_Report_7-19-19.pdf

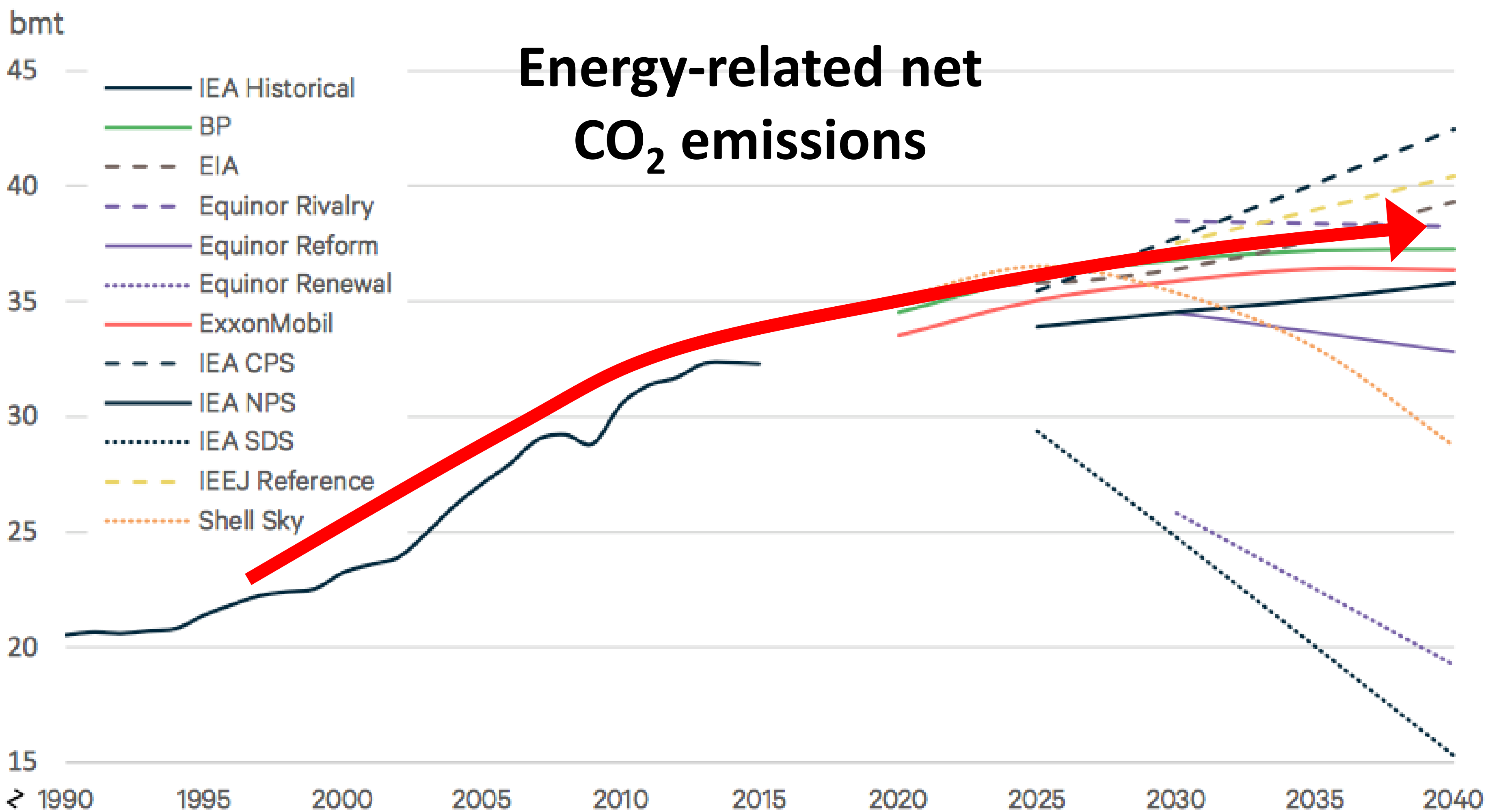
Outlook – Emissions continue to grow



- Under most scenarios, **carbon dioxide (CO2)** emissions from the global energy system are on a path to far exceed international targets of the Paris Agreement. CO2 energy-related emissions grow from 32 billion metric tons (bmt) in 2015 to as high as 43 bmt by mid-century.

