Sea Level Rise Outlook

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2015 was the warmest year on record (by 20%)

15 of the top 16 warmest years have occurred since 2000

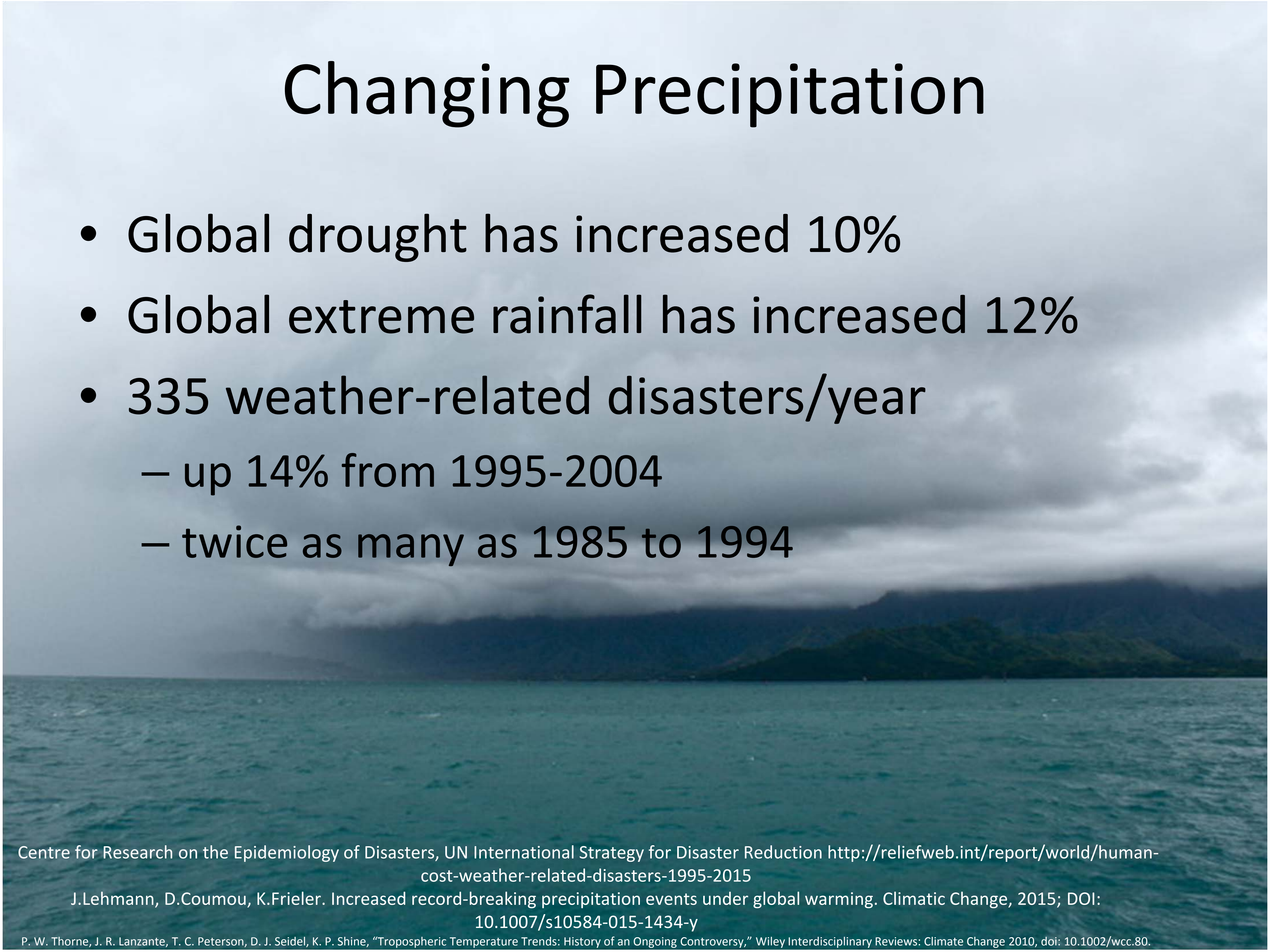
Climate Change in Globally and in Hawaii

- Heat Waves
- Changing Precipitation
- Food impacts
- Rain in Hawaii
- Ecosystem threats
- Changing storminess
- Optimism about Climate
- Sea-level Rise (SLR)

Heat Waves

- Most lethal type of climate impact
- Nine of the 10 deadliest heat waves have occurred since 2000
- 140,000 deaths around the world since 2000
- Extremely high temperatures observed once in 20 yrs will occur every 2 to 4 yrs by mid-century
- Monthly global heat records have been broken 34 times since 2000
- The last cold record was set 1916, and the coldest year was 1911
- In Hawaii
  – High heat is stressing the HECO grid with calls in the past 2 years to turn off our air conditioning at home
  – Hawaii appears to be taking no action on this issue

Seneviratne, S.I., Donat, M., Mueller, B., Alexander, L. ,2014, No pause in the increase of hot temperatures, Nature Climate change, p. 161-163, http://www.nature.com/nclimate/journal/v4/n3/full/nclimate2145.html
Coumou, D., Robinson, A., 2013 Historic and future increase in the global land area affected by monthly heat extremes. Environmental Research Letters; 8 (3): 034018 DOI: 10.1088/1748-9326/8/3/034018



Changing Precipitation

- Global drought has increased 10%
- Global extreme rainfall has increased 12%
- 335 weather-related disasters/year
  - up 14% from 1995-2004
  - twice as many as 1985 to 1994

Centre for Research on the Epidemiology of Disasters, UN International Strategy for Disaster Reduction http://reliefweb.int/report/world/human-cost-weather-related-disasters-1995-2015

J.Lehmann, D.Coumou, K.Frieler. Increased record-breaking precipitation events under global warming. Climatic Change, 2015; DOI: 10.1007/s10584-015-1434-y

P. W. Thorne, J. R. Lanzante, T. C. Peterson, D. J. Seidel, K. P. Shine, “Tropospheric Temperature Trends: History of an Ongoing Controversy,” Wiley Interdisciplinary Reviews: Climate Change 2010, doi: 10.1002/wcc.80.

Food

- Global wheat provides 20% of human protein.
  - Rising CO_2 decreases nutrient and protein content.
  - By 2050 demand will increase by 60% (9 billion people)
  - But wheat yields will decline by 15%.
- Food prices are projected to double by 2030
  - Local food production is critical
  - Dependent on irrigation

Myers et al, 2014 *Increasing CO_2 threatens human nutrition*, Nature 510, 139-142.
Feng et al, 2015 *Constraints to nitrogen acquisition of terrestrial plants under elevated CO_2*, Global Change Biology, DOI: 10.1111/gcb.12938

Rain in Hawaii

- In Hawaii, future rainfall still unclear
  - Decreased winter rain in dry areas
  - Longer and drier dry season
  - Greater demand on irrigation
  - Intense precipitation (flooding) occurring in some areas

Elison Timm, O. et al., 2014. Statistical Downscaling of Rainfall for the Hawaiian Islands using CMIP3 and CMIP5 Model Scenarios. Asia-Pacific Data-Research
IPRC http://apdrc.soest.hawaii.edu/projects/SD/ (03/19/14)
Chu, P.-S., Y.R. Chen, and T.A. Schroeder. 2010. Changes in Precipitation Extremes in the Hawaiian Islands in a Warming Climate. Journal of Climate 23(18):4
doi:10.1175/2010JCLI3484.1

Ecosystem Threats

- New climate envelope (new temperature extremes)
- Changing rainfall
- Inviting conditions for invasive species
- Spread of tropical diseases
- Reef bleaching and ocean acidification

C Mora *et al. Nature* **502**, 183-187 (2013) doi:10.1038/nature12540
Enochs, I.C. et al. (2015) Shift from coral to macro algae dominance on a volcanically acidified reef. Nature Climate Change, v. 5, Aug. 10, pp. 1083-1088.
Hoegh-Guldberg, H., et al., 2007

Changing Storminess

- Localized increase in rain intensity.
- Tropical cyclone paths shifting to the north.
- Increased rainfall and wind speed associated with tropical cyclones.
- Greater frequency in El Niño years.
- 15 TC in 2015, average is 4 to 5 (record high was 11, 1992 and 1994)

Cai, W. et al. (2015) Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change* **4**, 111–116 (2014) doi:10.1038/nclimate2100
Kossin et al., 2014 The poleward migration of the location of tropical cyclone maximum intensity, Nature, 509, 349–352 (15 May)
Murakami, H., et al., 2013 Projected increase in tropical cyclones near Hawaii, Nature Climate Change, May 5, DOI:10.1038/NCLIMTE1890

