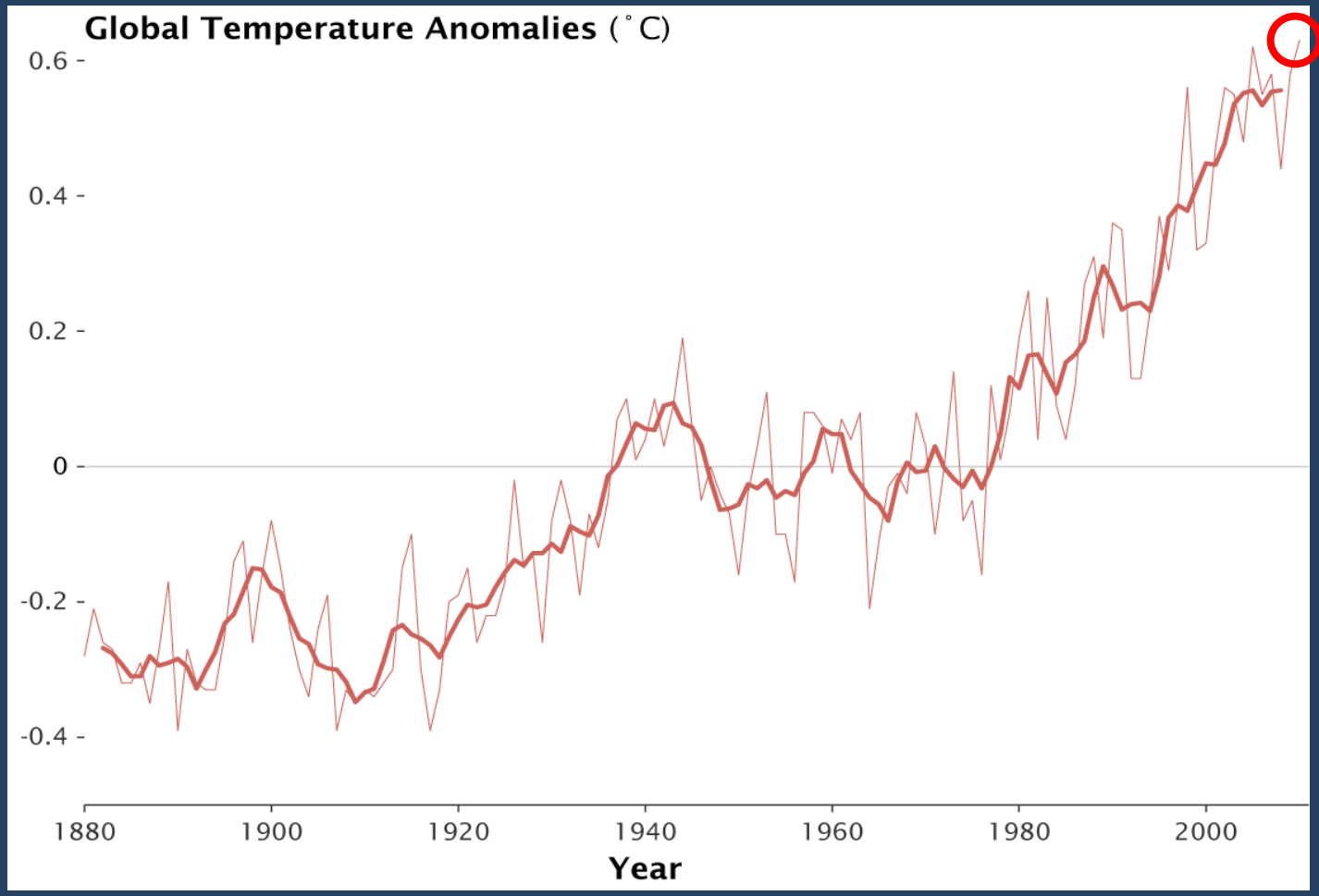
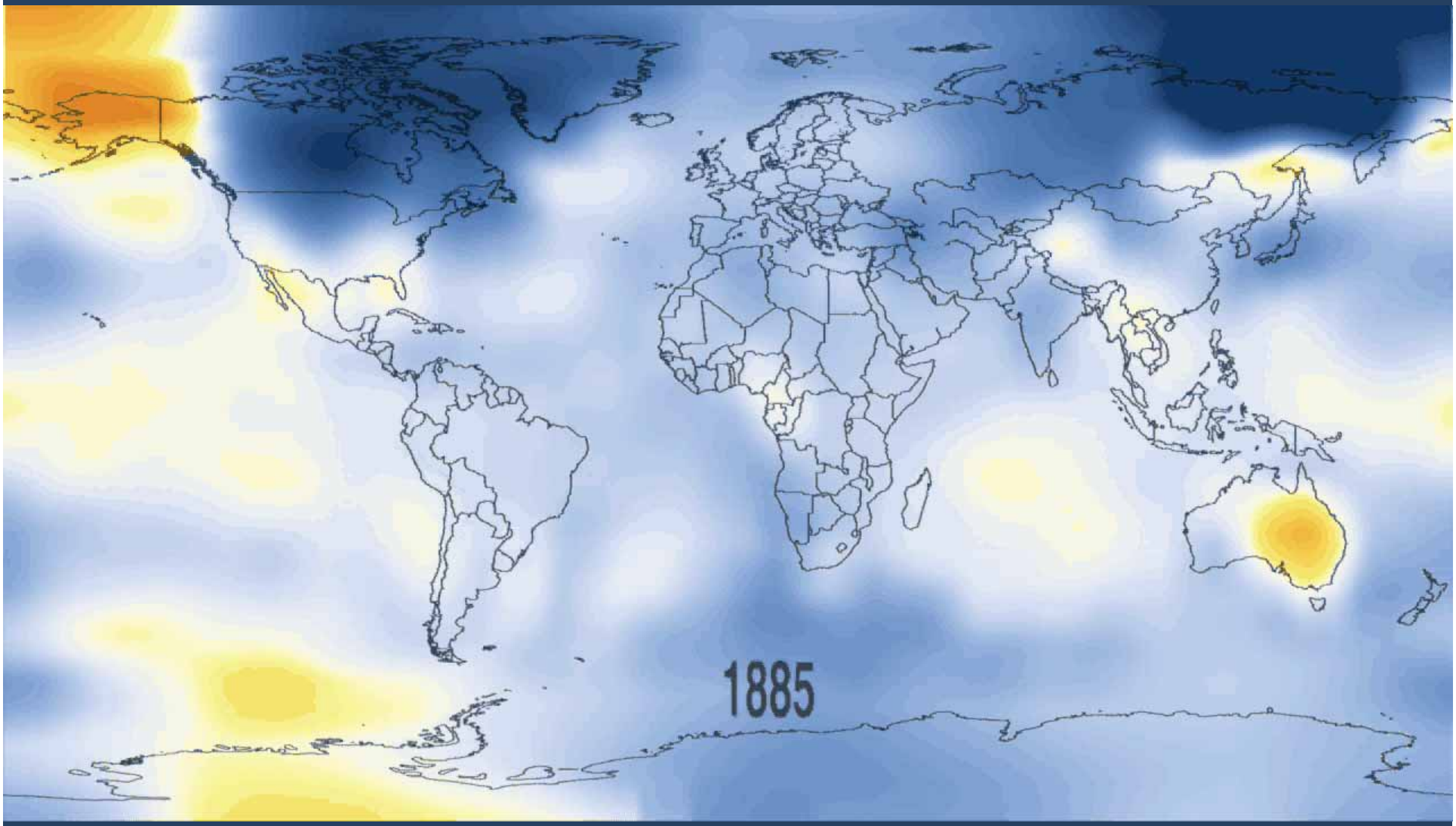
2010 – Tied as warmest year
1.34ºF (0.8ºC) total warming



2010, tied for warmest year

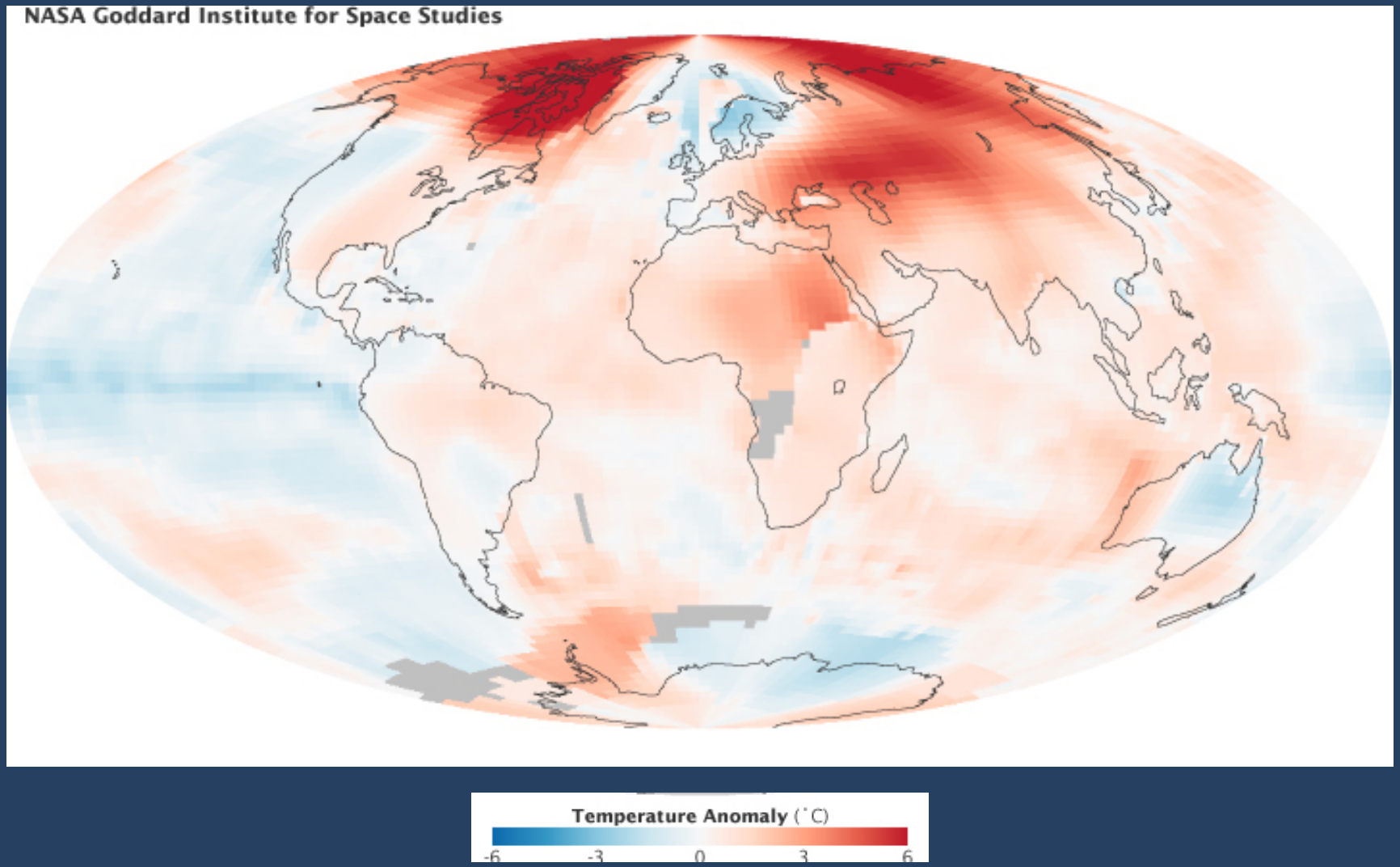
Chip Fletcher, University of Hawaii at Manoa
School of Ocean and Earth Science and Technology,

Global Surface Temperature Change, J. Hansen, R. Ruedy, M. Sato, K. Lo, 2010, NASA Goddard Institute for Space Studies, NY, NY

