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2023 ASHRAE Annual Conference

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Seminar 16: Fundamentals of Climate Science Part 3: Recent Developments and Issues

Understanding the relationship between extreme events and global warming

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Learning Objectives

1. Know some of the key contributions to climate science in the last 20 years.
2. Describe how climate models work and what CMIP6 is.
3. **Understand whether global warming and extreme events are strongly linked to each other**
4. Understand how the impacts of climate change are quantified

Acknowledgements

- Thanks to my wife Marina and kids Sophia, Amanda, Miguel, Francesca, Cordelia, Timothy, Trinity, and baby Cecilia
- This series has heavily relied on organizations that freely allow figures to be re-used. Thank you! (IPCC, WWA, NOAA, NASA, USGS, WB etc…)

- Bias Disclosure
  - Sandia National Laboratories
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Extreme Weather Events

Extreme Events	Effect
Heat Waves	Temperature Rise
Cold Snaps	Temperature Drop
Winter Storms	High Winds
Tornados	Flooding
Heavy Rainfall	Multiple Effects
Hurricanes	
Droughts	
Floods	

Example U.S. extreme weather since 2000:

Hurricane Katrina	Aug. 2005	1,800 deaths
Winter Storm Uri	Feb. 2021	250+ deaths
Oregon Heat Wave	June 2021	100 deaths