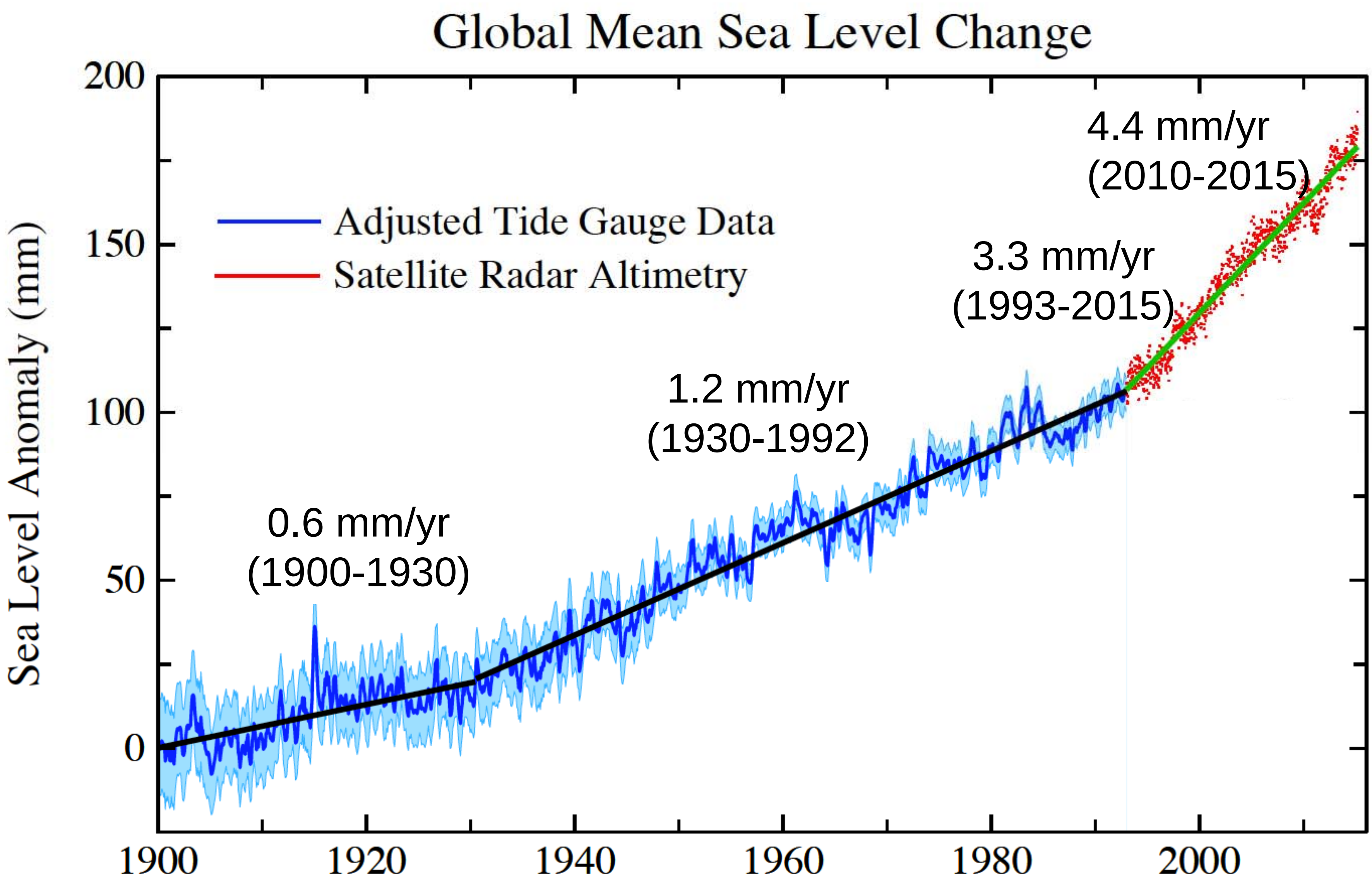
Optimism About Climate Change

- Energy transformation appears to be solidly underway
  - 2005 coal, 50% of US power
  - 2015 coal is down to 34%
- COP21 provides a framework for global action
- Compared to unchecked global warming, keeping the temperature rise below 2^{o}C would reduce:
  - Heat waves by 89%,
  - Flooding by 76%,
  - Cropland decline by 41% and
  - Water stress by 26%.

UK – AVOID Project: http://www.avoid.uk.net/indcs/

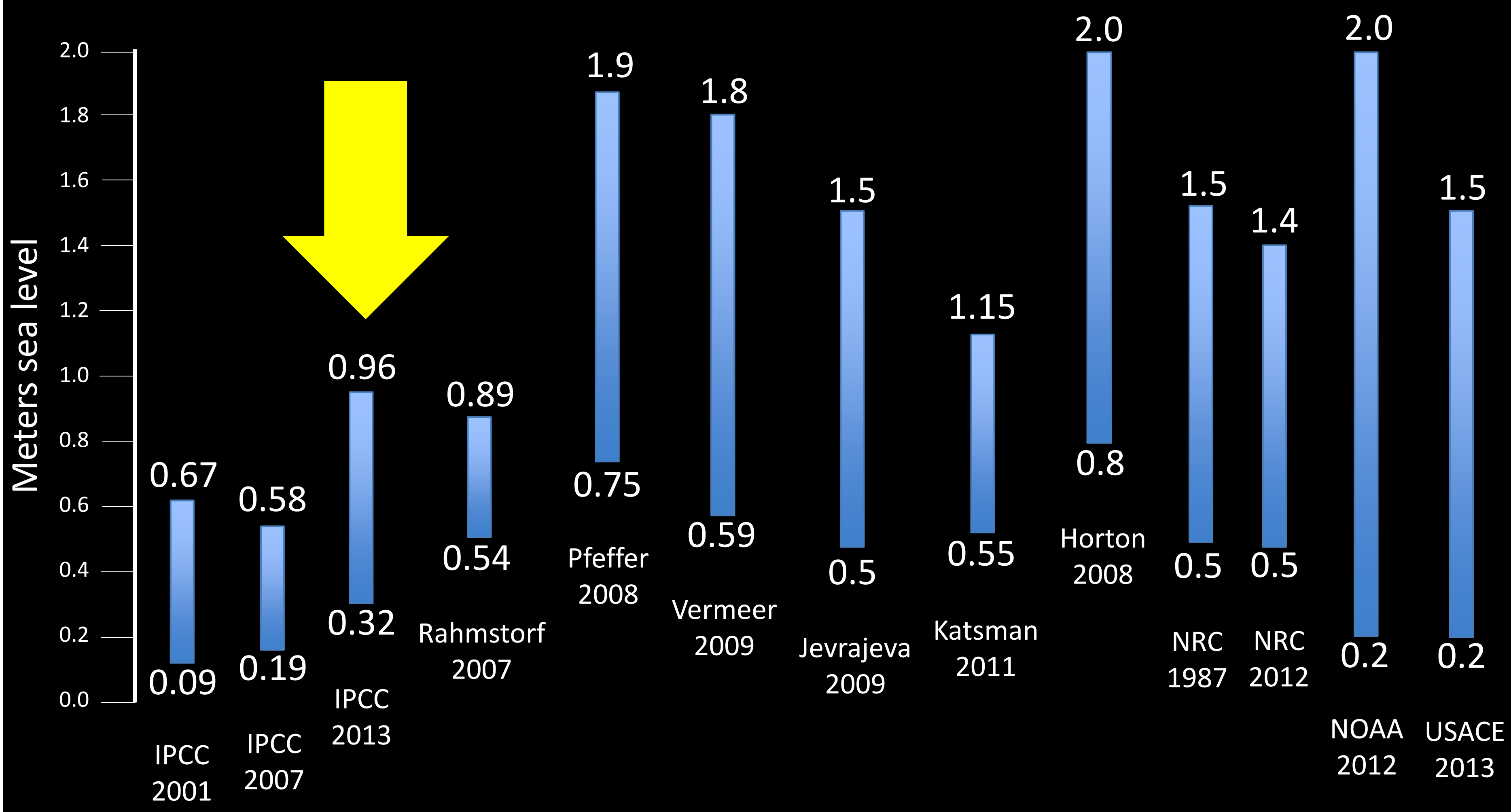
Sea Level Rise

- NASA December, 2015
  - "Given what we know now about how the ocean expands as it warms and how ice sheets and glaciers are adding water to the seas, it's pretty certain we are locked into at least 3 feet [0.9 meter] of sea level rise, and probably more."
- Coastal erosion
- Wave flooding
- Groundwater inundation
- Drainage failure
- Hurricane and tsunami vulnerability

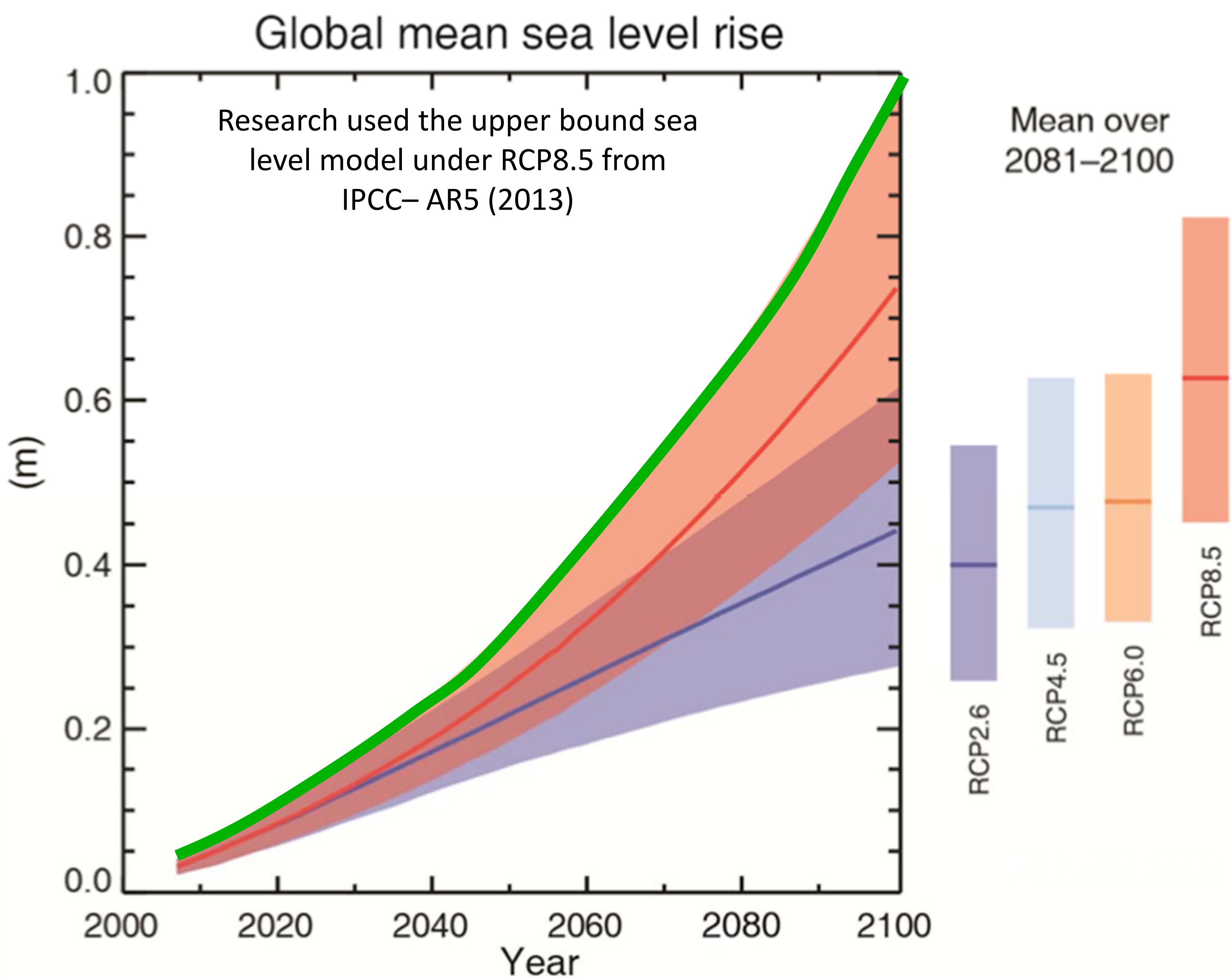


Hansen et al., 2015; Church and White, 2011; Nerem et al., 2010; Hay et al., 2015; Yi et al., 2015