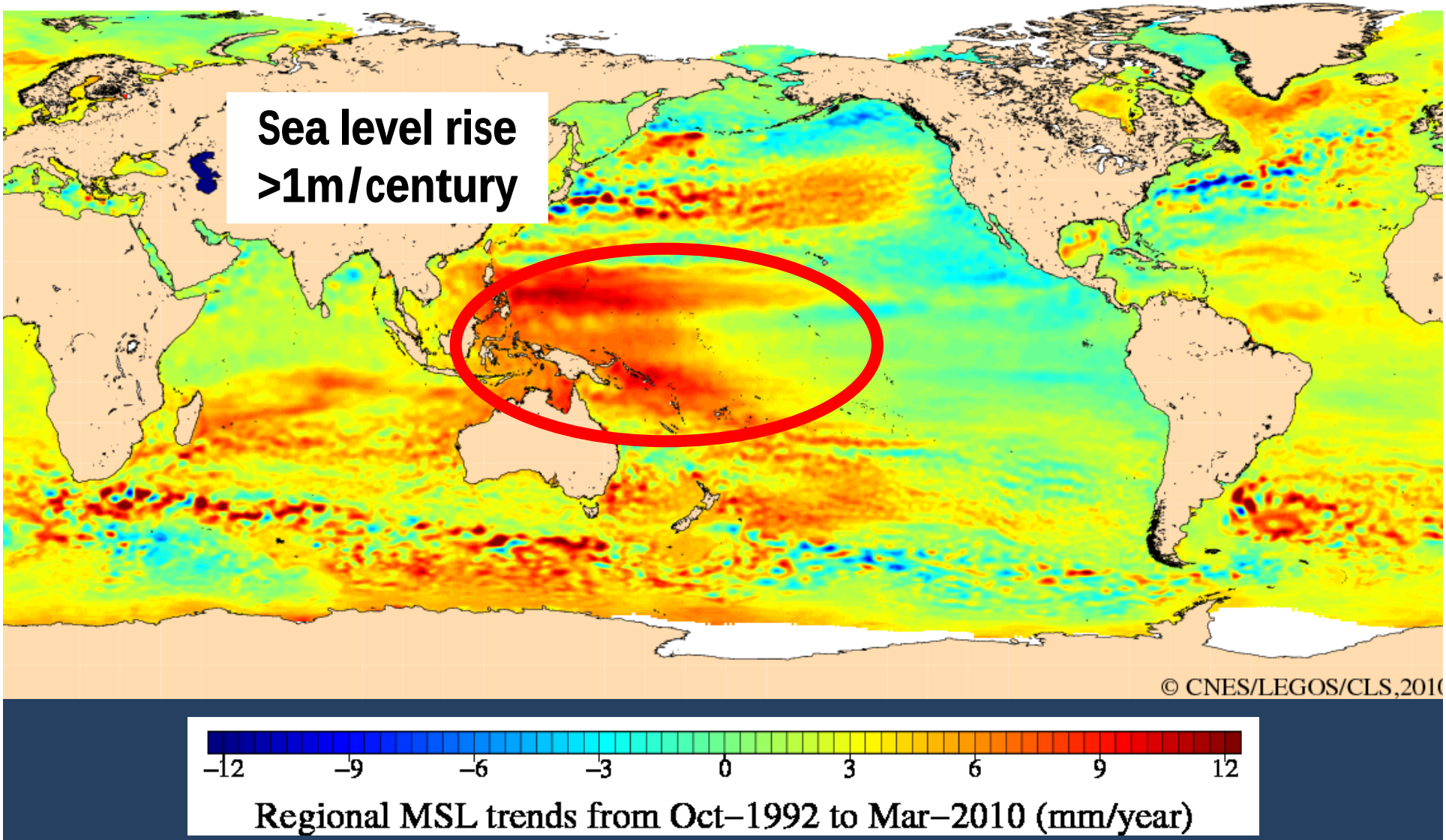


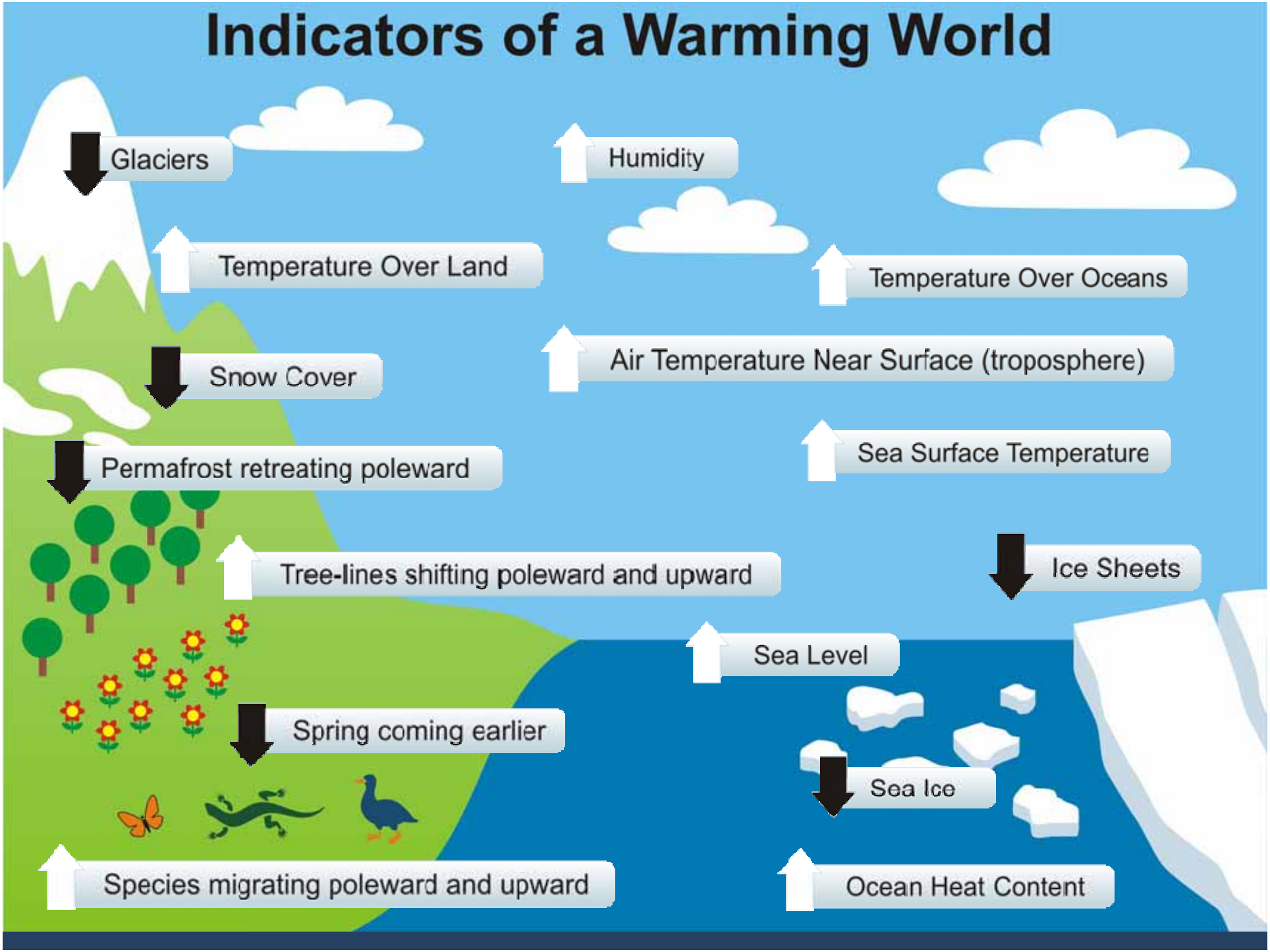
NASA Goddard Institute for Space Studies, NY, NY http://data.giss.nasa.gov/gistemp/

The Arctic – ground zero for warming



Western tropical Pacific – ground zero for sea-level rise

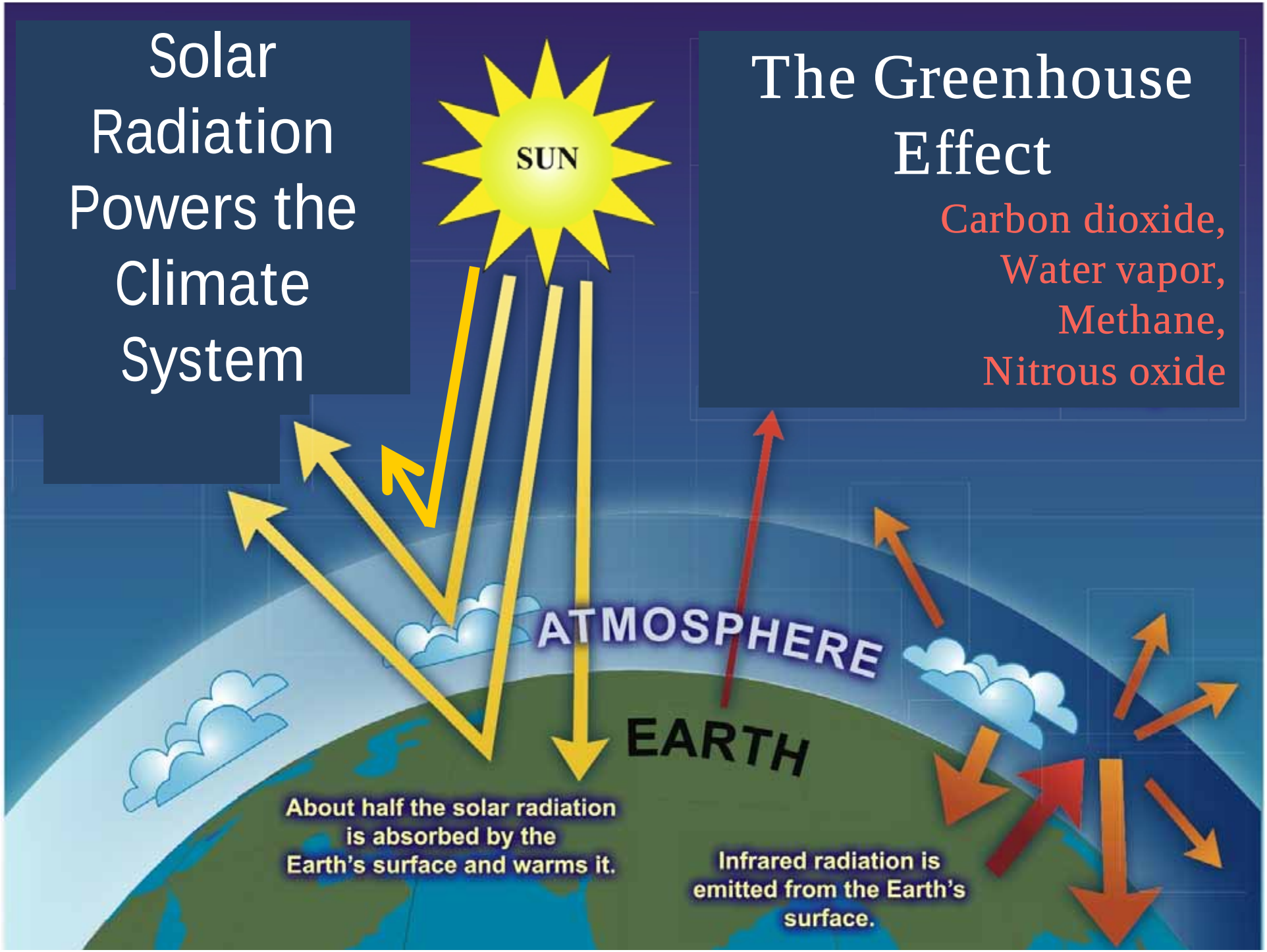



Indicators of a Warming World
Glaciers
Humidity
Temperature Over Land
Temperature Over Oceans
Snow Cover
Air Temperature Near Surface (troposphere)
Permafrost retreating poleward
Sea Surface Temperature
Tree-lines shifting poleward and upward
Ice Sheets
Sea Level
Spring coming earlier
Sea Ice
Species migrating poleward and upward
Ocean Heat Content

Solar Radiation Powers the Climate System

The Greenhouse Effect

Carbon dioxide,
Water vapor,
Methane,
Nitrous oxide



Industrial Pollution

Deforestation

Industrial
Agribusiness

U.S. National Academy of Science and Engineering

May 29, 2010

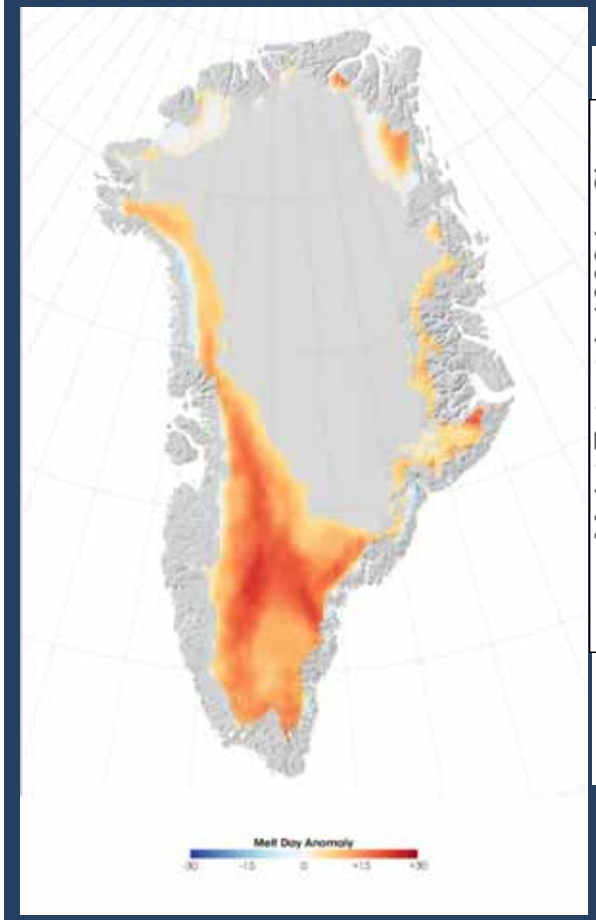
Some scientific conclusions have been so thoroughly examined and tested, and supported by so many independent observations and results, that their likelihood of being found wrong is vanishingly small. Such conclusions are then regarded as settled facts. This is the case for the conclusions that the Earth system is warming and that much of this warming is very likely due to human activities.