NASA – public domain image

Hurricanes

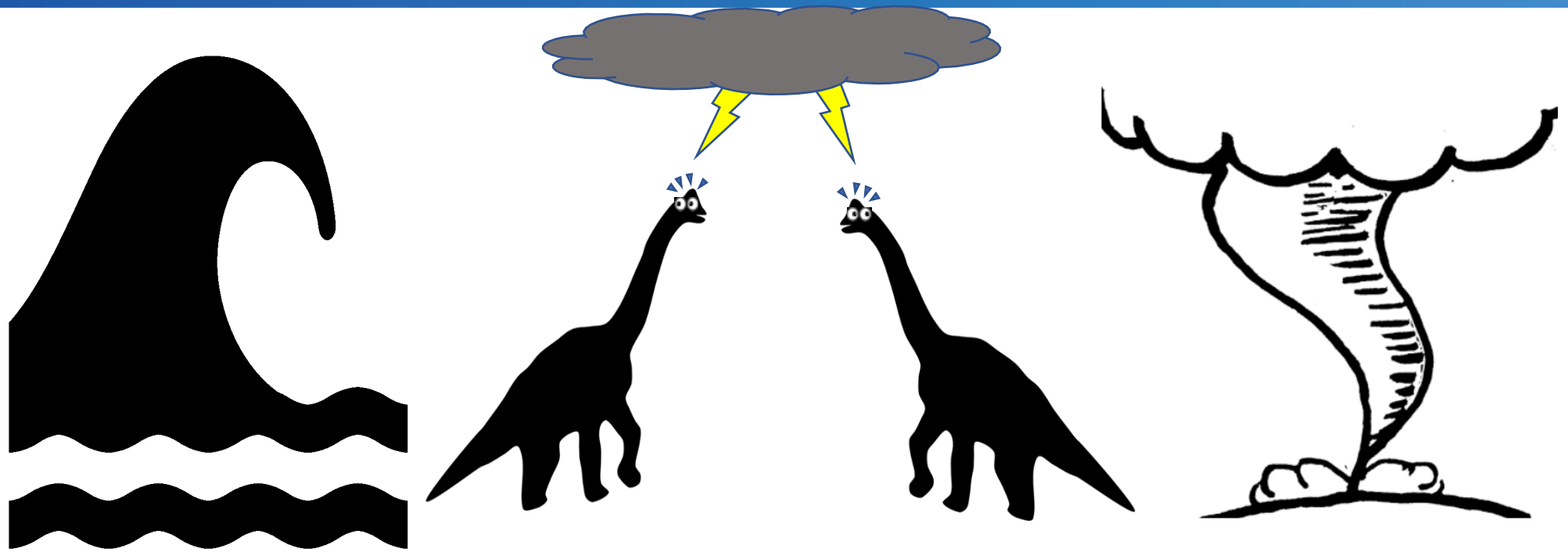
NOAA – public domain image

Tornadoes

NOAA – public domain image

Floods

What's the big deal? Extreme events have always existed

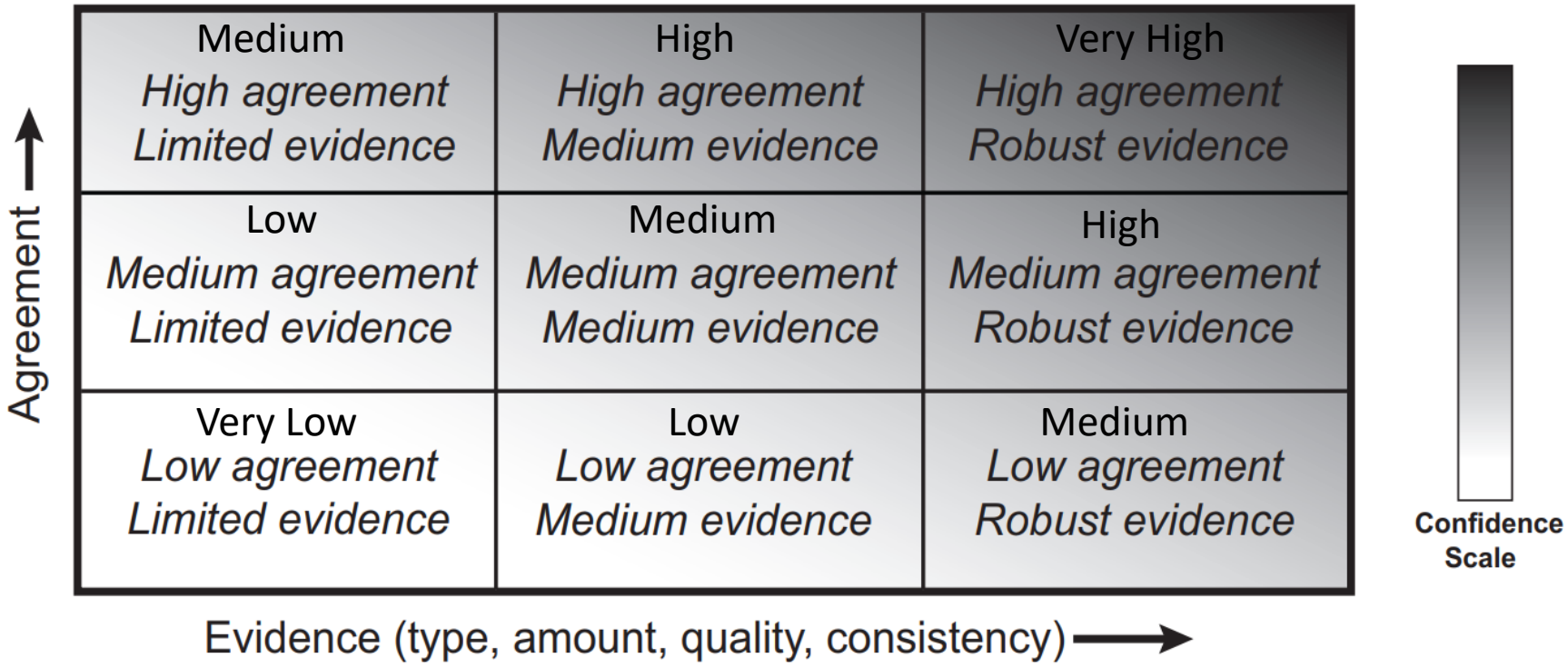


- **Exactly** "Prehistoric history shows that the five great mass extinctions the planet has so far witnessed were all connected **to radical heating or cooling of the planet,** as well as changes in the chemical cycles in the sea or on land." (DW, 2023)
- For us, the main concern is the speed of change (centuries vs. millions of years)
- Concern: Even though climate is changing thousands of times faster than historic levels, the time scales involved can seem irrelevant to human life-spans.