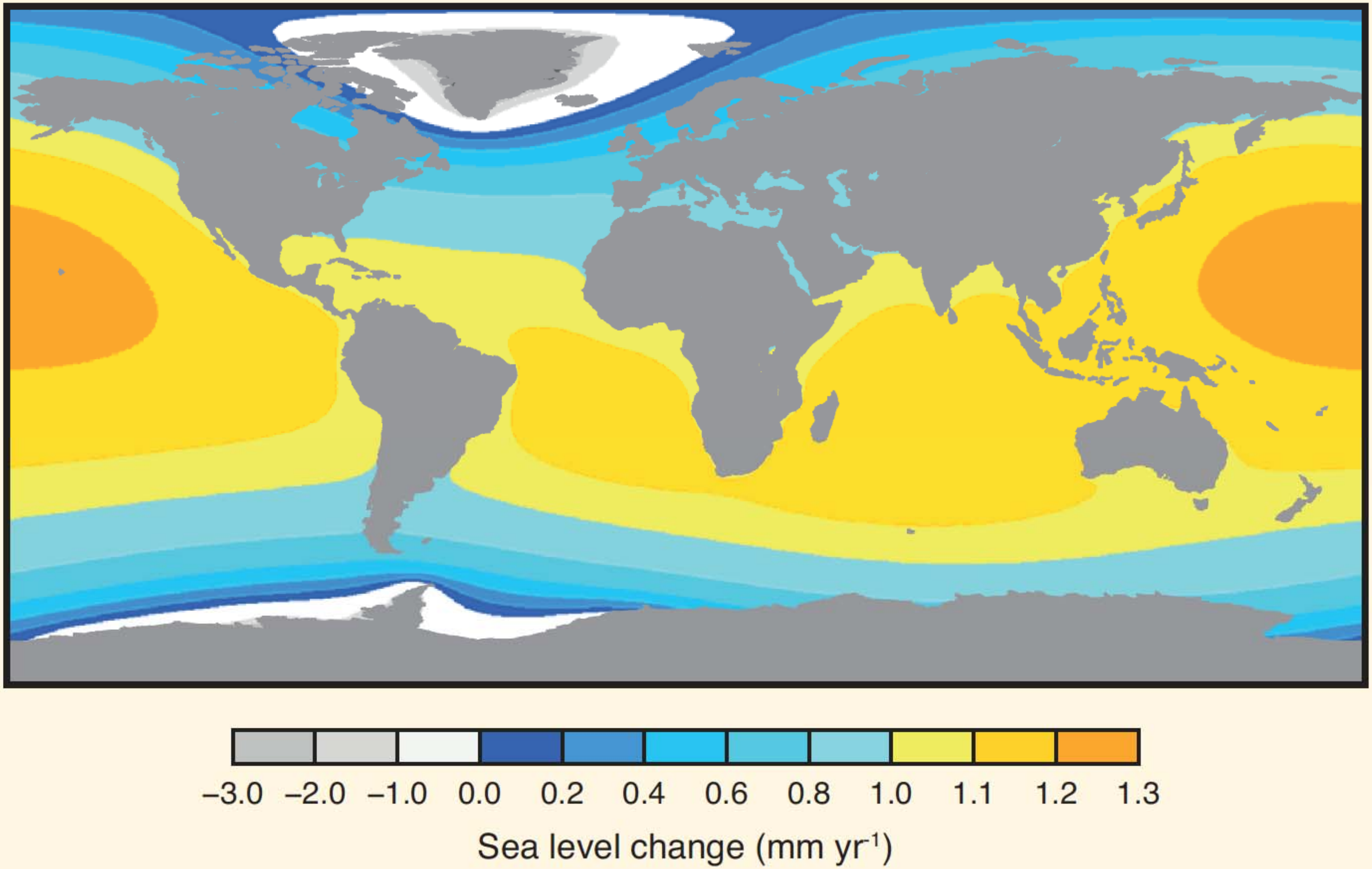
The literature is FILLED with SLR projections to 2100



Procedures to evaluate sea level change: Impacts, Responses, and Adaptation. Technical Letter, no. 1100-2-1, 30 June, 2014.
http://www.publications.usace.army.mil/Portals/76/Publications/EngineerTechnicalLetters/ETL_1100-2-1.pdf

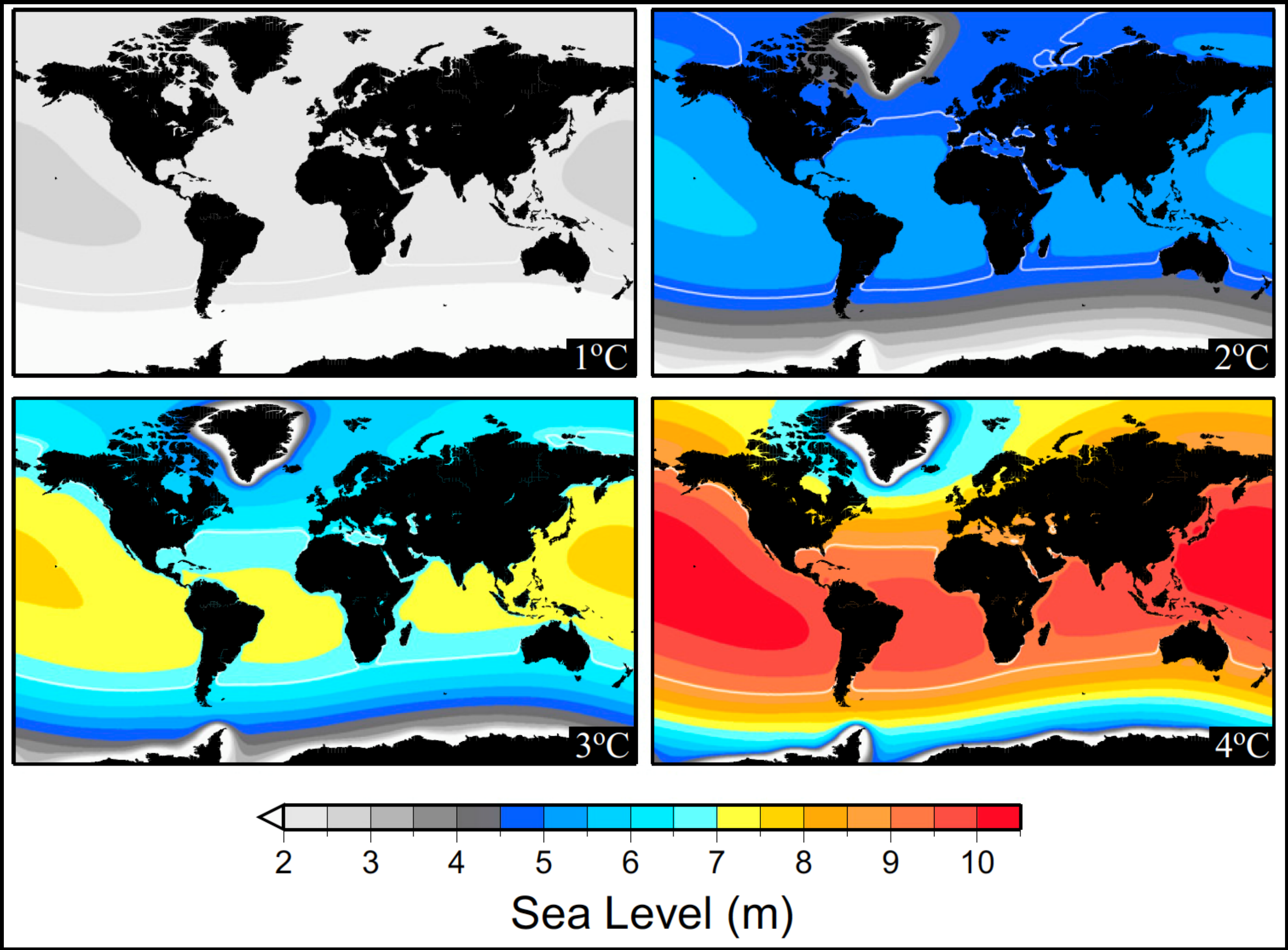

Global mean sea level rise
Research used the upper bound sea level model under RCP8.5 from IPCC– AR5 (2013)
Mean over 2081–2100
1.0
0.8
0.6
0.4
0.2
0.0
(m)
2000
2020
2040
2060
2080
2100
Year
RCP2.6
RCP4.5
RCP6.0
RCP8.5

Equatorial Pacific may experience sea-level heights 10 to 20% greater than the global mean (IPCC-AR5, 2013)



Sea level rise will not stop at 2100

3 m
10 ft

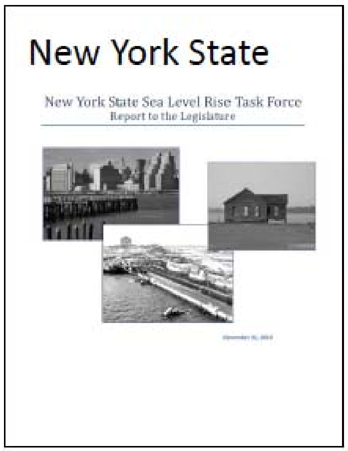


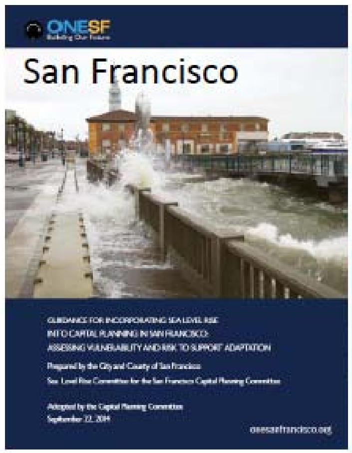
6 m
20 ft

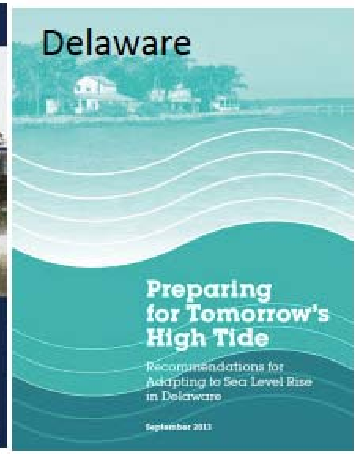
Levermann et al., 2013 The multimillennial sea-level commitment of global warming, PNAS, 110.34, 13745-13750
Clark, P., et al. (2016) Consequences of twenty-first-century policy for multi-millennial climate and sea-level change. Nature, PUBLISHED ONLINE: 8 FEBRUARY 2016 | DOI: 10.1038/NCLIMATE2923

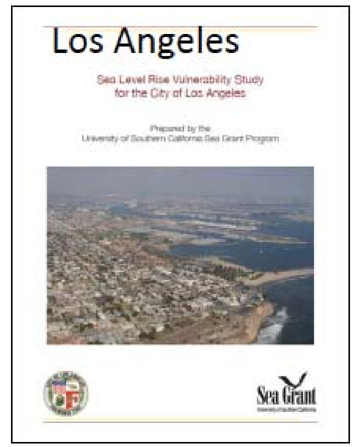
What will ICAC report look like?