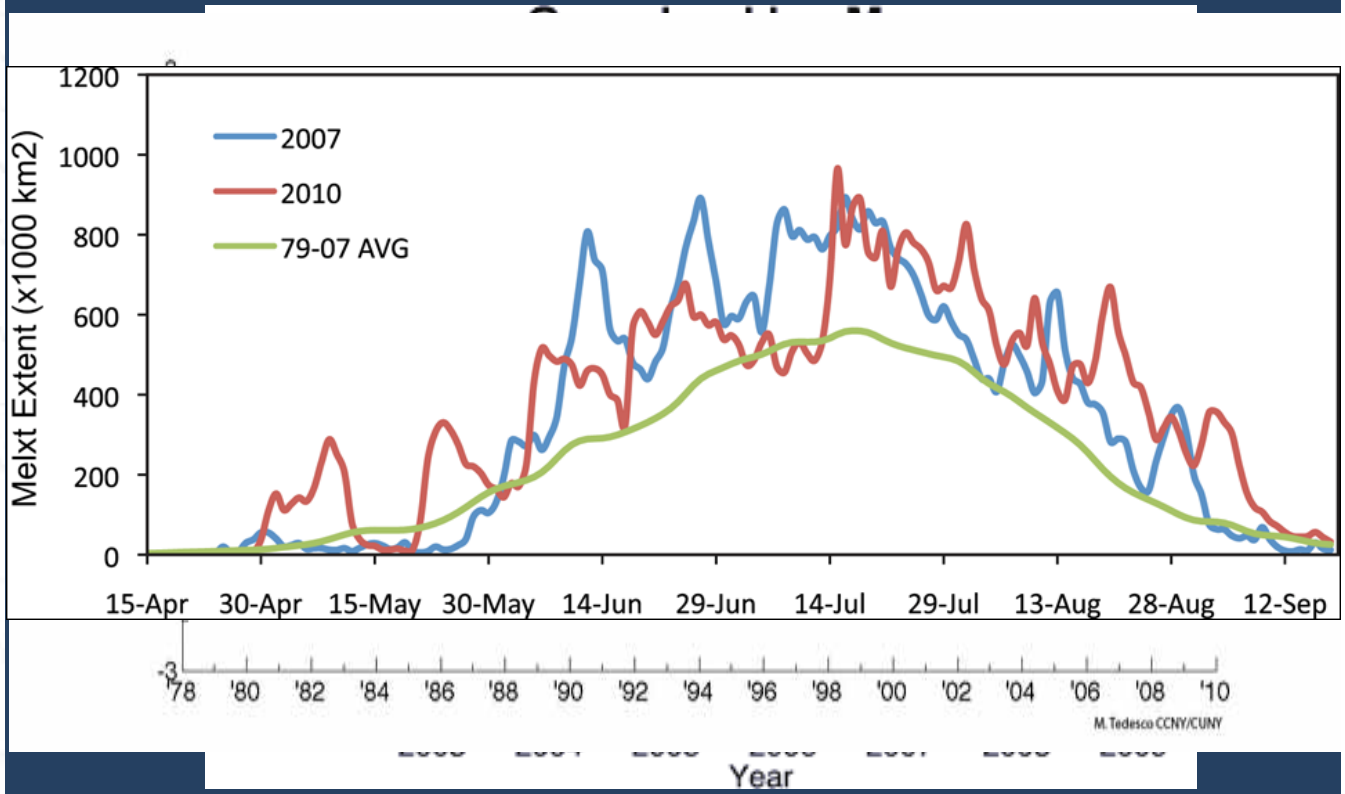
Note: a scientist is prone to say "The Sun will very likely rise tomorrow."

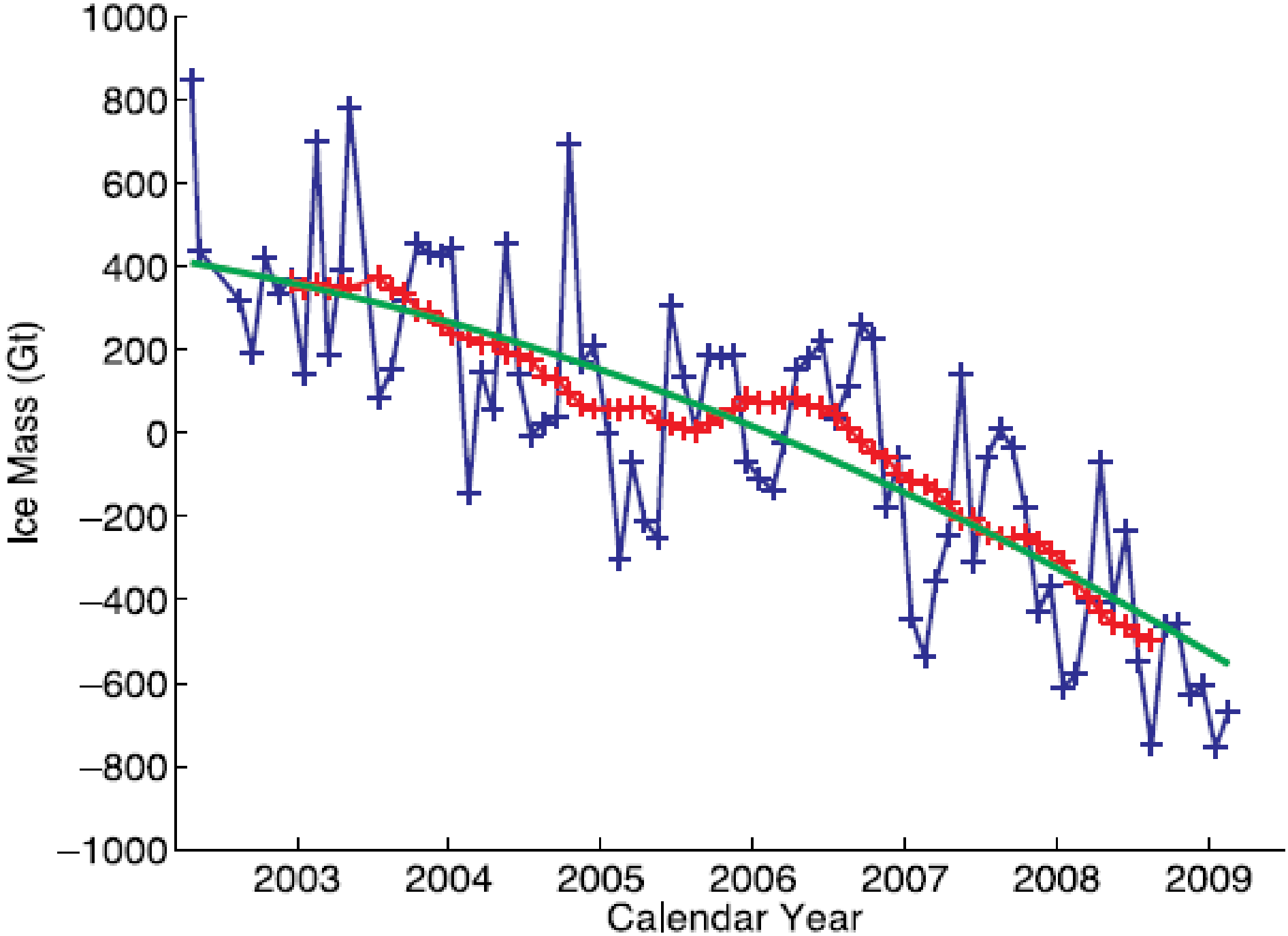
Advancing the Science of Climate Change – National Academies: http://americasclimatechoices.org/

The worlds ice is melting

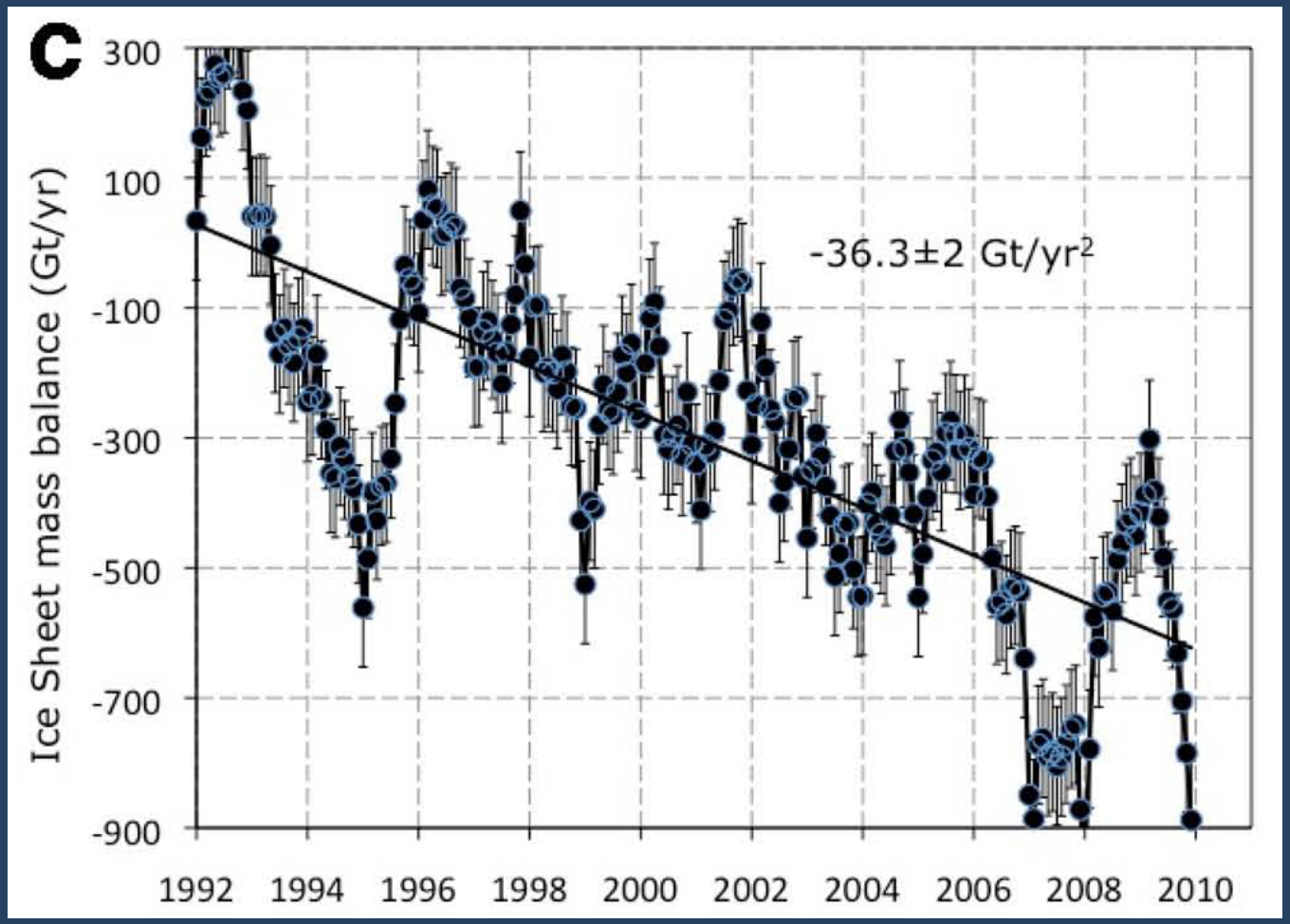
In the past decade, the annual difference of melting and snowfall on Greenland tripled.



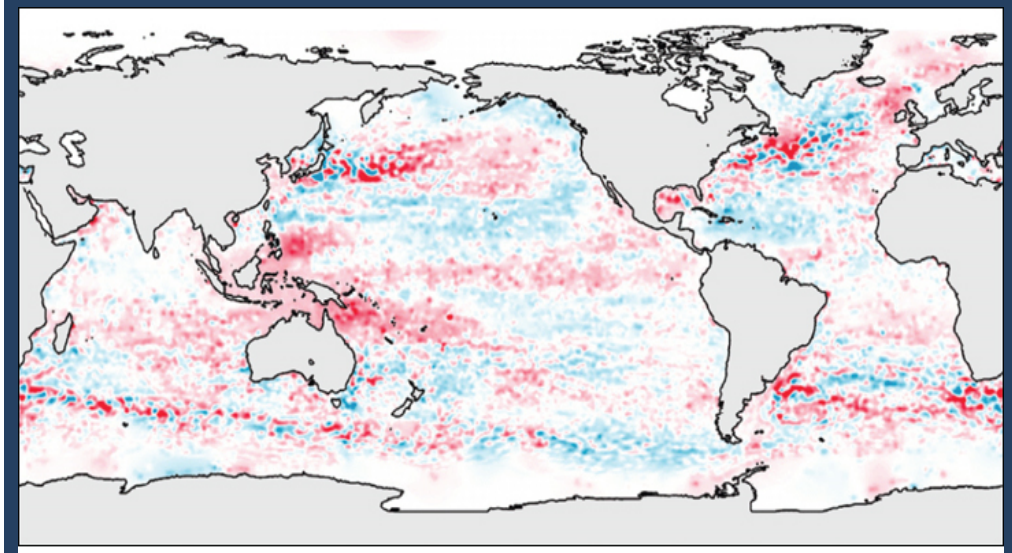


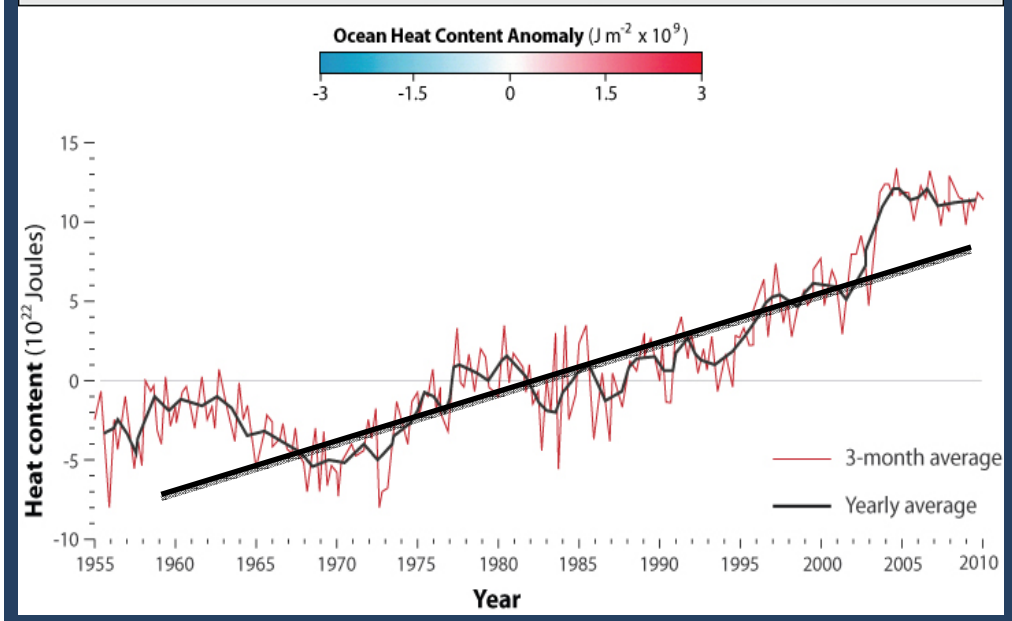

1000
800
600
400
200
0
−200
−400
−600
−800
−1000
Ice Mass (Gt)
2003
2004
2005
2006
2007
2008
2009
Calendar Year

Combined Greenland + Antarctica melting = 23 ±6cm sea level rise by 2050



Rignot, E., I. Velicogna, M. van den Broeke, A. Monaghan, and J. Lenaerts (2011), Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise, Geophys. Res. Lett., doi:10.1029/2011GL046583, in press.