Global Energy Outlook 2019, The Next Generation of energy: https://media.rff.org/documents/GEO_Report_7-19-19.pdf

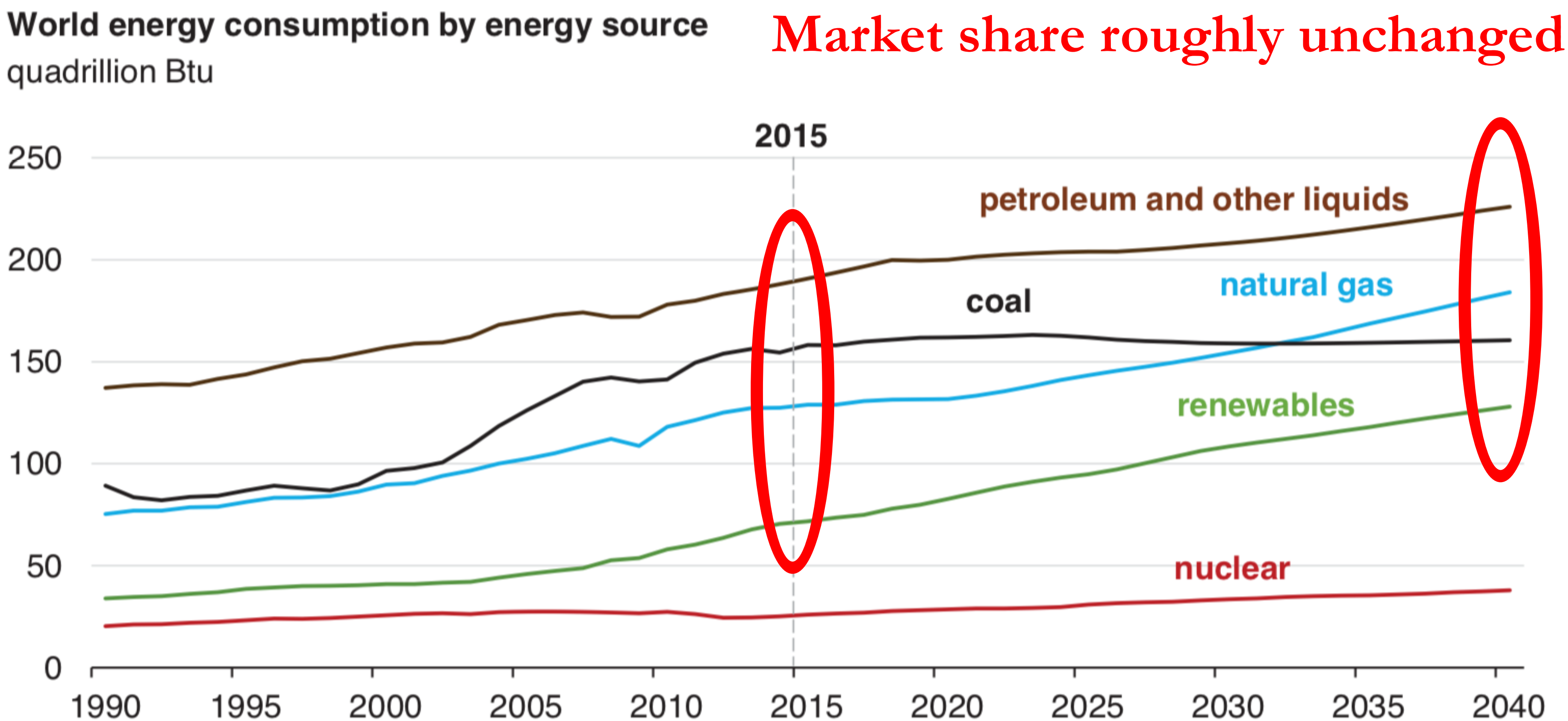
"Under most scenarios, **carbon dioxide (CO_2)** emissions from the global energy system are on a path to far exceed international targets of the Paris Agreement."