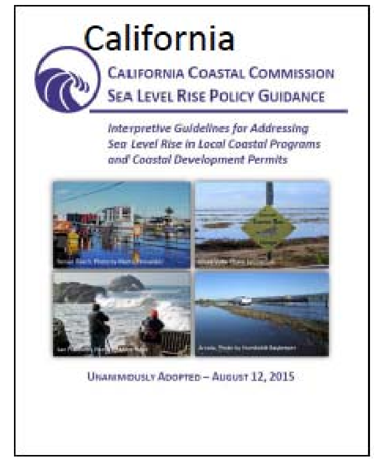
The SLR Sampler











Storm surge
Static sea level rise

100 yr flood with
Static sea level rise

Static sea level rise

Storm surge
Static sea level rise

Policy guidance
no modeling

Hawaii ICAC modeling

- Static sea level rise
- Groundwater inundation (Rotzoll and Fletcher, 2013)
- Coastal erosion (Anderson et al., 2015)
- Seasonal (non-storm) wave inundation (XBEACH)
- 100 yr coastal flooding

Modelers

Tiffany Anderson, PhD
Coastal Modeler

Matt Barbee, MS
Cartographer


Ewa Beach

First test area – Ewa Beach, Oahu

64,000 pop., 50% growth since 2000

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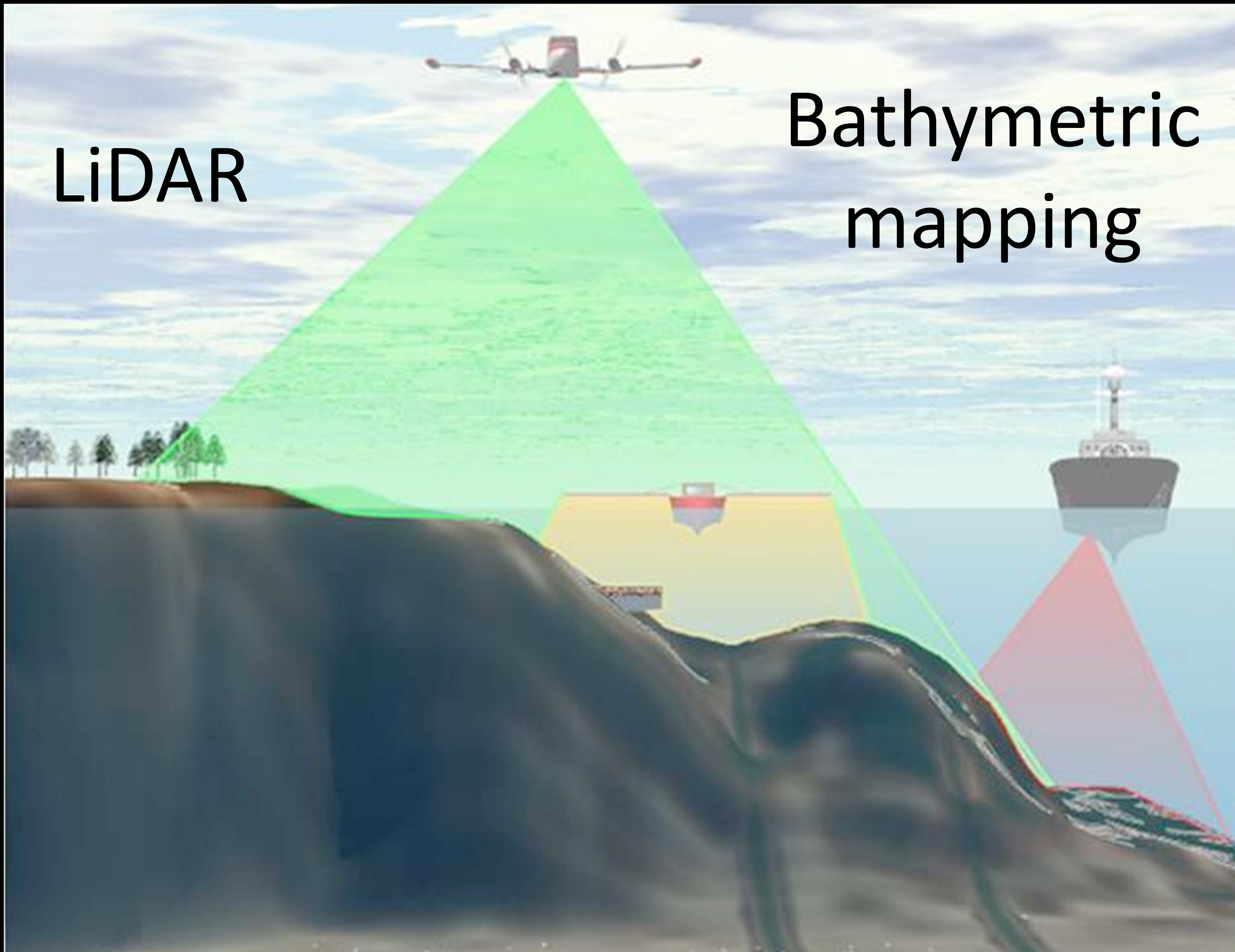