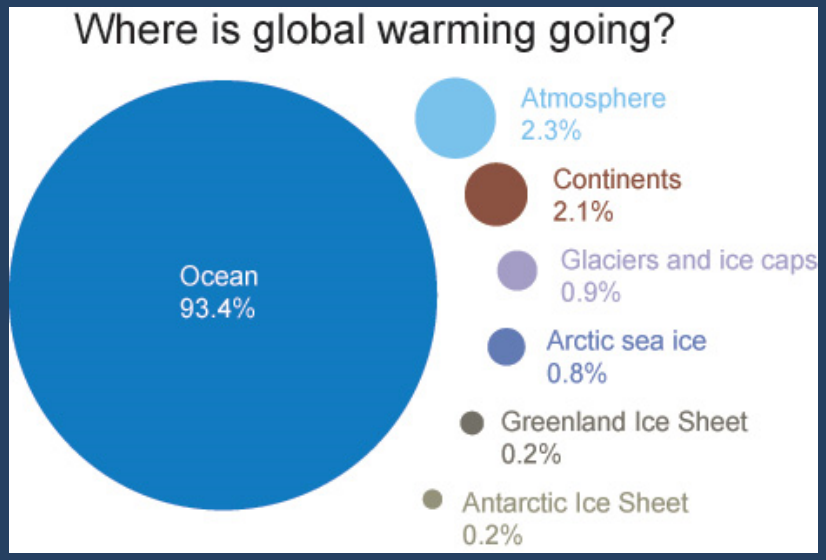




Thermal expansion of shallow ocean

9 ±3cm sea level rise by 2050

Over 90% of warming since 1955 has gone into the ocean.



NOAA Climate Watch Magazine (on-line)

http://www.climatewatch.noaa.gov/2010/images/new-evidence-on-warming-ocean

Cazenave, A., Llovel, W., 2010, Contemporary sea level rise, Ann. Rev. Mar. Sci., 2:145-73

How high?

2050 sea level if ice sheet acceleration continues:
Ice sheets 23 ±6cm
Thermal expansion 9±3 cm (based on average IPCC scenarios)

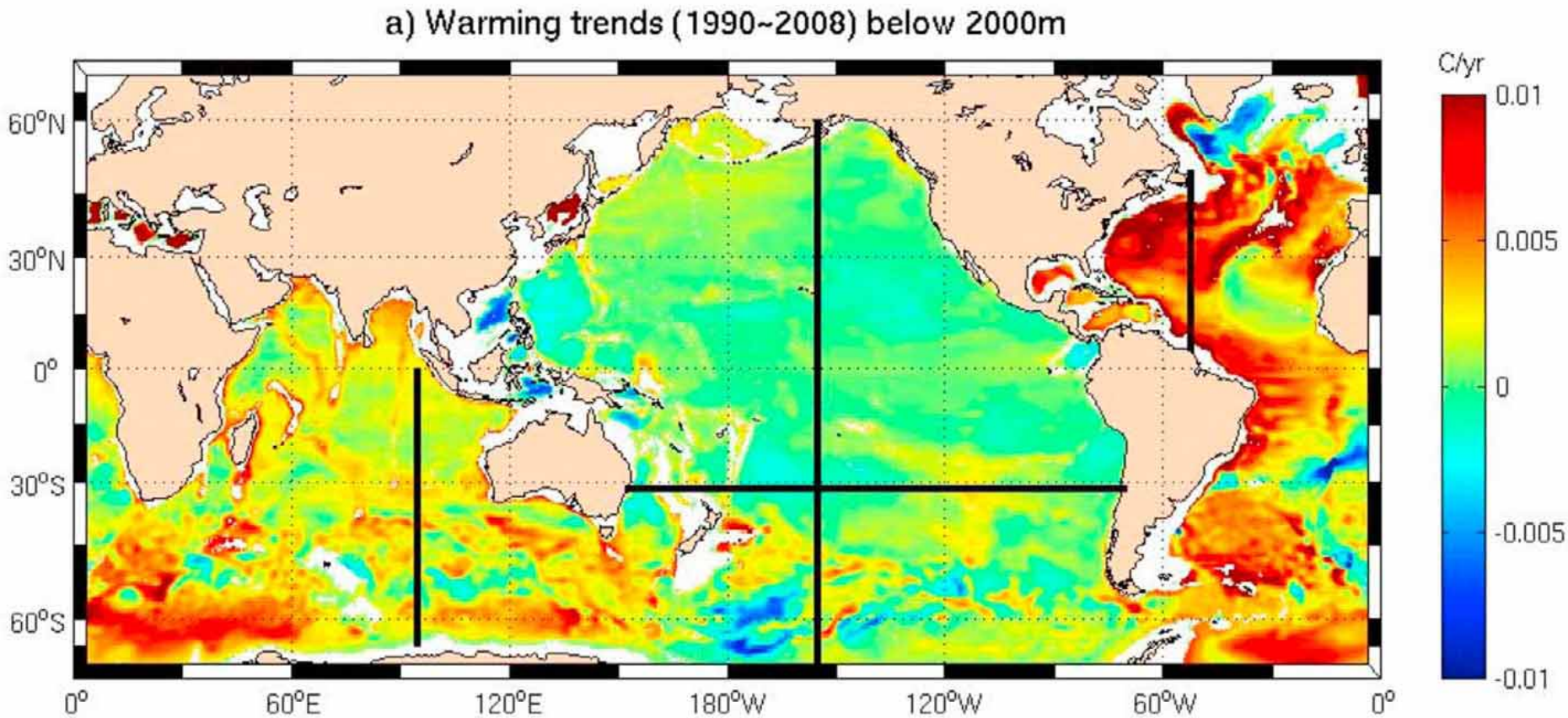
Total rise of 32±5 cm (1 foot)

Does not count deep warming or alpine glaciers

Rignot, E., I. Velicogna, M. van den Broeke, A. Monaghan, and J. Lenaerts (2011), Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise, Geophys. Res. Lett., doi:10.1029/2011GL046583, in press.

Warming in the deep ocean

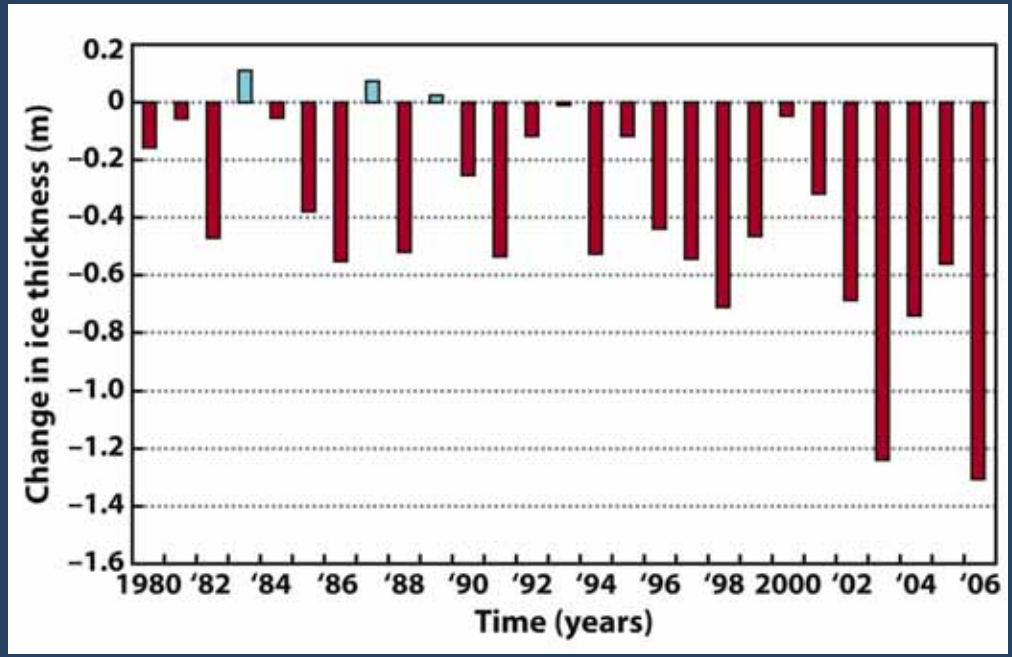
~1.1 mm/yr

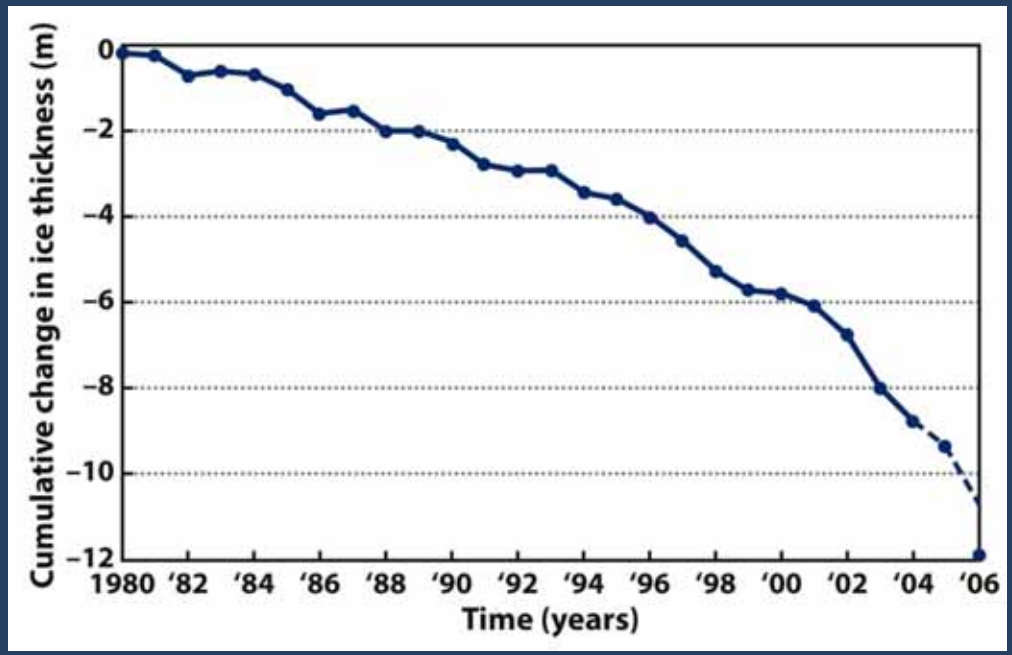


Song, Y. T., and F. Colberg (2011), Deep ocean warming assessed from altimeters, Gravity Recovery and Climate Experiment, in situ measurements, and a non Boussinesq ocean general circulation model, J. Geophys. Res., 116, C02020, doi:10.1029/2010JC006601.