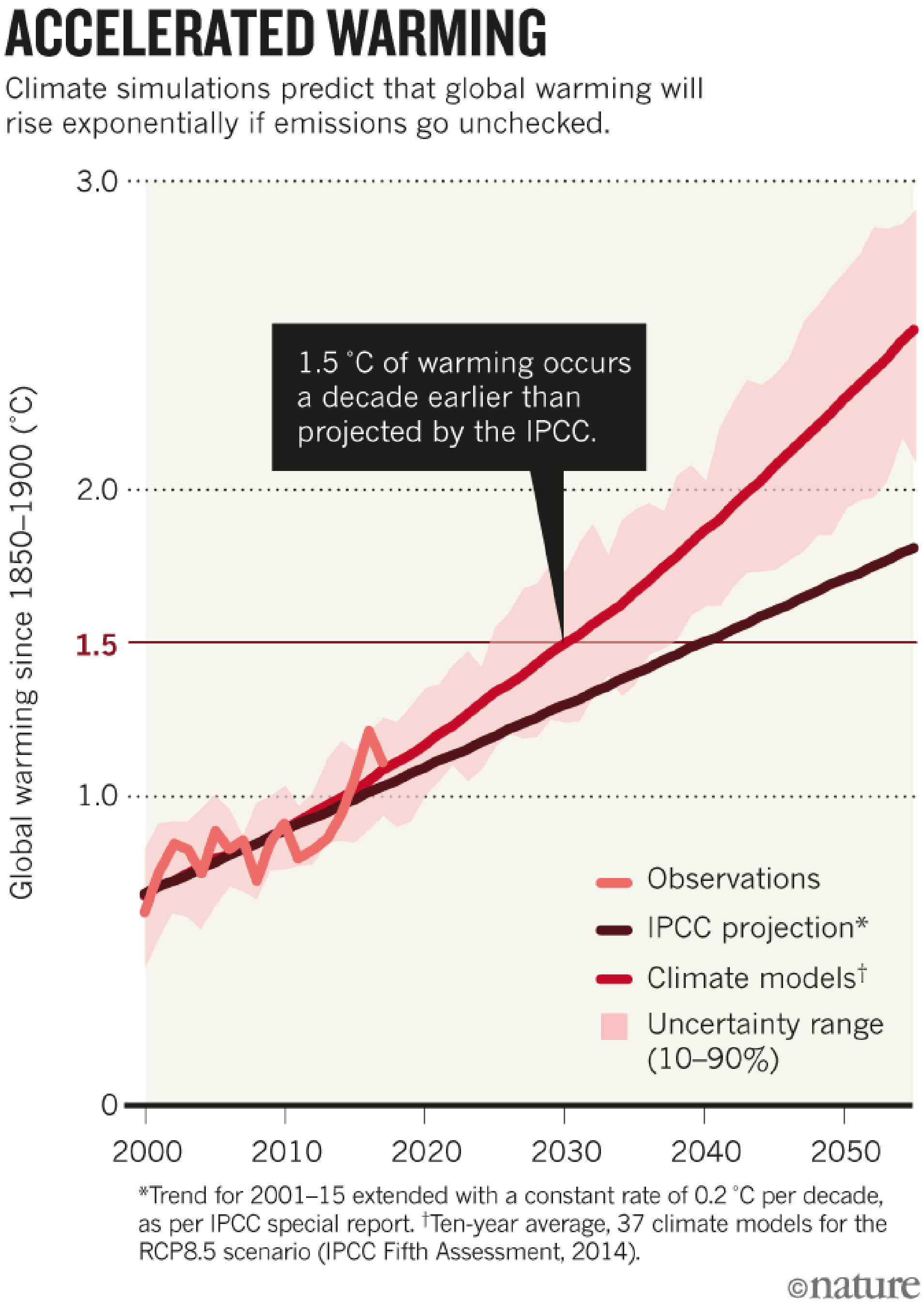


Global Energy Outlook 2019, The Next Generation of energy: https://media.rff.org/documents/GEO_Report_7-19-19.pdf