LiDAR
Bathymetric
mapping

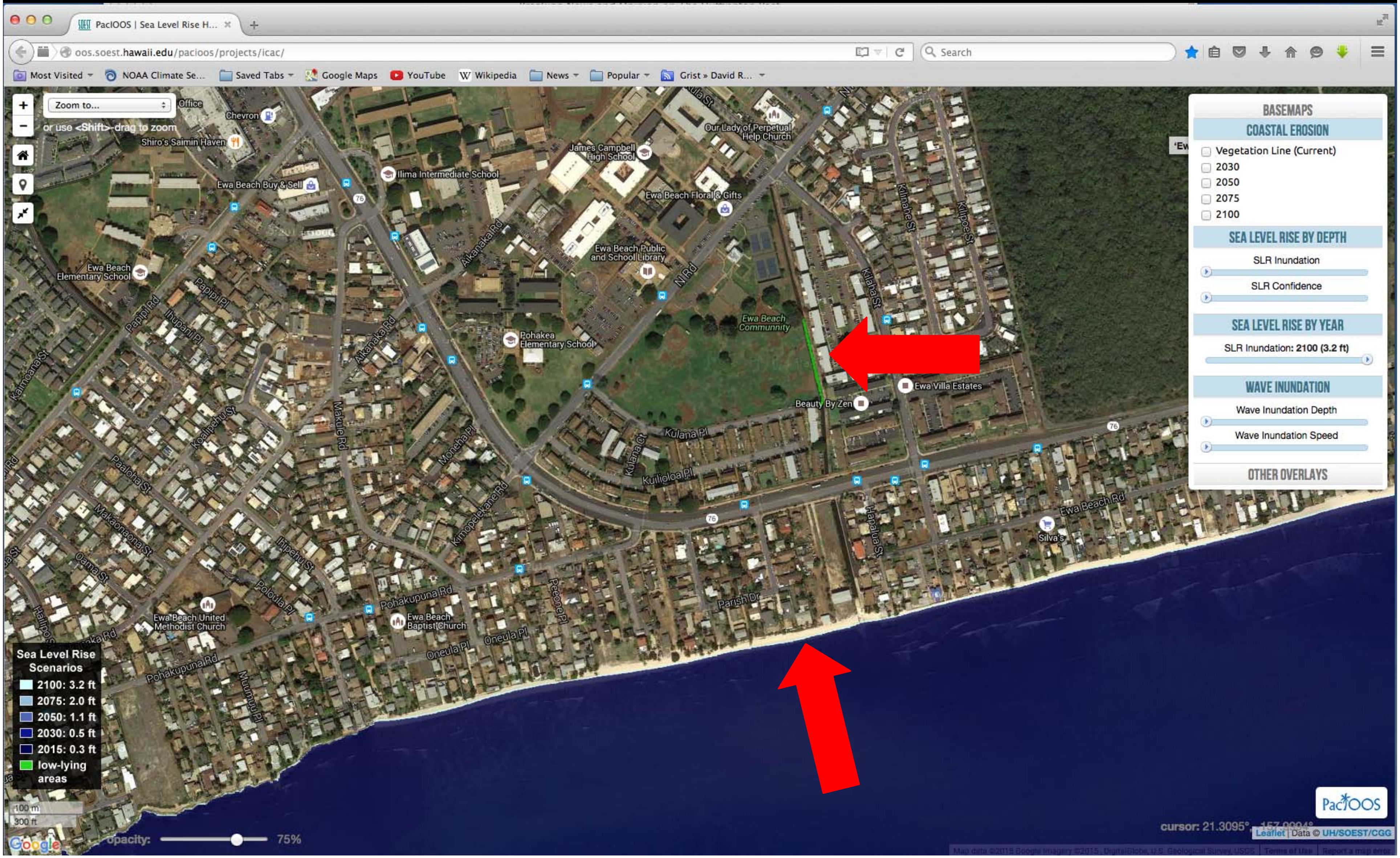
U.S. Army Corps

Joint Airborne Lidar Bathymetry Technical Center of Expertise

2013, 1 m, 31 cm

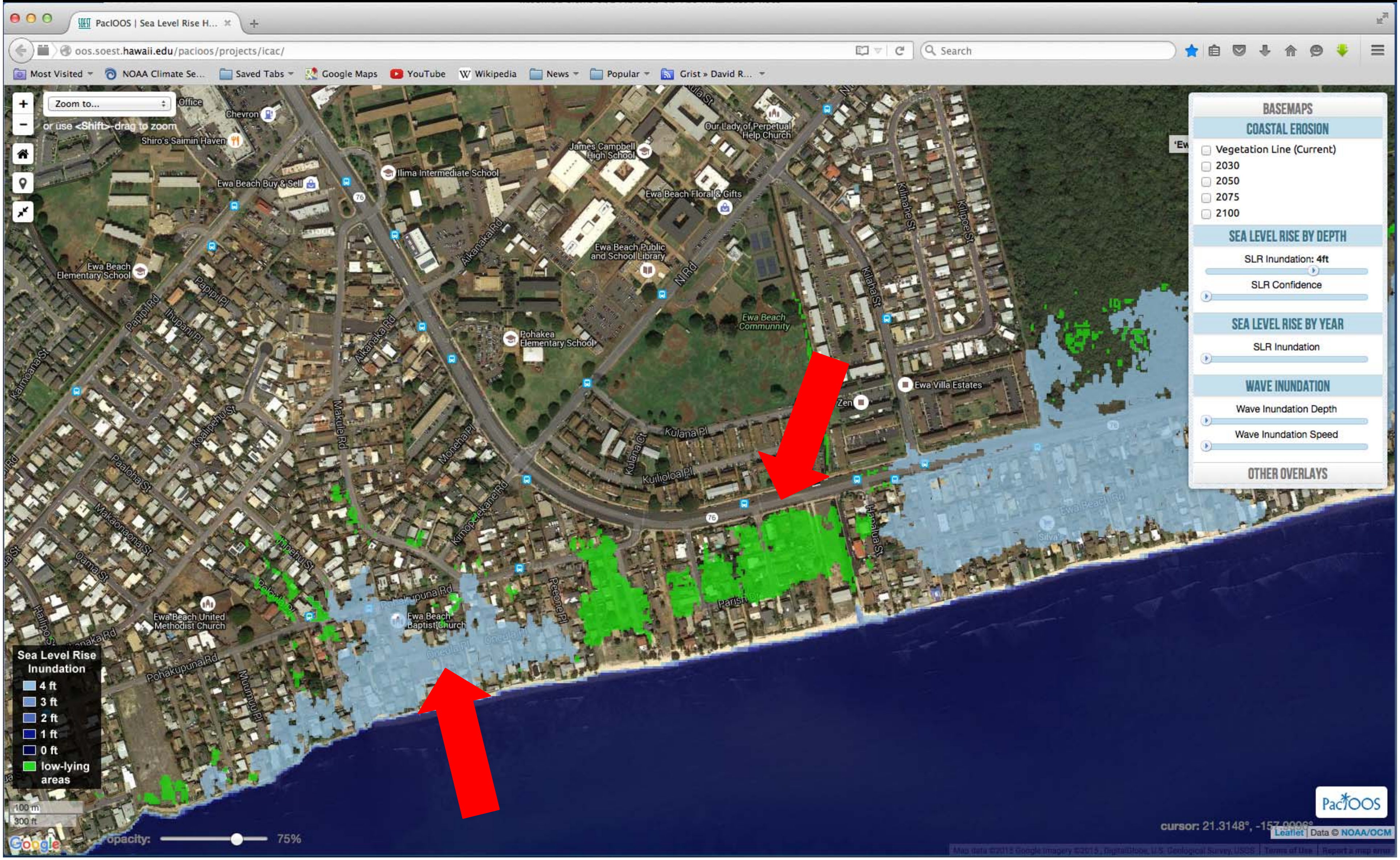
Static + Groundwater Inundation

3.2 ft, 2100



Static + Groundwater Inundation

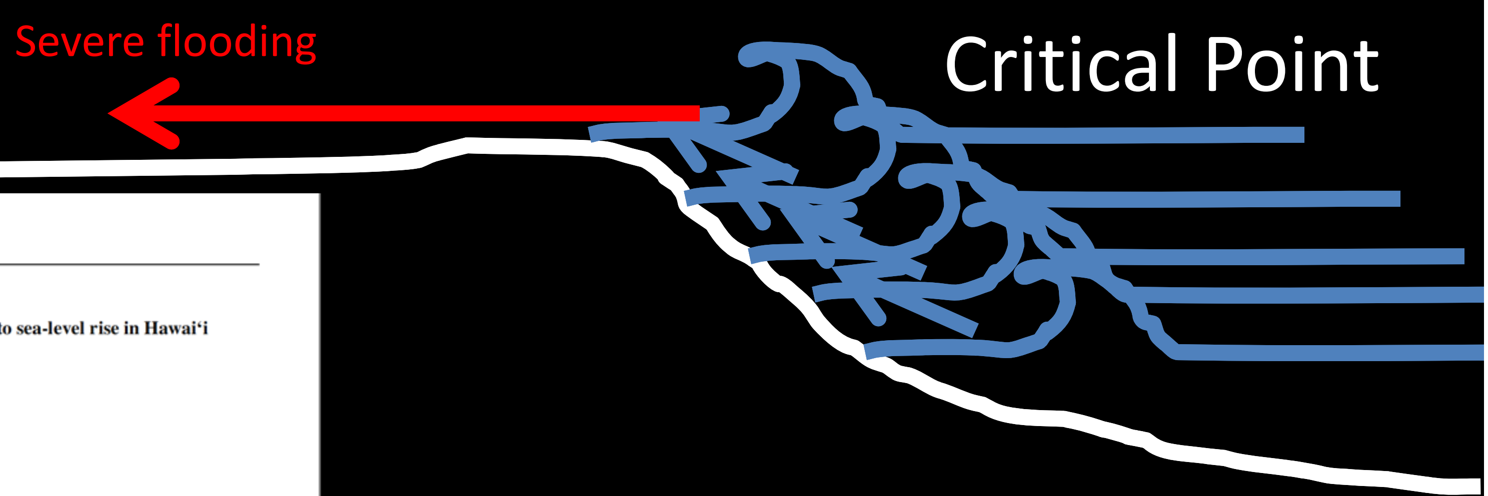
4.0 ft, 2100

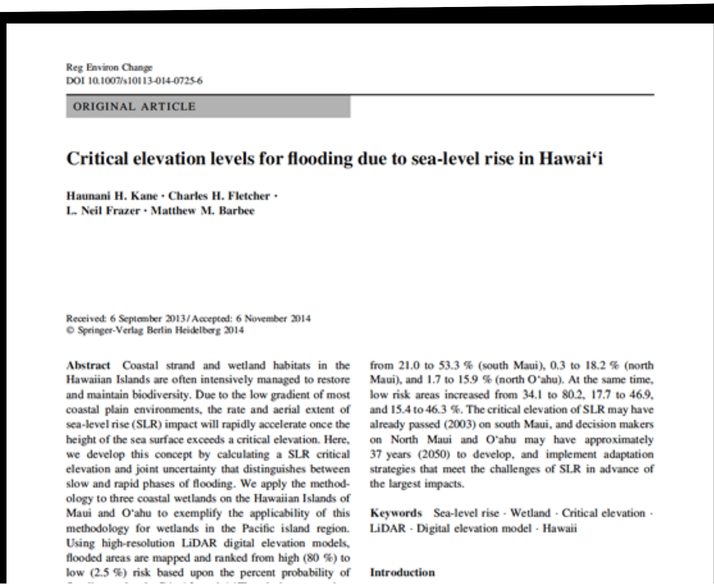


The SLR “Critical Point”

Kane, H., Fletcher, C., Frazer, N., Barbee, M. (2015) Critical elevation levels for flooding due to sea-level rise. Regional environmental change. DOI:10.1007/s10113-014-0725-6

Managers find it useful to not only plan for a critical elevation, but also the timeframe in which the critical elevation may be exceeded.





Reg Environ Change
DOI 10.1007/s10113-014-0725-6

ORIGINAL ARTICLE

Critical elevation levels for flooding due to sea-level rise in Hawai‘i

Haunani H. Kane · Charles H. Fletcher · L. Neil Frazer · Matthew M. Barbee

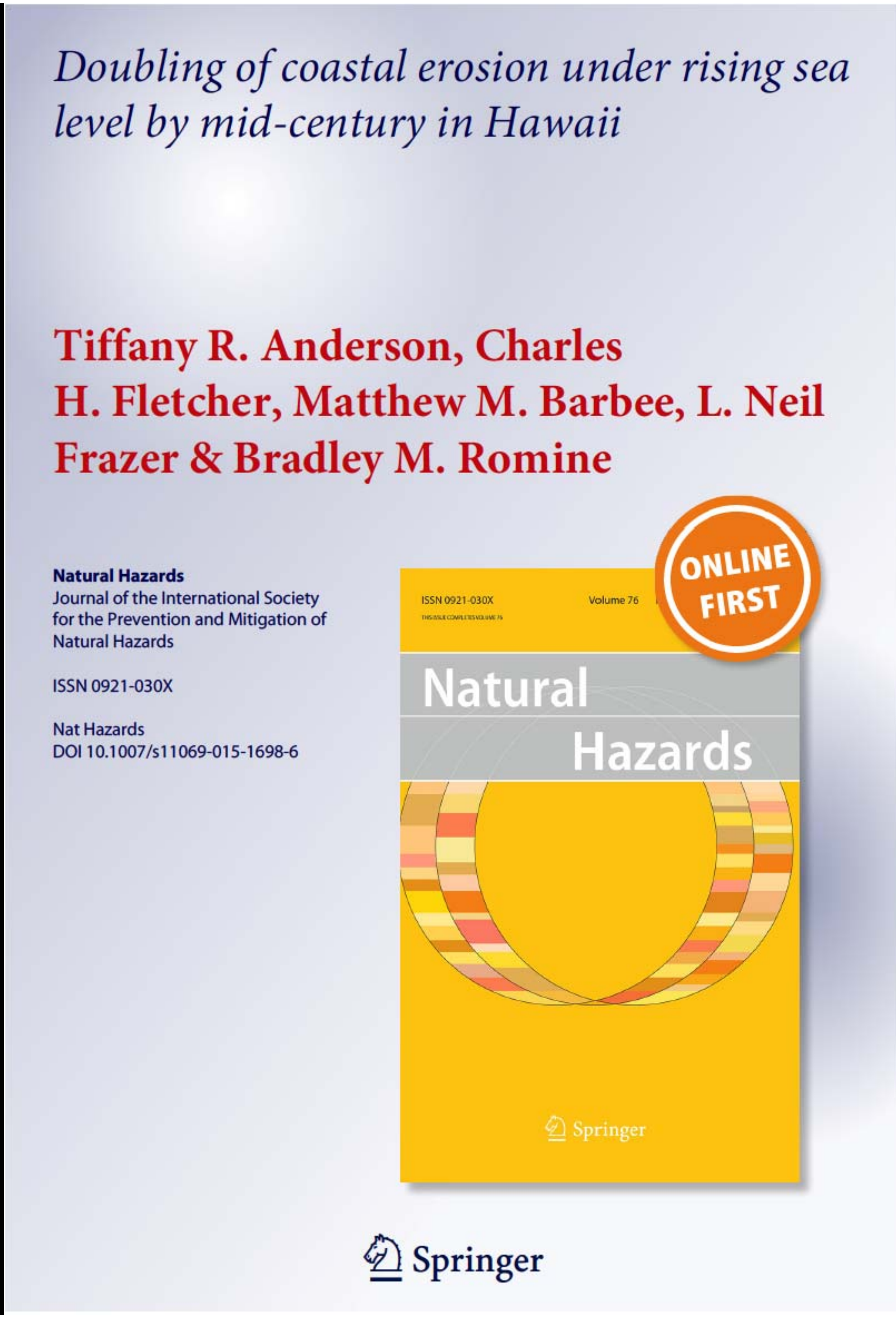
Received: 6 September 2013 / Accepted: 6 November 2014

Abstract Coastal strand and wetland habitats in the Hawaiian Islands are often intensively managed to restore and maintain biodiversity. Due to the low gradient of most coastal plain environments, the rate and aerial extent of sea-level rise (SLR) impact will rapidly accelerate once the height of the sea surface exceeds a critical elevation. Here, we develop this concept by calculating a SLR critical elevation and joint uncertainty that distinguishes between slow and rapid phases of flooding. We apply the methodology to three coastal wetlands on the Hawaiian Islands of Maui and O‘ahu to exemplify the applicability of this methodology for wetlands in the Pacific island region. Using high-resolution LiDAR digital elevation models, flooded areas are mapped and ranked from high (80 %) to low (2.5 %) risk based upon the percent probability of

from 21.0 to 53.3 % (south Maui), 0.3 to 18.2 % (north Maui), and 1.7 to 15.9 % (north O‘ahu). At the same time, low risk areas increased from 34.1 to 80.2, 17.7 to 46.9, and 15.4 to 46.3 %. The critical elevation of SLR may have already passed (2003) on south Maui, and decision makers on North Maui and O‘ahu may have approximately 37 years (2050) to develop, and implement adaptation strategies that meet the challenges of SLR in advance of the largest impacts.