Alpine glacier ice

1.4±0.25 mm/yr

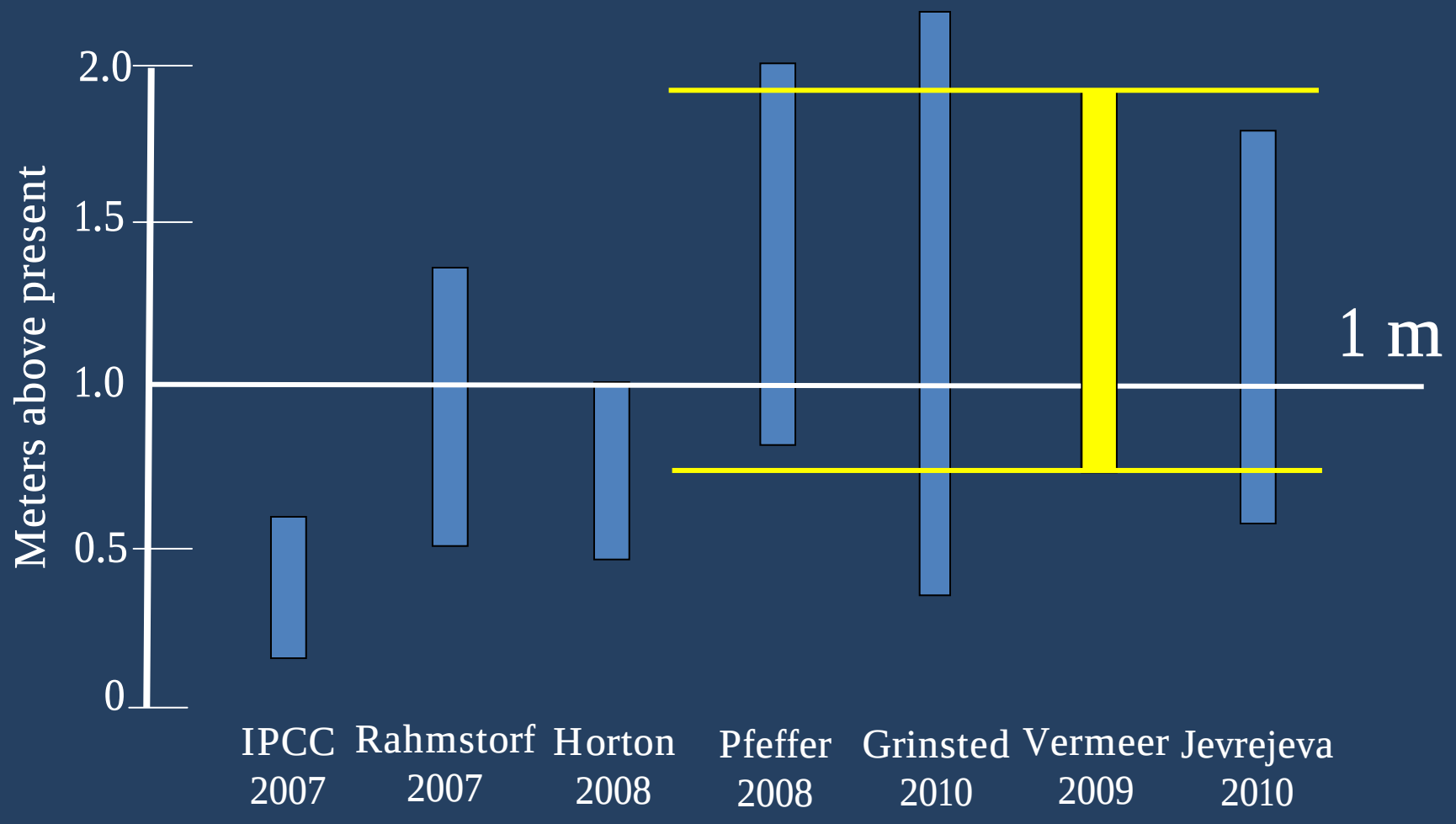


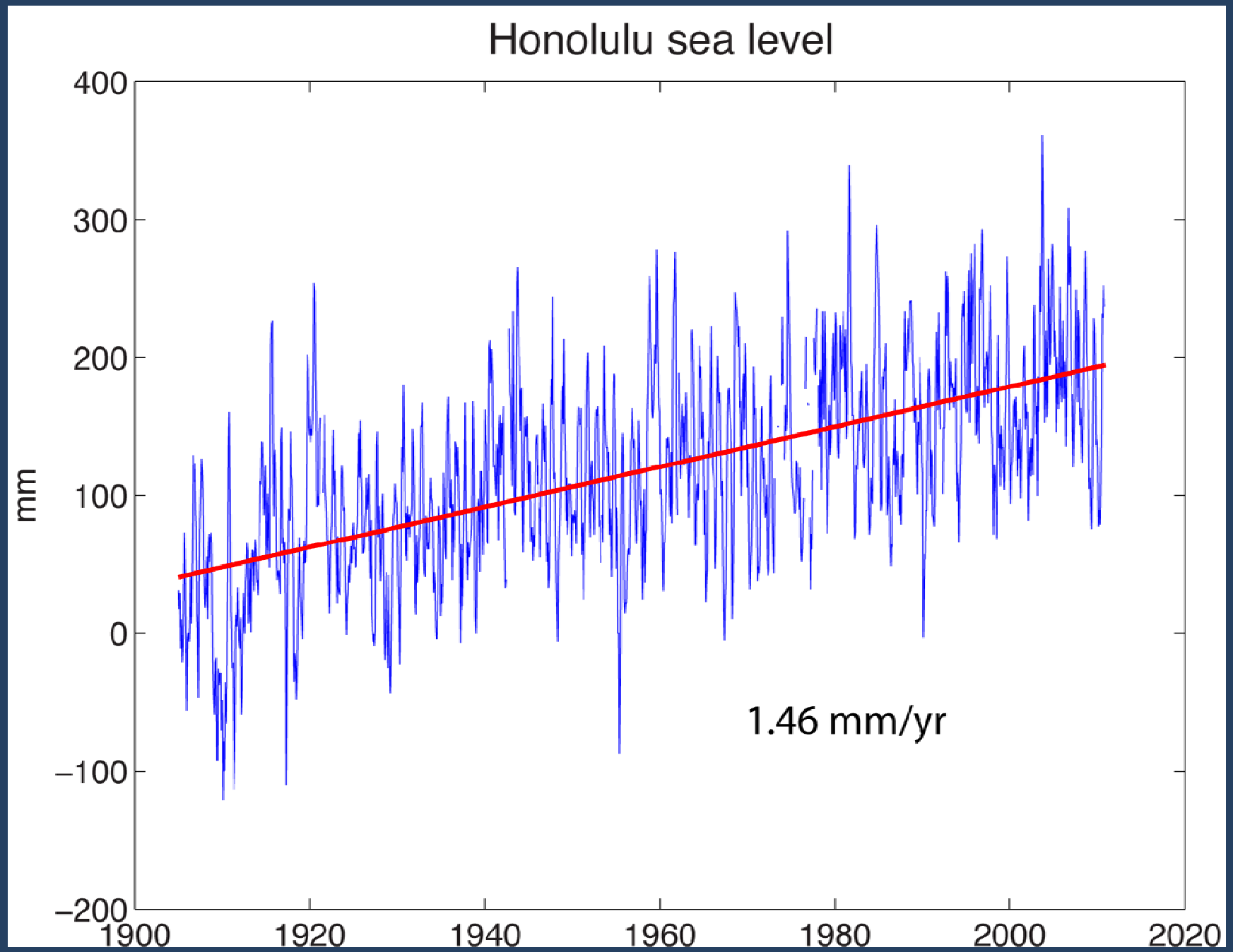


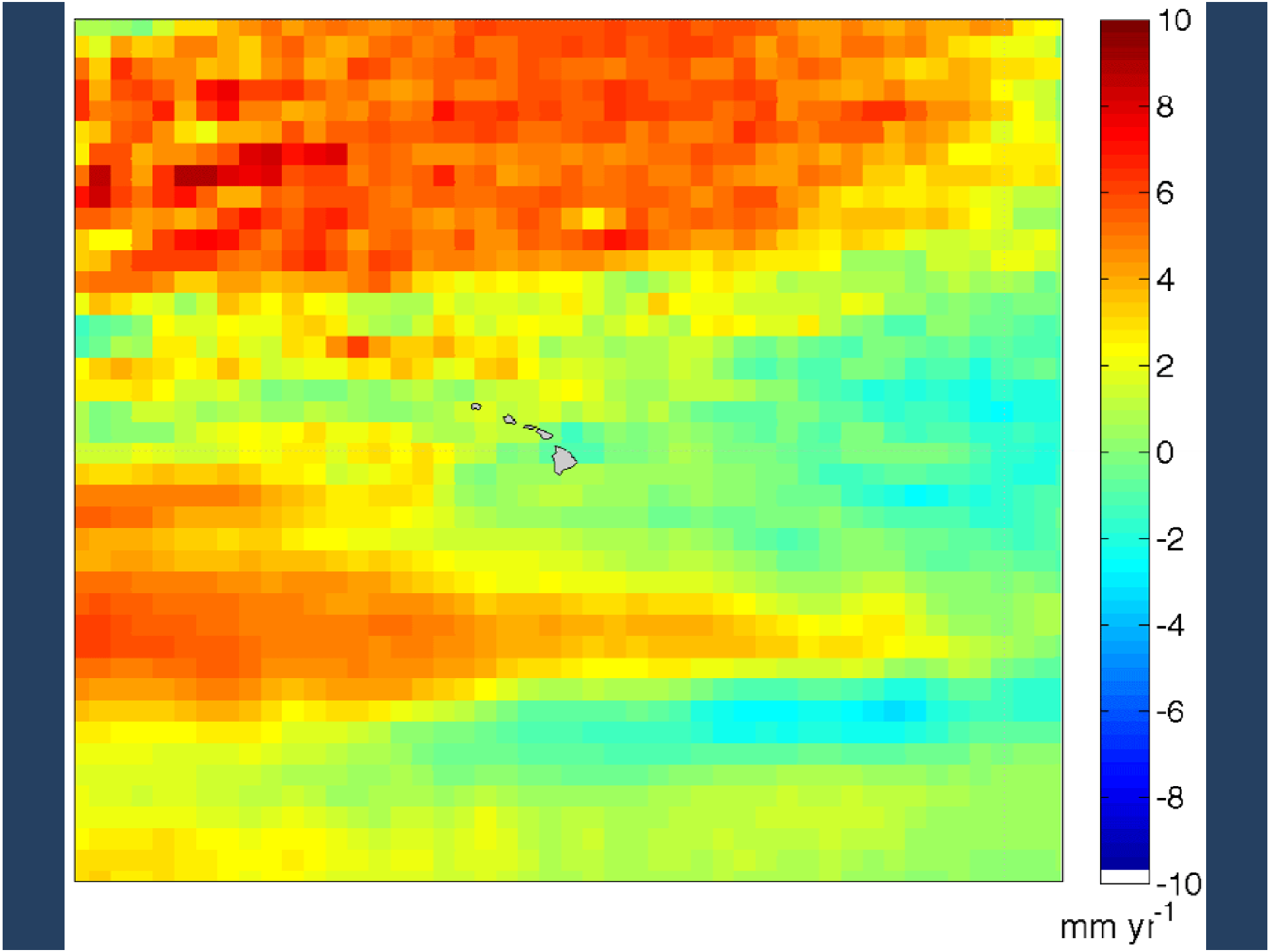
Meier MF, Dyurgerov MB, Rick UK, O'Neel S, Pfeffer WT, et al. 2007. Glaciers dominate Eustatic sea-level rise in the 21st century. *Science 317:1064–67*

Cogley JC. 2009. Geodetic and direct mass balance measurements: Comparison and joint analysis. *Ann. Glaciol.* 50:96–100

Sea level Estimates – 2100
75 to 190 cm

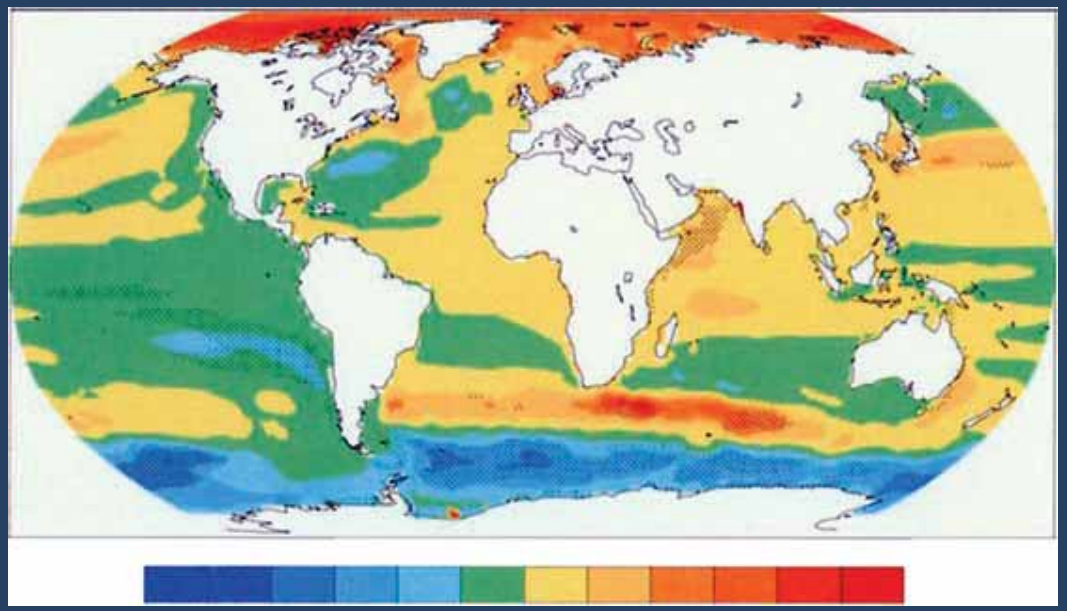



Honolulu sea level
400
300
200
100
0
−100
−200
mm
1900
1920
1940
1960
1980
2000
2020
1.46 mm/yr


10
8
6
4
2
0
-2
-4
-6
-8
-10
mm yr-1

Hawaii sea level?