U.S. Energy Information Administration

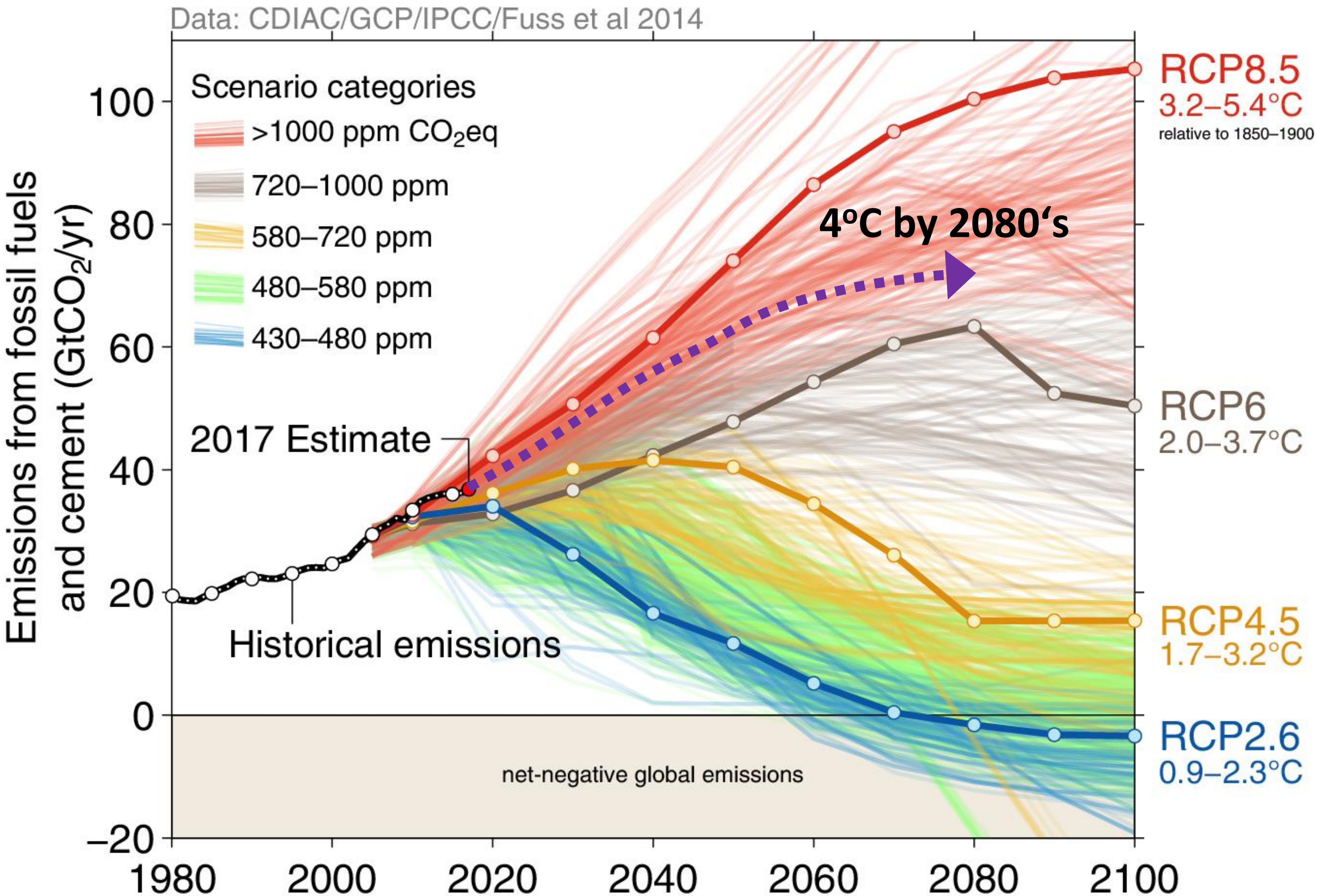
Energy Consumption increases to 2040 for all fuels but coal