Climate Science Uncertainty Lingo

Confidence – subjective survey based information (e.g., collection of expert opinions)

Evaluate the type, amount, quality, and consistency of evidence → limited, medium, robust
Robust = multiple lines of independent evidence each with multiple redundancy



Confidence:

- Very high
- High
- Medium
- Low
- Very Low

This Figure is adapted from Mastrandrea et. al., 2010

Climate Science Uncertainty Lingo

Likelihood – Expresses quantified uncertainty

Term	Likelihood of the Outcome
Virtually certain	99-100% (i.e. <1% chance of not occurring)
Very likely	90-100%
Likely	66-100%
Unlikely	0-33%
Very unlikely	0-10%
Exceptionally unlikely	0-1%

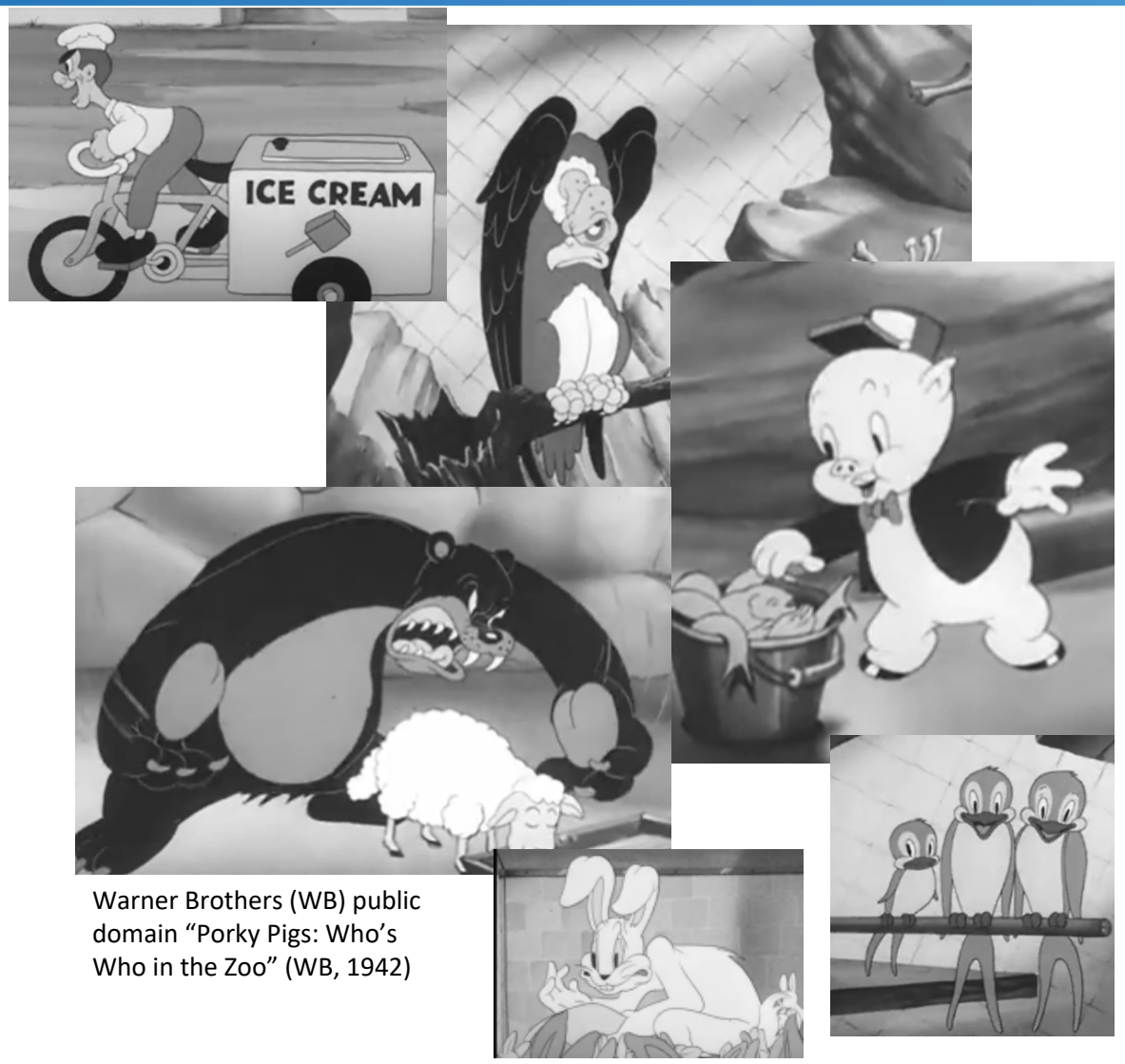
Mastrandrea et. al., 2010

Extreme Event Attribution Science

Who done it?