- Rising now
- Likely to accelerate
- Global SLR
  - >1ft by 2050
  - 2.5 to 6.2ft by 2100
- Hawaii near or slightly below (5%) global SLR, 2100



Sea level regional variability (m) due to circulation and density differences by 2100

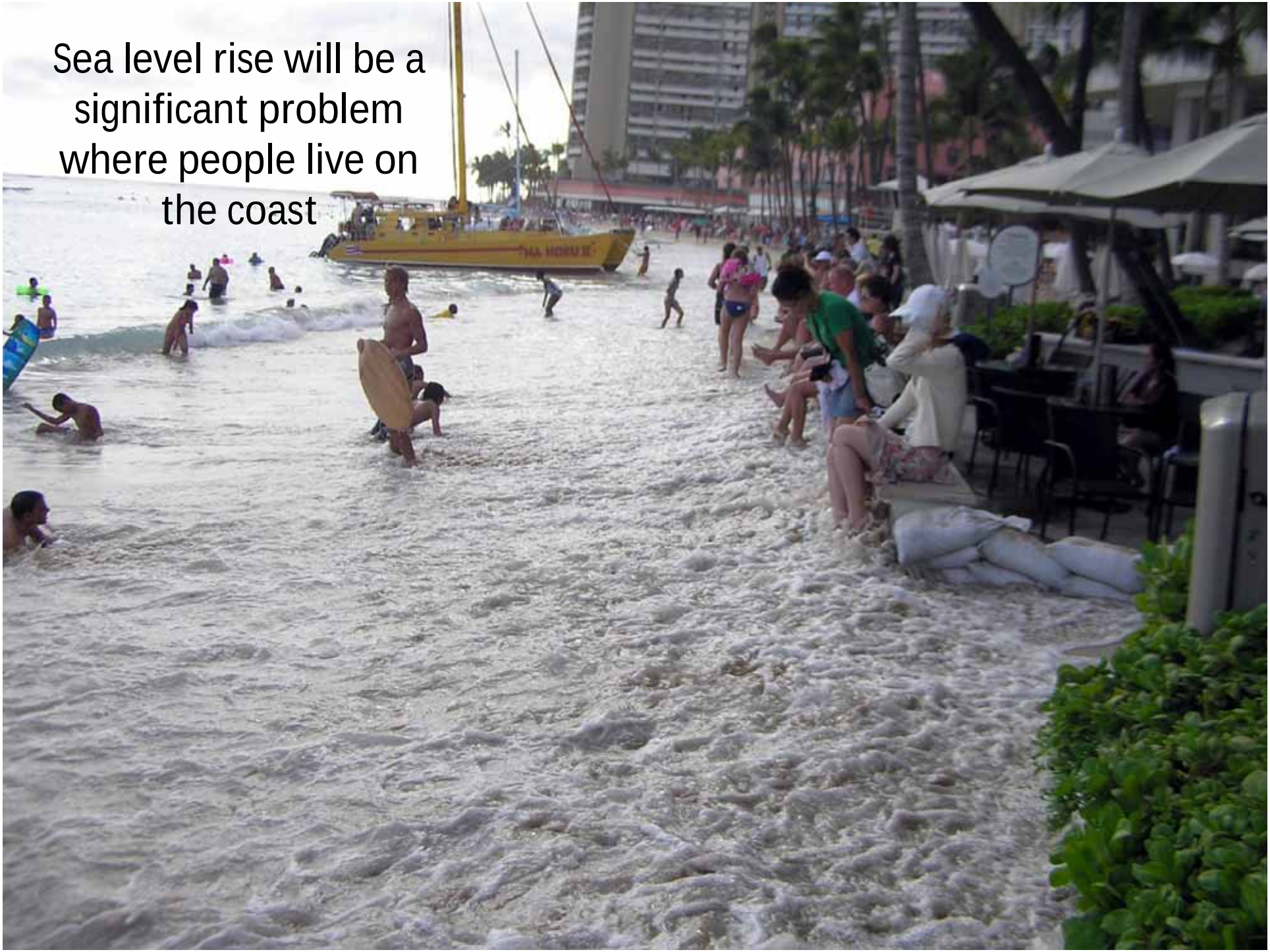
Cazenave, A., Llovel, W., 2010, Contemporary sea level rise, Ann. Rev. Mar. Sci., 2:145-73

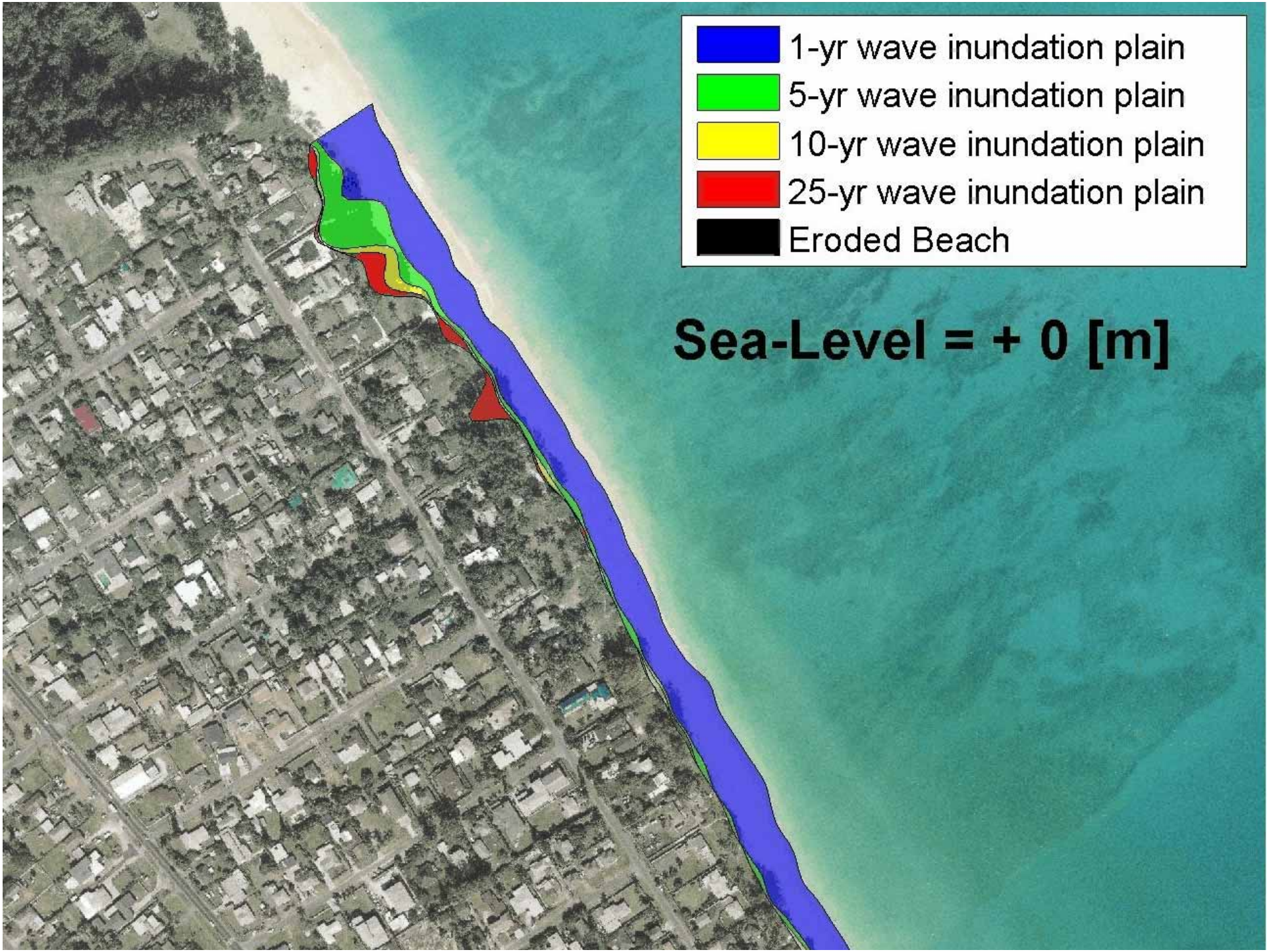
IPCC. 2007. *Fourth Assessment Report (AR4), Climate Change 2007: The Physical Science Basis, Contribution of* Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. S Solomon et al. Cambridge, UK: Cambridge Univ. Press

Pacific Island Climate is Changing

In Hawaii

- Rainfall (-15%) and stream discharge have decreased
- Air temperature is increasing (0.3^{o}F/decade)
- Rainstorm intensity has increased (+12%)
- Sea surface temperature is rising (0.22^{o}F/decade)
- Ocean has grown more acidic
- Sea level is rising

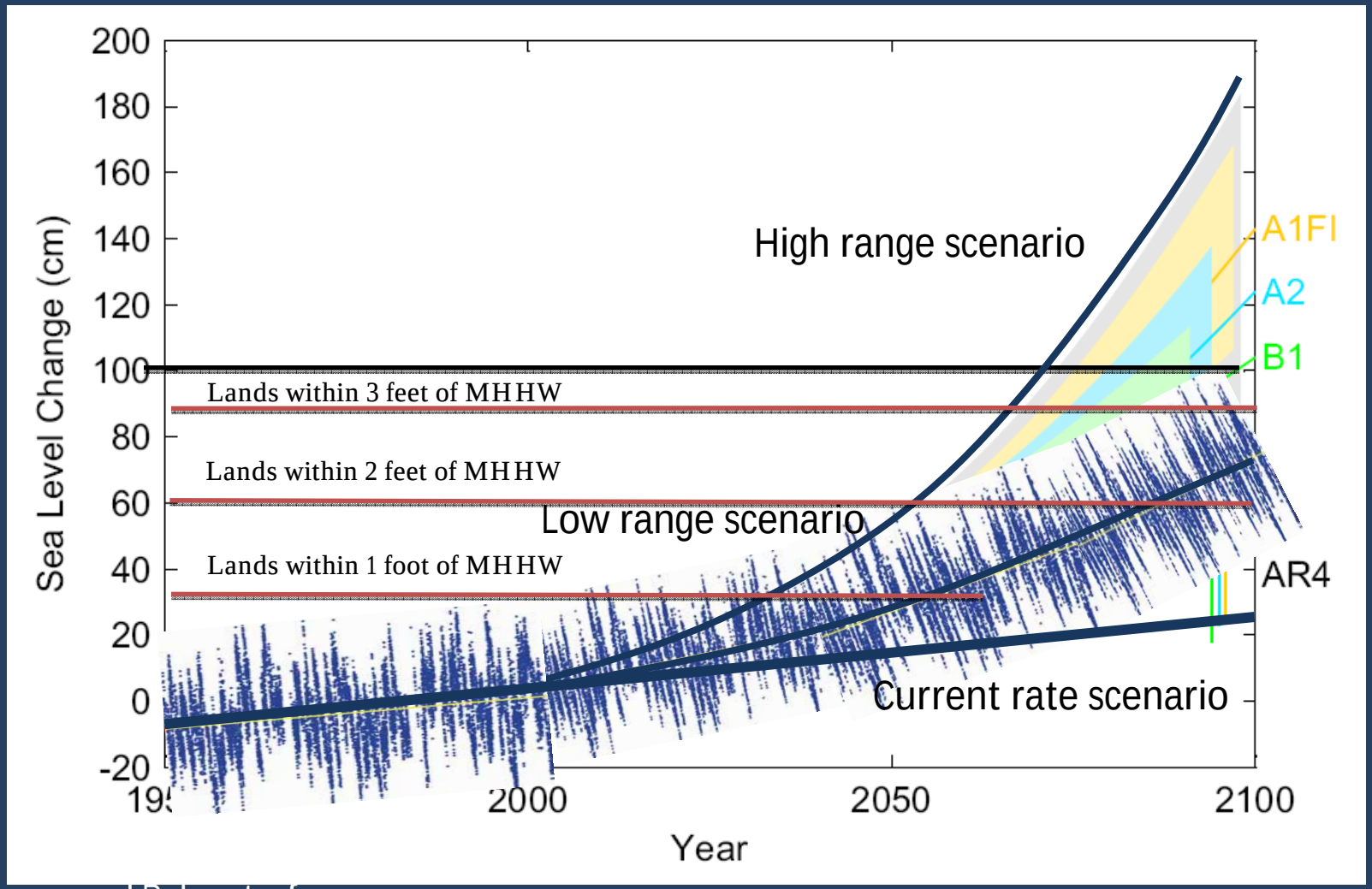

Sea level rise will be a significant problem where people live on the coast


1-yr wave inundation plain
5-yr wave inundation plain
10-yr wave inundation plain
25-yr wave inundation plain
Eroded Beach
Sea-Level = + 0 [m]

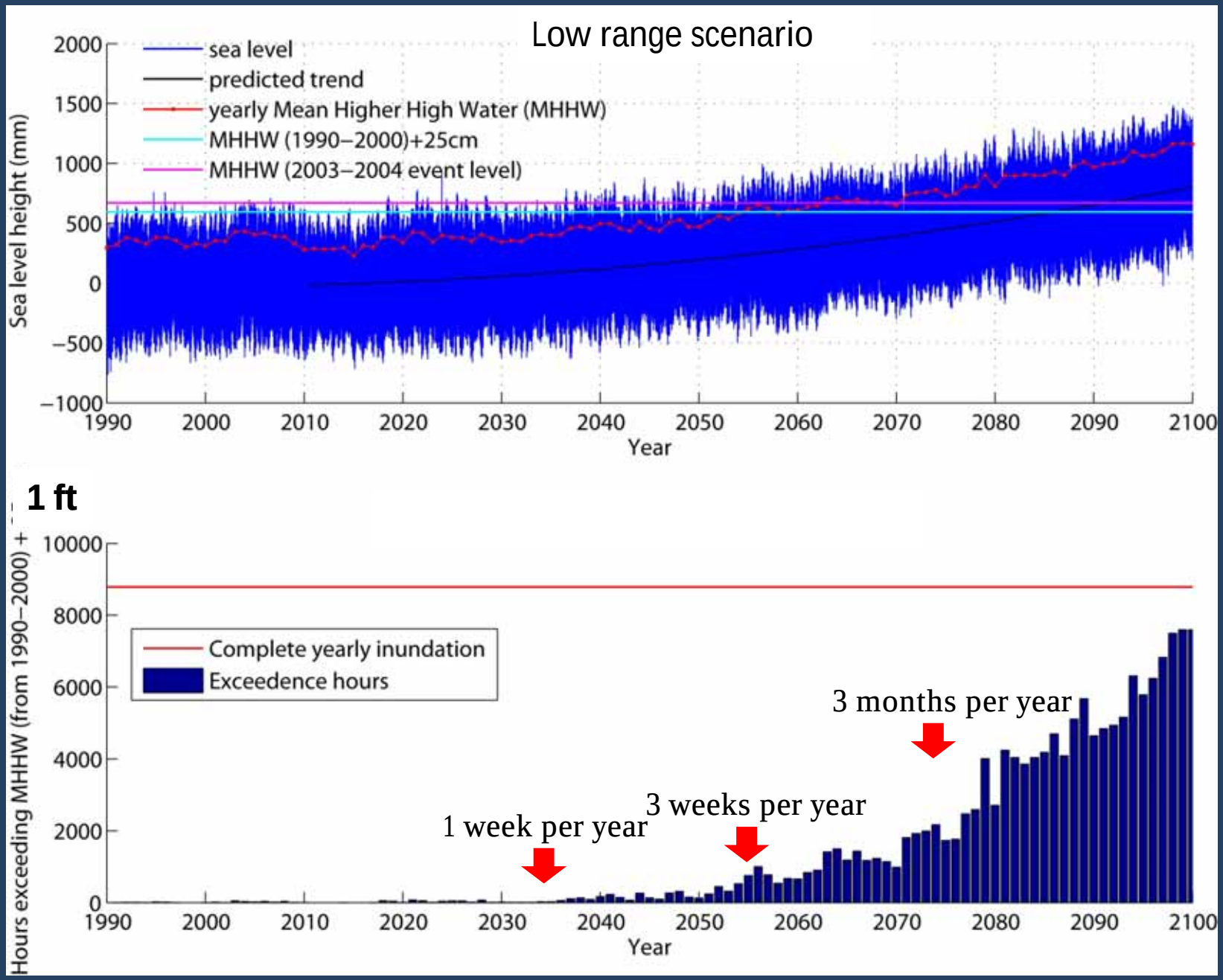
Impacts?