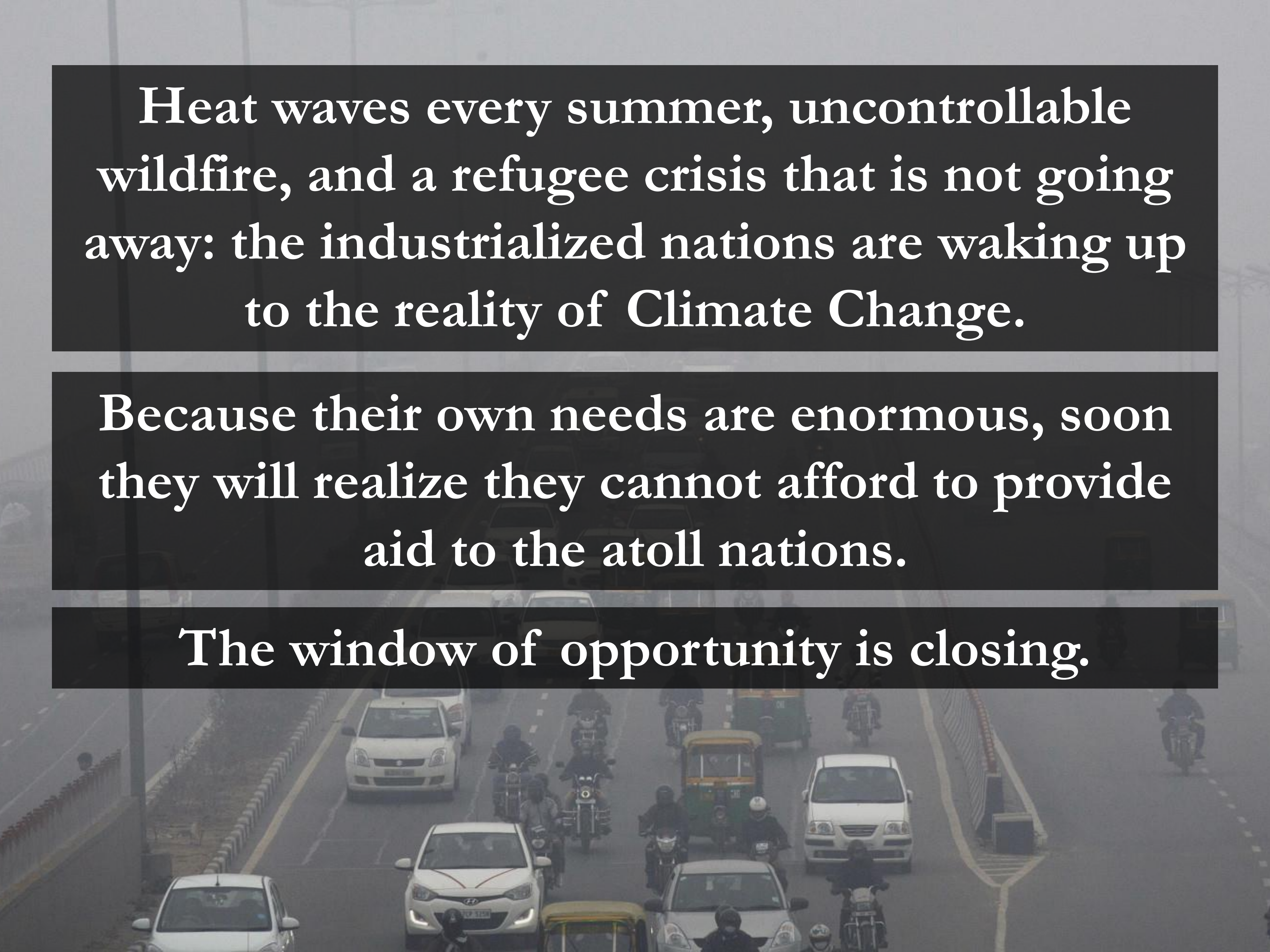


- Global Warming is Accelerating
  - Emissions rising
  - Emissions cleaner
  - Decreased ocean circulation
  - Pacific releasing heat (IPO)
- 1.5°C by 2030
- 2.0°C by 2045