Keywords Sea-level rise · Wetland · Critical elevation · LiDAR · Digital elevation model · Hawaii

Introduction


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

Tiffany R. Anderson, Charles H. Fletcher, Matthew M. Barbee, L. Neil Frazer & Bradley M. Romine

Natural Hazards
Journal of the International Society for the Prevention and Mitigation of Natural Hazards

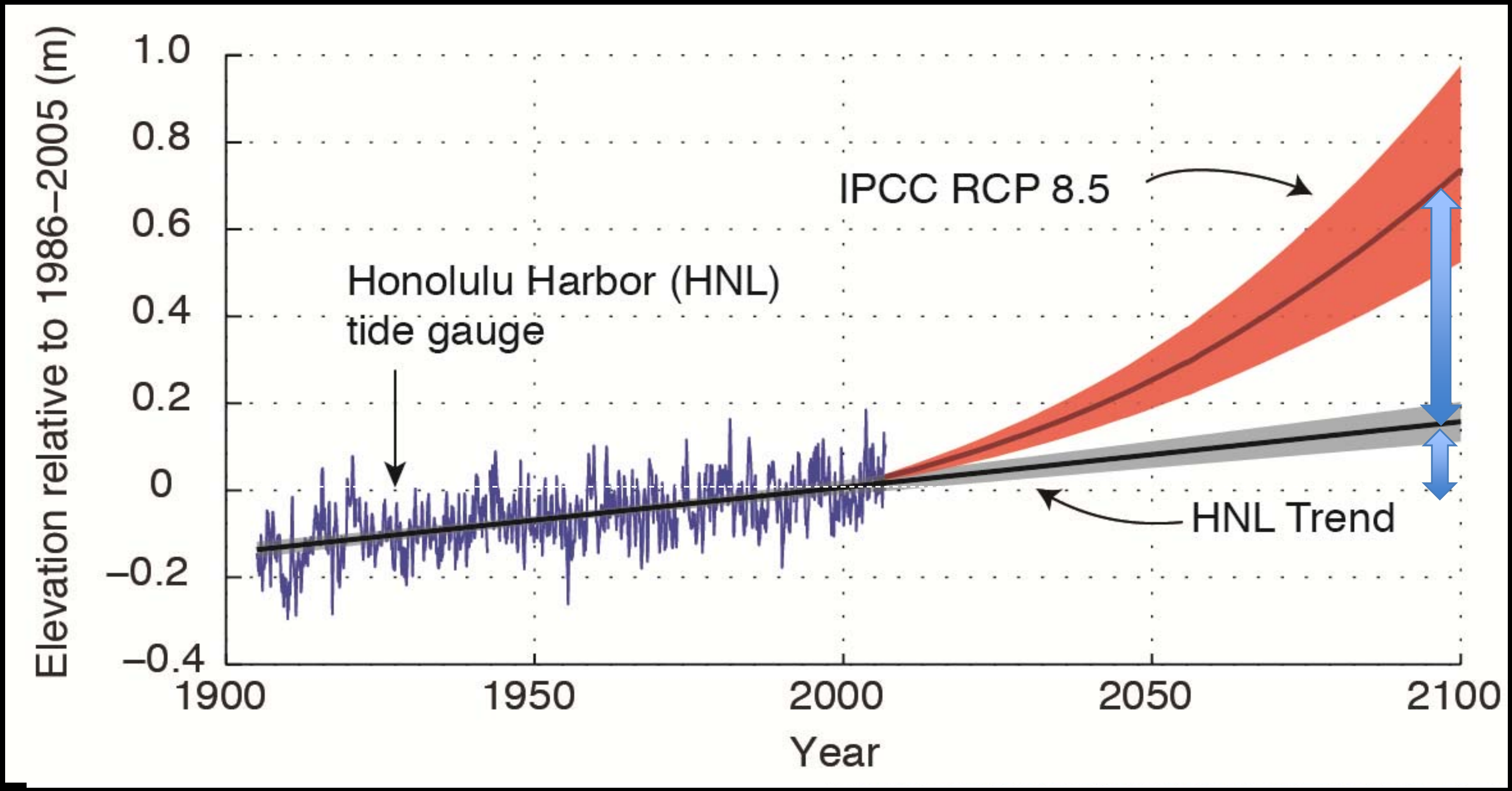
ISSN 0921-030X

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

Springer

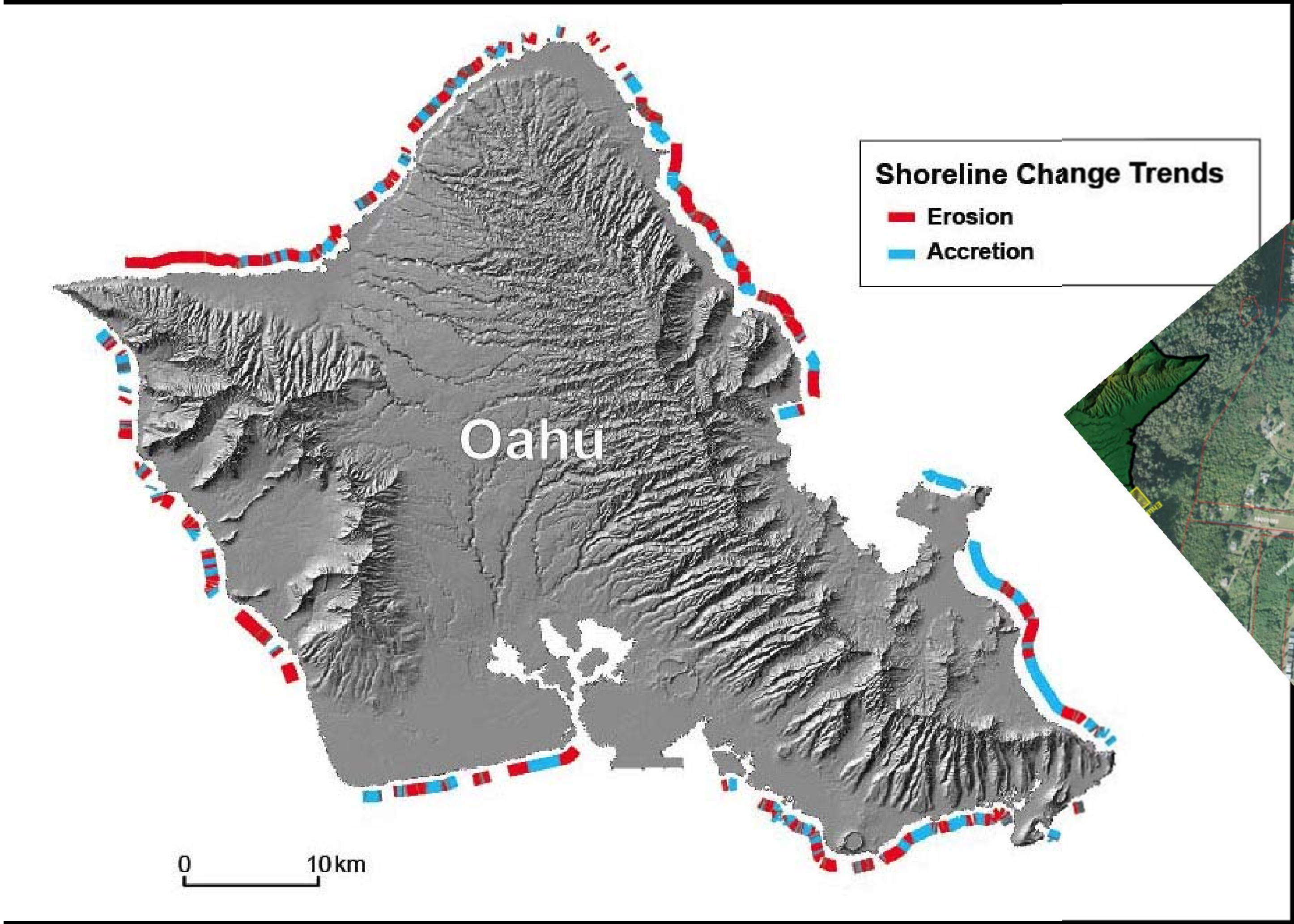
- Anderson et al., 2015
- ~92% and 96 % of shorelines are projected to retreat by 2050 and 2100 (resp.)
- 80% of projections range up to 80 ft of erosion by 2050 and 200 ft of erosion by 2100
- Twice historical extrapolation by 2050