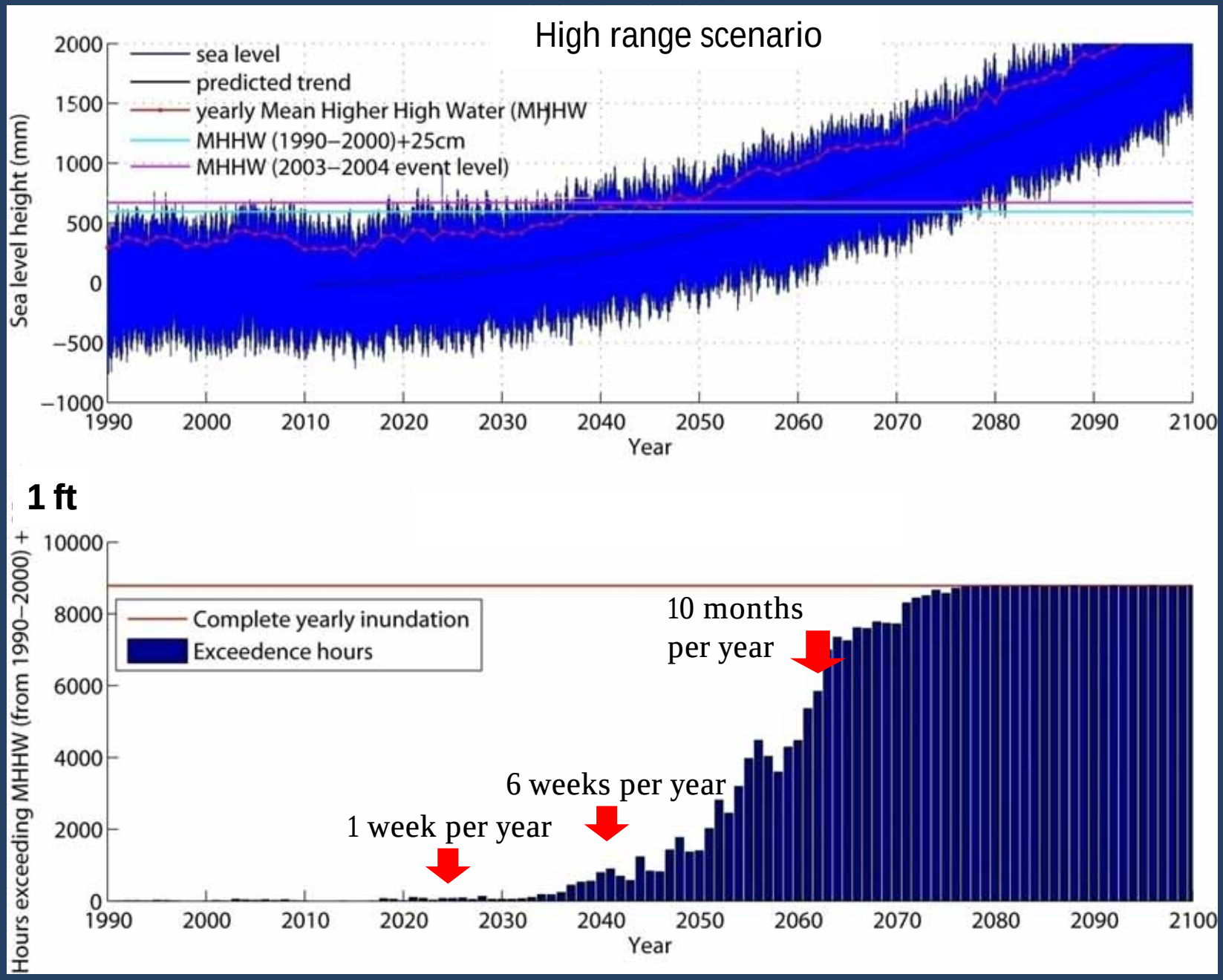
- Increasing rain intensity + SLR = FLOODING
- Wave overtopping = CLOSED ROADS
- Vulnerable infrastructure?
  - Wastewater plants
  - Areas that flood now
  - Coastal roads
  - Sagging roadbeds due to slumping/compaction/slope failure (Pali Hwy)
  - Soil exposure/unstable slopes
- High traffic flow/Low elevation
  - Hawai´i Kai, Waikiki, Kalihi, Airport Industrial
  - N. Nimitz, Dillingham, Ala Moana, Kapiolani
  - Kamehameha (windward and N. Shore)
  - Kalaniana'ole

Projected Sea Level
0.75-1.90 m



Vermeer and Rahmstorf, 2009


Low range scenario
sea level
predicted trend
yearly Mean Higher High Water (MHHW)
MHHW (1990–2000)+25cm
MHHW (2003–2004 event level)
Sea level height (mm)
2000
1500
1000
500
0
−500
−1000
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
1 ft
Hours exceeding MHHW (from 1990–2000) +
10000
8000
6000
4000
2000
0
Complete yearly inundation
Exceedence hours
3 months per year
3 weeks per year
1 week per year
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year


High range scenario
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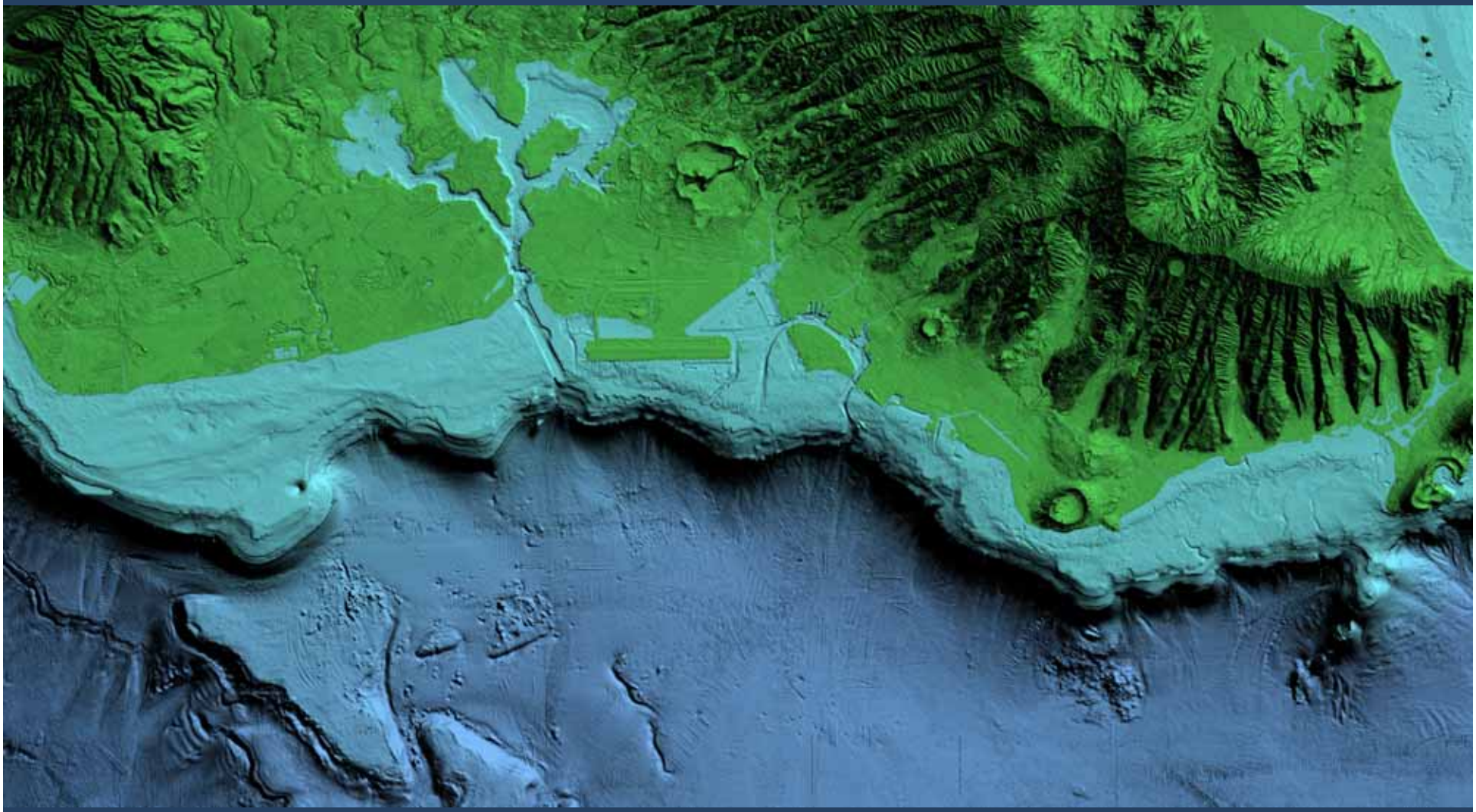
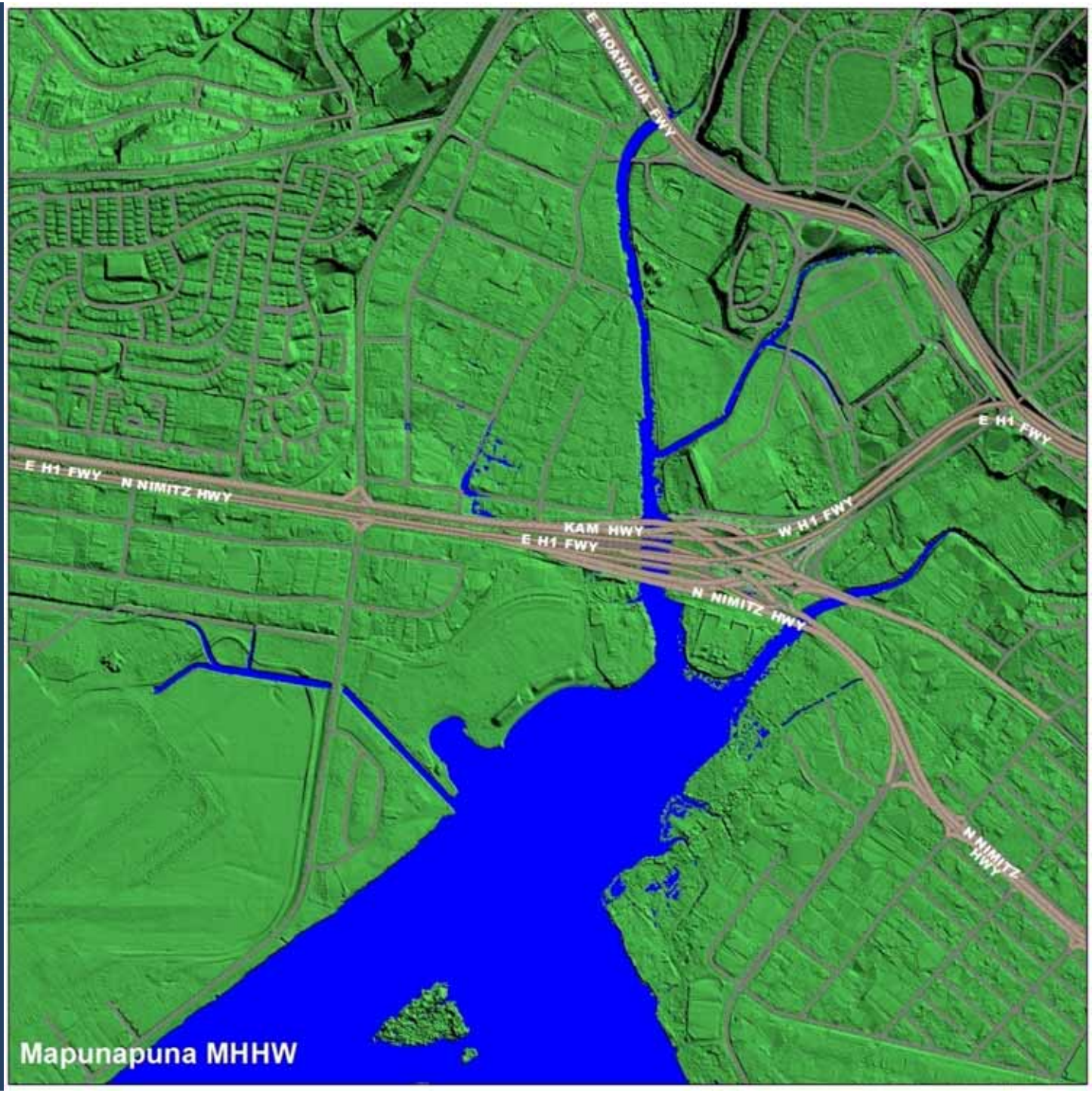
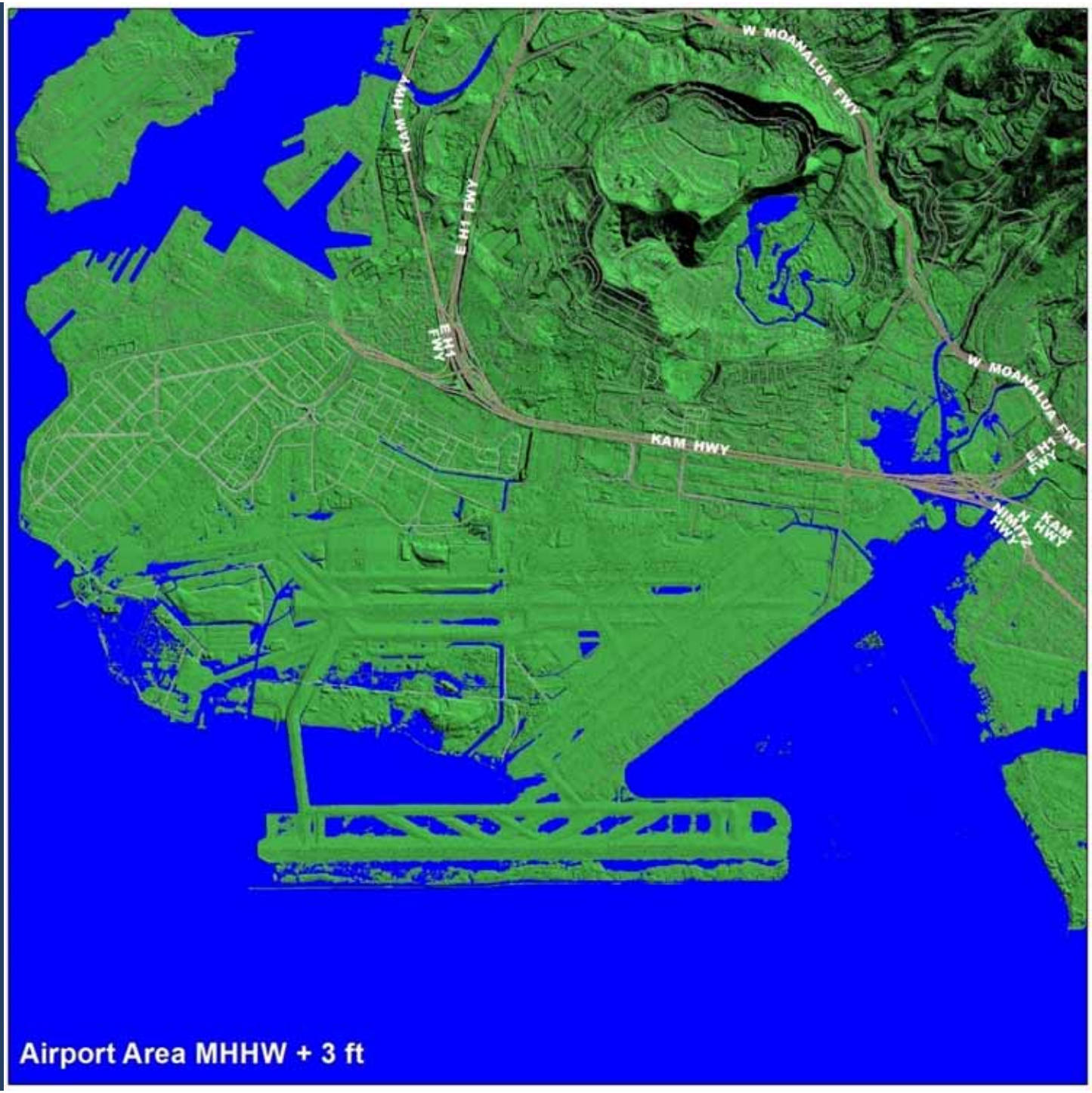
MHHW (1990–2000)+25cm
MHHW (2003–2004 event level)
Sea level height (mm)
2000
1500
1000
500
0
−500
−1000
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
1 ft
Hours exceeding MHHW (from 1990–2000) +
10000
8000
6000
4000
2000
0
Complete yearly inundation
Exceedence hours
10 months
per year
6 weeks per year
1 week per year
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year