Xu, Y. et al. (2018) Global warming will happen faster than we think, *Nature*, v. 564, Dec. 6



Data: CDIAC/GCP/IPCC/Fuss et al 2014
Emissions from fossil fuels and cement (GtCO2/yr)
Scenario categories
>1000 ppm CO2eq
720–1000 ppm
580–720 ppm
480–580 ppm
430–480 ppm
4oC by 2080's
2017 Estimate
Historical emissions
net-negative global emissions
RCP8.5
3.2–5.4°C
relative to 1850–1900
RCP6
2.0–3.7°C
RCP4.5
1.7–3.2°C
RCP2.6
0.9–2.3°C
100
80
60
40
20
0
−20
1980
2000
2020
2040
2060
2080
2100



Heat waves every summer, uncontrollable wildfire, and a refugee crisis that is not going away: the industrialized nations are waking up to the reality of Climate Change.

Because their own needs are enormous, soon they will realize they cannot afford to provide aid to the atoll nations.

The window of opportunity is closing.

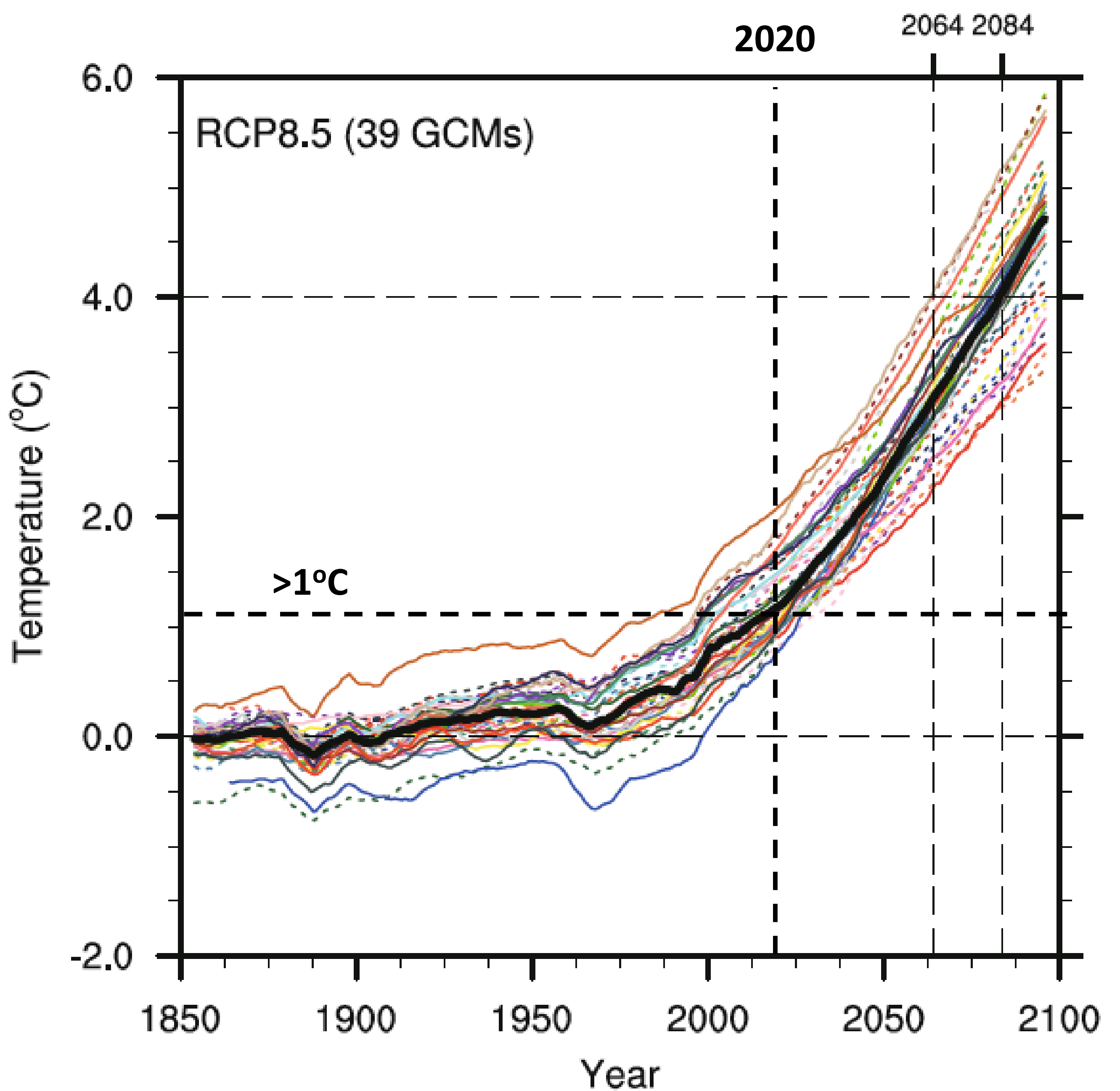
Slides for Discussion

Global Mean Sea Level Rise (GMSLR)

- Ice melt on Greenland and Antarctica, and among global mountain glaciers is accelerating.
  - There is a 66% probability that the Greenland ice sheet will enter a phase of irreversible melting at 1.8^{o}C global warming.
  - Portions of West Antarctic Ice Sheet are now irreversibly retreating.
  - Antarctic ice melt has 'tripled over the past five years.'
- Heat storage in the ocean and related thermal expansion are accelerating.
- GMSLR is now accelerating at a rate that reaches ~65 cm (>2 ft) by end of the century.
- Extrapolating the global rate of ice melt and marine thermal expansion indicates that GMSLR may reach ~1 m (~3.3 ft) by end of the century.
- The Antarctic ice sheet remains the largest single source of uncertainty in projections of future sea-level rise.
  - Major adaptation projects require long lead times.
  - Coastal communities cannot wait for Antarctic science to clear up.
- A recent expert elicitation identified a 10% probability of reaching 2 m GMSLR by 2100.
  - On our current emissions path, sea level will exceed 7.5 m by 2200 and
  - 9.7 m by 2300.
  - If every 10th airplane crashed into the sea, you would decide to never fly.
  - 10% probability is a compelling reason to make a no regrets decision to save a coastal community.
- GMSLR will continue for centuries regardless of future emissions.