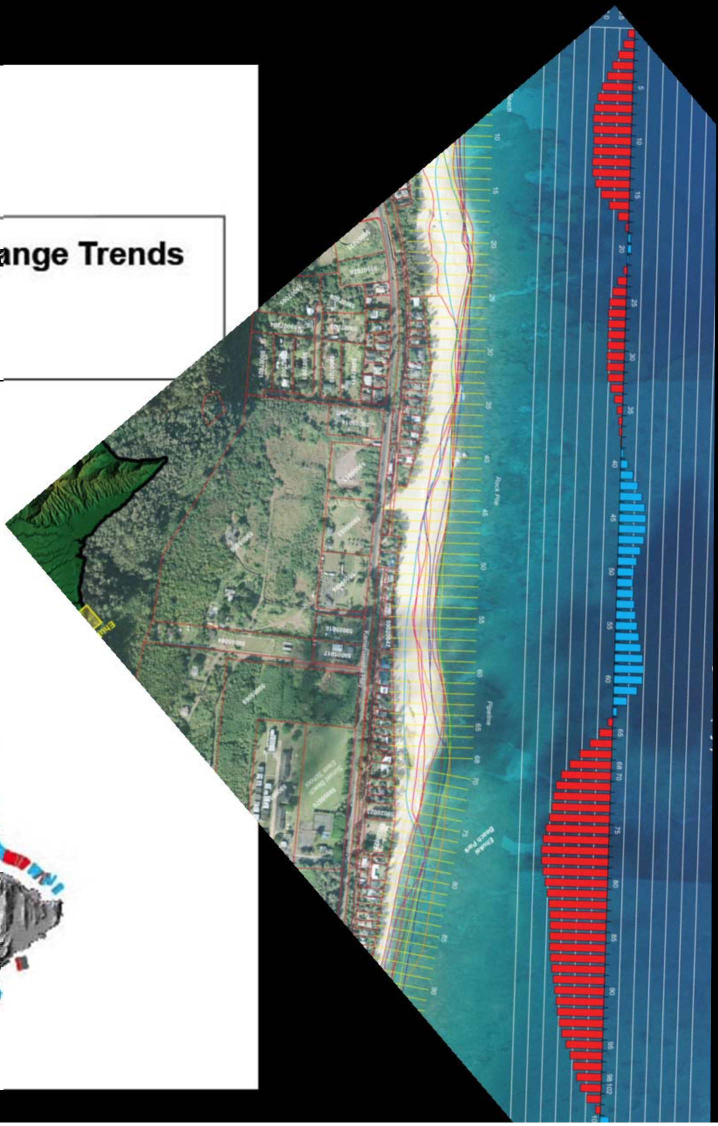
Modeling Shoreline Change with SLR



- Represents past behavior - does not include future increases in SLR
- Use a geometric model to account for additional changes due to increased SLR, and combine with historical change

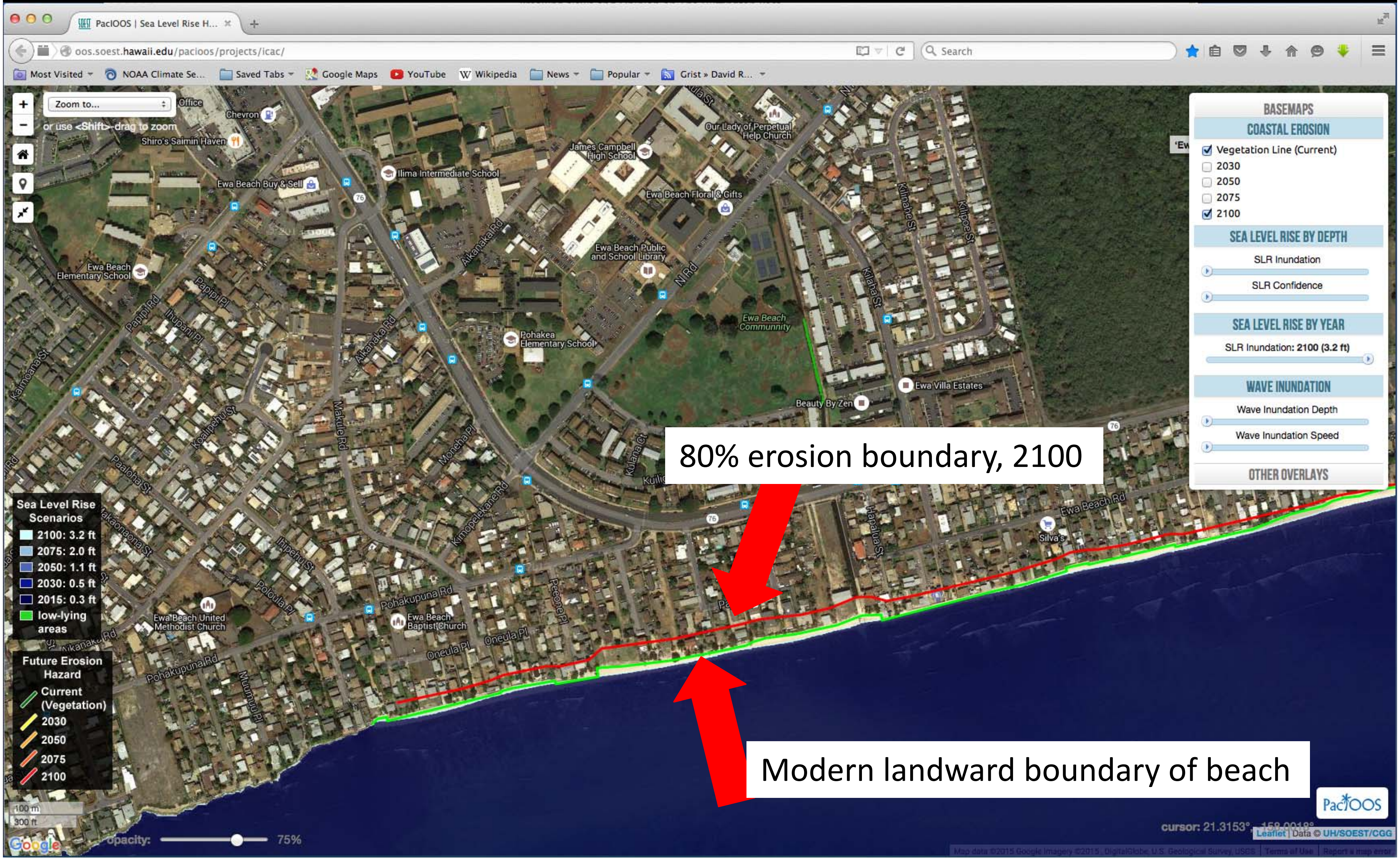
Hawaiian shoreline, while overall erosional, has high alongshore variability due to sediment availability