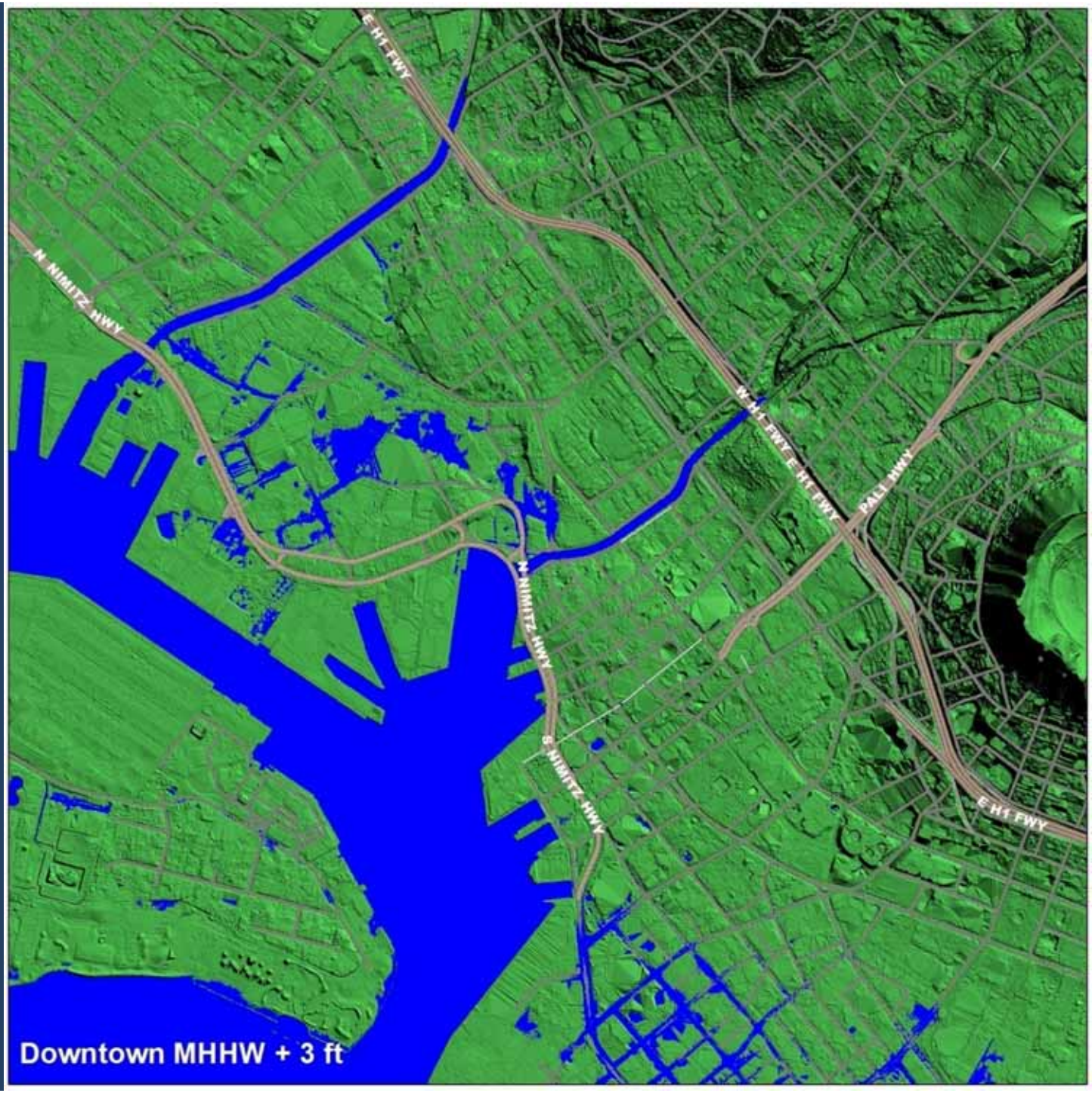


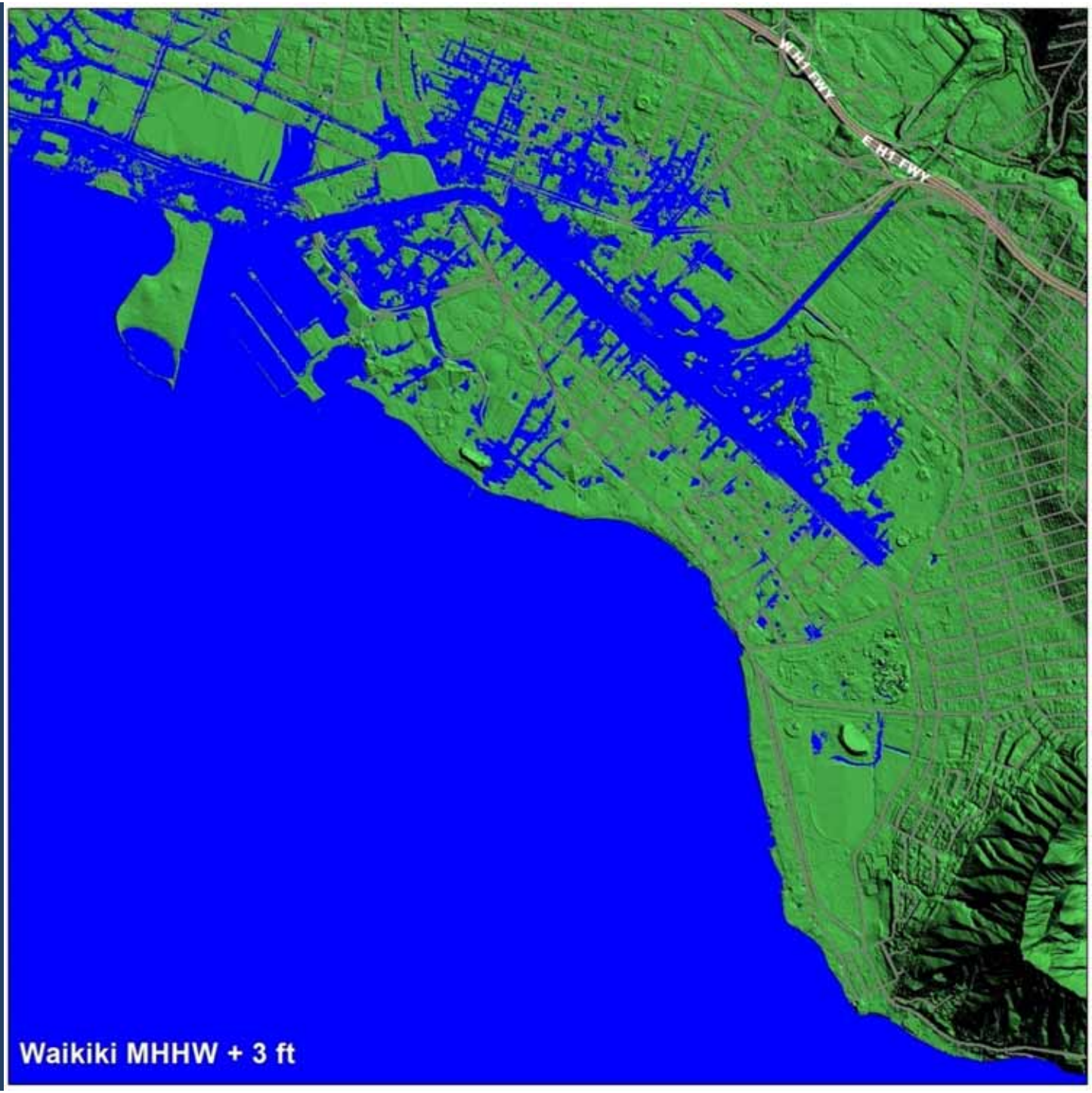

E MOANALUA FWY
E H1 FWY
N NIMITZ HWY
KAM HWY
E H1 FWY
W H1 FWY
E H1 FWY
N NIMITZ HWY
N NIMITZ HWY
Mapunapuna MHHW



Airport Area MHHW + 3 ft

S NIMITZ HWY
W H1 FWY
E H1 FWY
W H1 FWY
Ala Moana MHHW + 3 ft


E H1 FWY
N NIMITZ HWY
W H1 FWY
E H1 FWY
PALI HWY
N NIMITZ HWY
S NIMITZ HWY
E H1 FWY
Downtown MHHW + 3 ft


H-1 FWY
E H-1 FWY
Waikiki MHHW + 3 ft

Missing Data

- Water Table Height maps and how the water table behaves
- Current Problem Area maps
  - Flooding
  - Wave overwash
  - Erosion
  - Chronic slope/rock fall problems
- Commuter volume and timetable maps

Adapting to sea-level rise and inundation

1. Explore the issues of sea level rise with the community to develop a shared vision of what is at risk and the qualities stakeholders want to protect (community-based climate risk management).
2. Map the problem using best and worst case scenarios.
3. Develop adaptation strategies
   a) Building codes
   b) Retreat strategies
   c) Defense strategies
   d) Food, flood, transportation engineering
4. No regrets policy – areas troubled now, are likely to get worse
5. Identify funding, create plans, establish an authority
6. Stage activities, apply triage priorities

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION UNITED STATES DEPARTMENT OF COMMERCE

USGS science for a changing world

Thank you