Global Warming

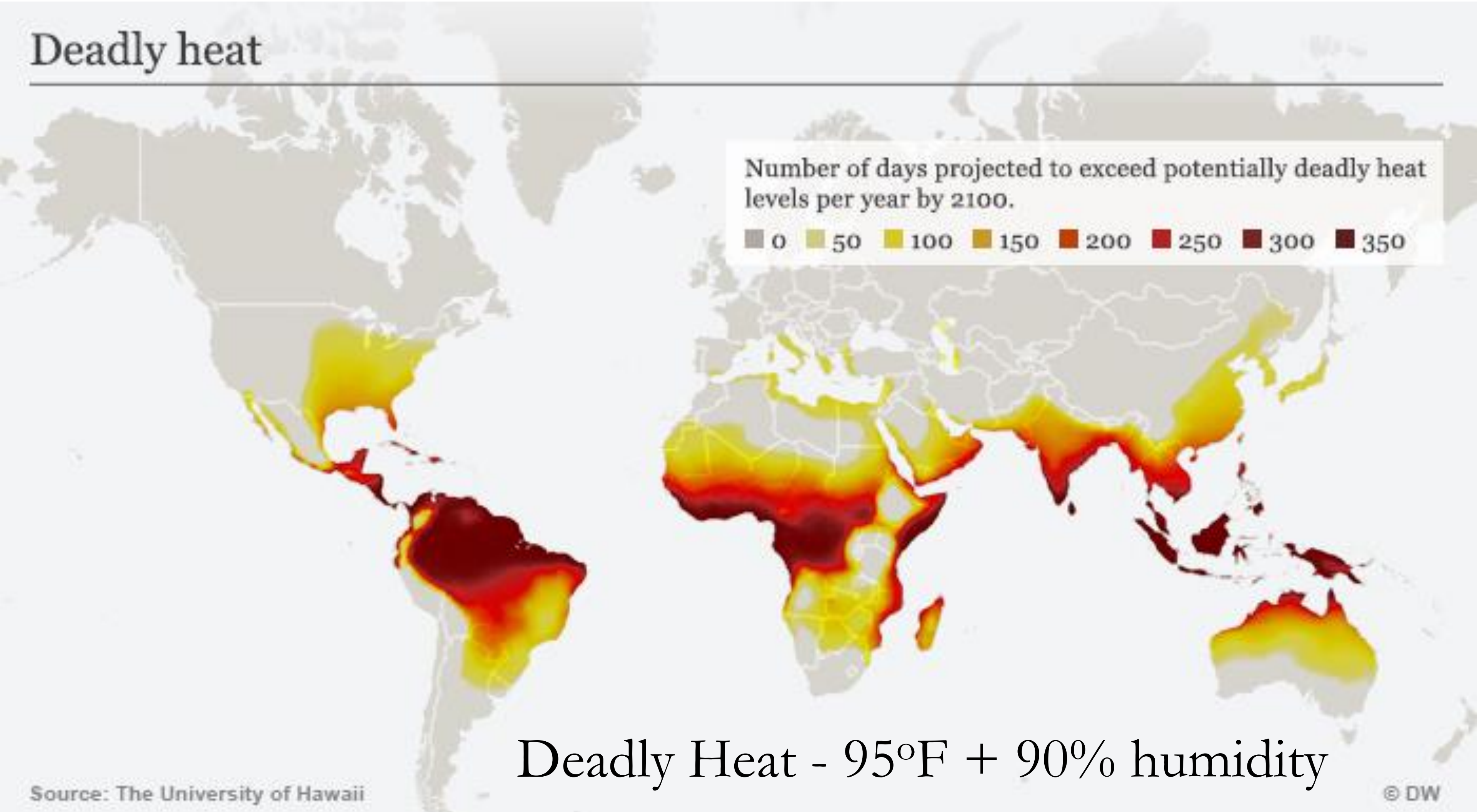
- The atmosphere has warmed >1°C since the nineteenth century.
- Global warming is accelerating and projected to reach 1.5°C by 2030 and 2°C by 2045.
- Conventional approaches to mitigating climate change are not working.
- The rate of CO_2 accumulation in the atmosphere is accelerating.
- In 2018 CO_2 emissions increased 2.7%
    - CO_2 emissions rose because energy & climate policy could not overcome economic growth.
    - The biggest factors pushing emissions down were energy efficiency & renewables.
    - But they would have to be about three times larger to overcome economic growth.
- To stop warming at 1.5°C, CO_2 emissions must decrease next year and every year thereafter.
- Solutions must simultaneously:
    - End carbon emissions,
    - Sequester 1 trillion tons of CO_2, and
    - Adapt to centuries of growing weather disasters.
    - Any one of these costs more than any one nation can afford.
- Decreases need to equal 50% per decade.
    - Emissions must end completely by 2050.
    - CO2 must be removed from the air for the next few centuries.
- IEA, USEIA, BP, and other global economists project that global CO_2 emissions will continue rising to mid-century due to demand for new energy, largely from developing nations.
- Energy demand set to grow >25% by 2040.
    - Renewables make up only two-thirds of new capacity
    - Oil consumption grows due to rising demand for petrochemicals, trucking, aviation, energy
    - CO_2 emissions continue to increase to mid-century
- Assuming continued emissions, experiments using 39 CMIP5 climate models project that 4°C warming will emerge in the decade of the 2080's
- Regionally, the strongest warming is projected to appear in the Arctic, with 8°-12°C of warming in most areas



Wang et al., 2018

Wang et al. (2018) Climate change of 4oC warming above pre-industrial levels, *Advances in Atmospheric Sciences*, V. 35, July, 757–770

As the tropics grow increasingly unlivable a global scale refugee crisis will develop that forever changes the political landscape



Mora C, et al. (2017) Global risk of deadly heat. *Nature Climate Change 7,* 501-506

The New Tourism?