Coastal Erosion

3.2 ft, 2100

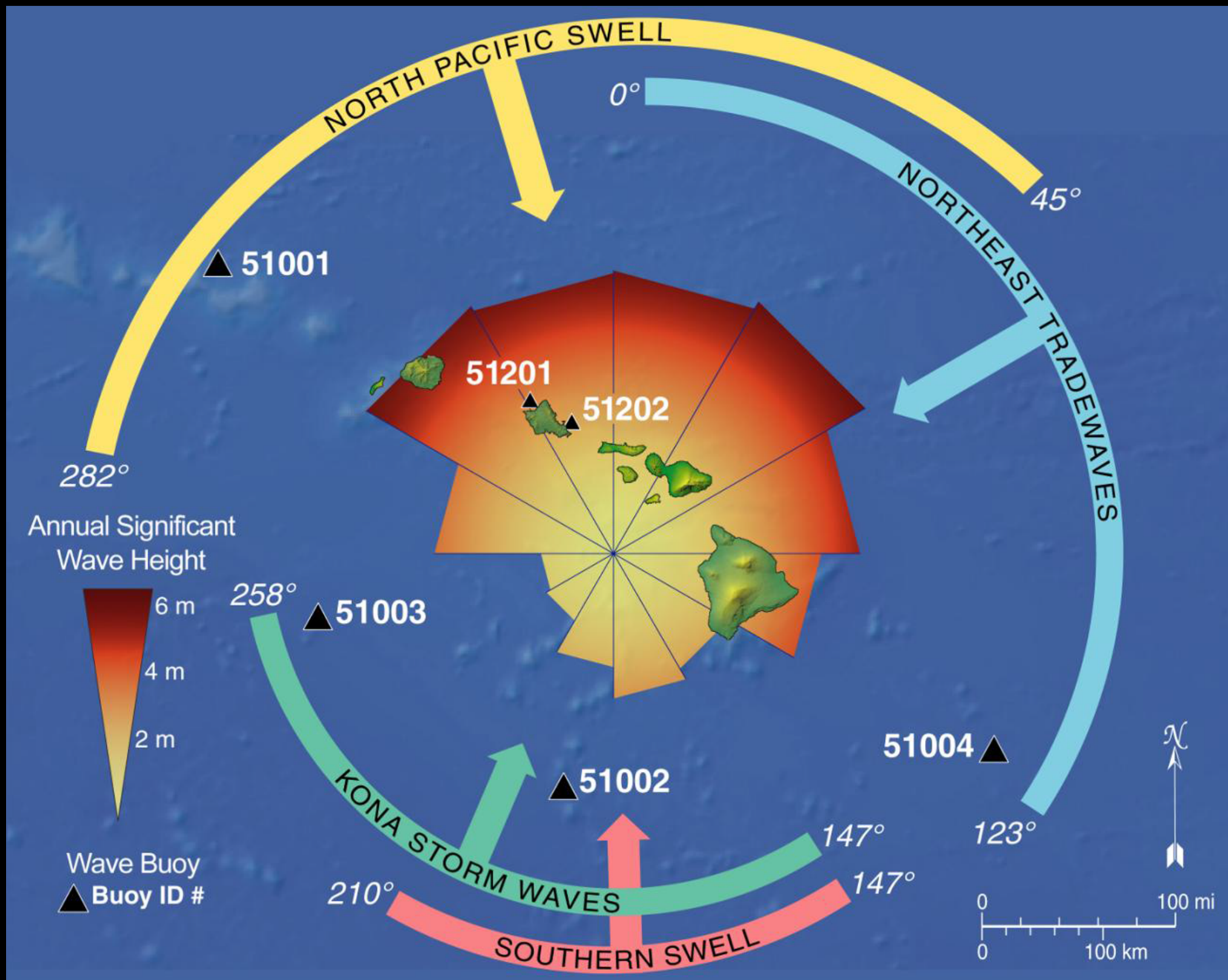


Coastal Erosion

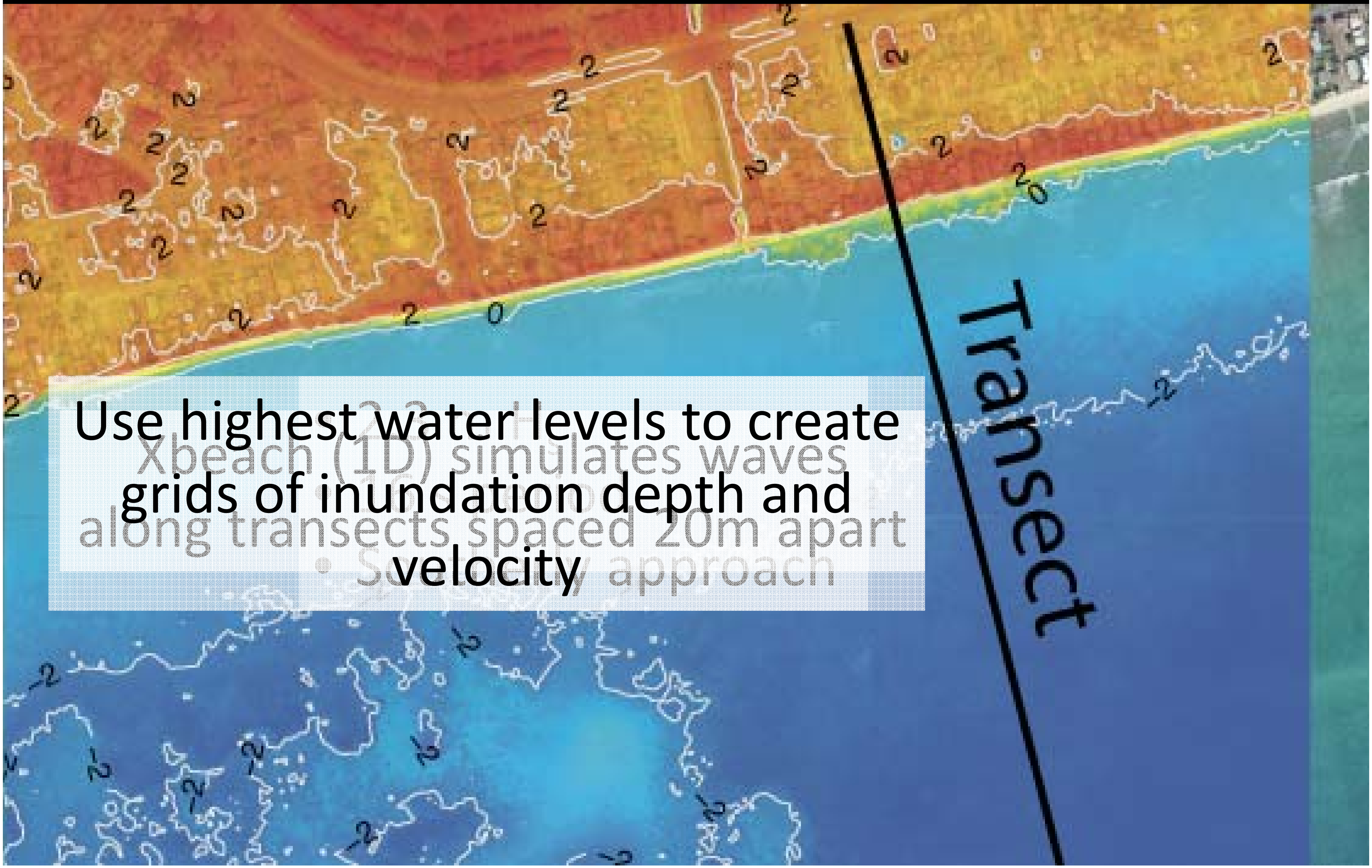
3.2 ft, 2100

Simulating Seasonal Wave Inundation

Simulating Seasonal Wave Inundation



Simulating Seasonal Wave Inundation with XBEACH



Use highest water levels to create grids of inundation depth and velocity

Ewa Beach – Wave Inundation

Ewa Beach – Wave Inundation

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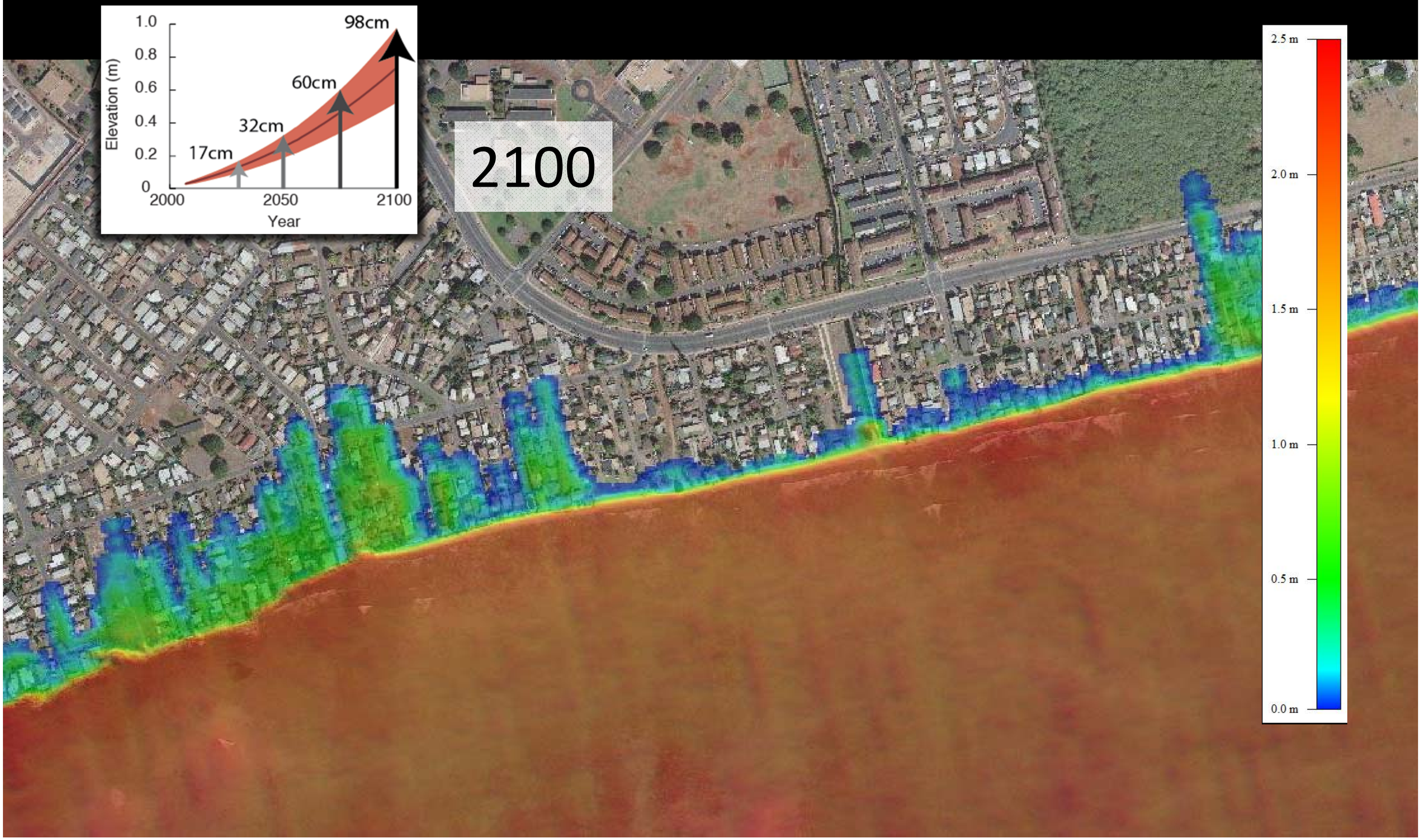
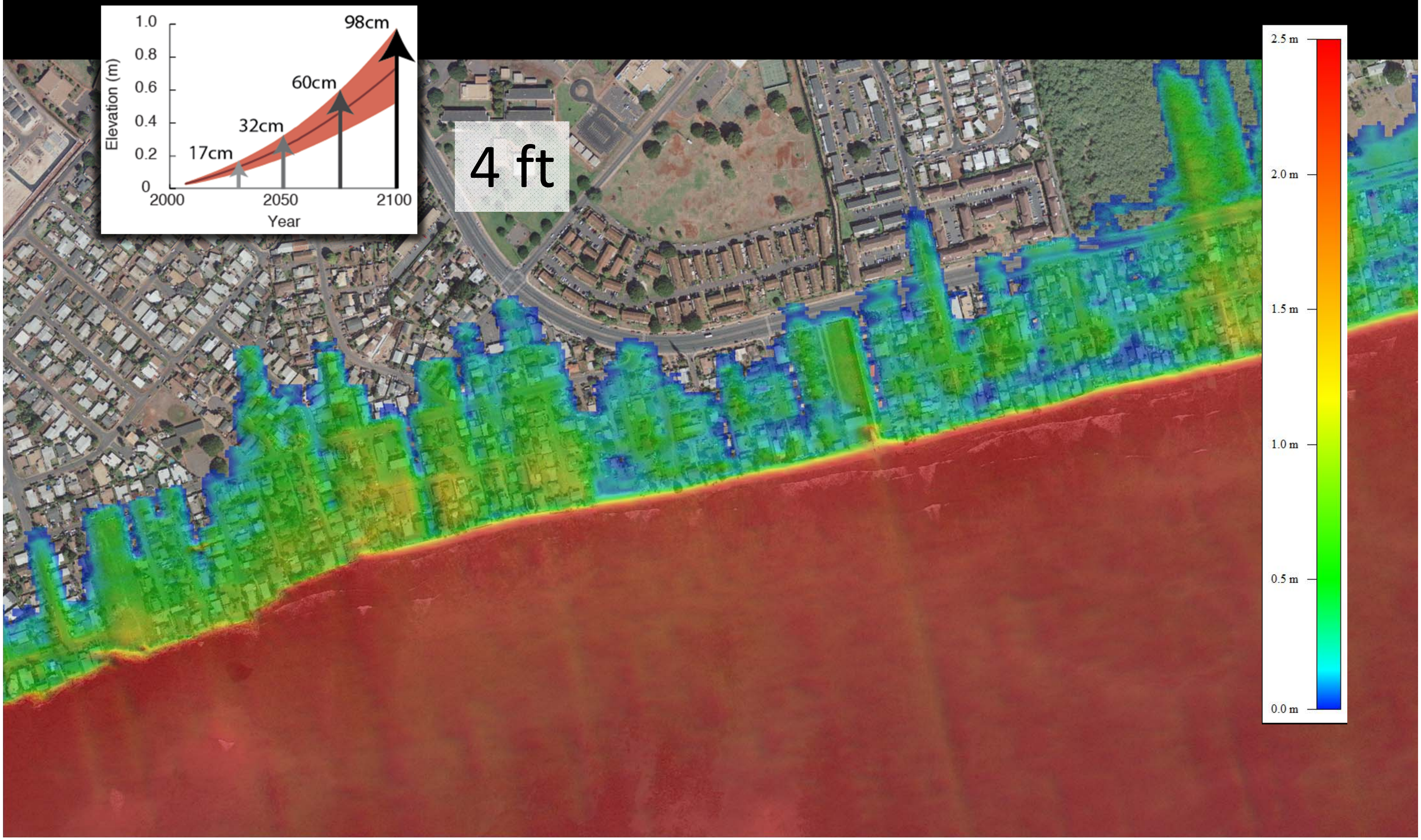
Ewa Beach – Wave Inundation

Ewa Beach – Wave Inundation



Ewa Beach – Wave Inundation (4ft)



Wave Run-Up, Erosion, and Static Flooding – North Shore and Windward Side