Answers the question whether human factors or natural variability account for an extreme event

Over 350 studies have analyzed 400 extreme events using extreme event attribution science (Clarke et. al., 2022)



Warner Brothers (WB) public domain “Porky Pigs: Who’s Who in the Zoo” (WB, 1942)

Logical Pitfalls

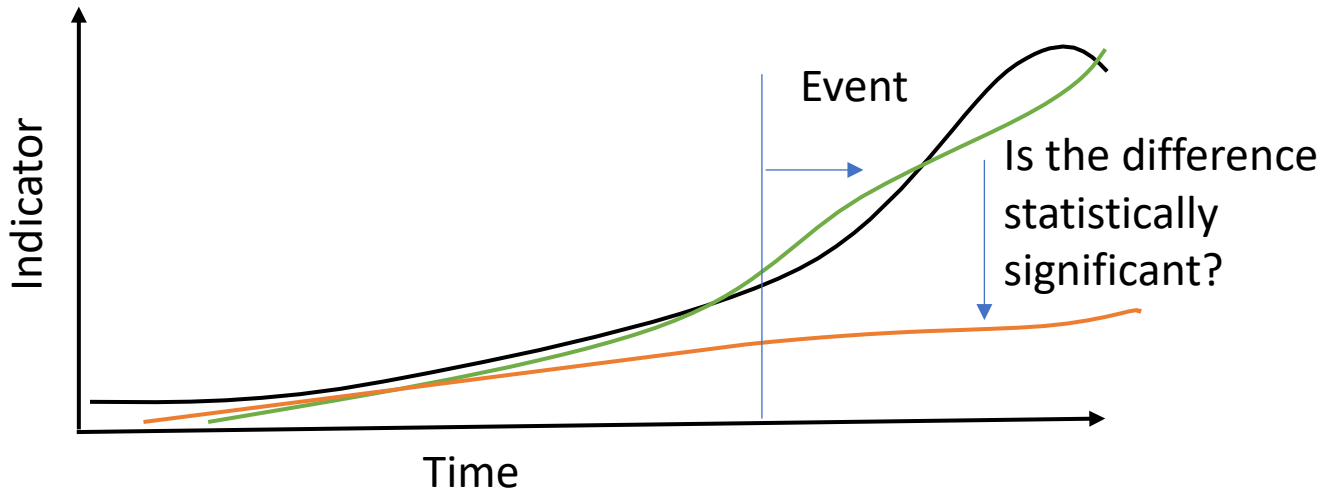
- Without a scientific study, no statement can be made for or against a hypothesis concerning extreme event attribution

1. We tend to want to think on overly detailed levels of attribution that cannot be objectively studied.
2. Conversely, even though many issues cannot be analyzed by attribution science, it does not mean there isn't a connection.

Attribution Science

World Weather Attribution (WWA) initiative, https://www.worldweatherattribution.org/

Direct attribution



Real world measured Indicator

Climate model **with** existing human factors

Climate model **without** existing human factors (i.e., preindustrial earth 1850-1900)

Invalidation

Are we sure the model isn't overly sensitive?
Are we sure the data and model are correct?

Attribution Science

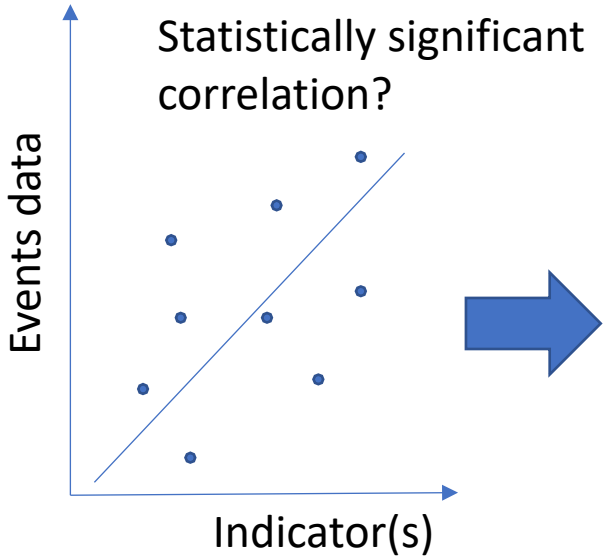
Attribution to events that are higher resolution than climate models can resolve

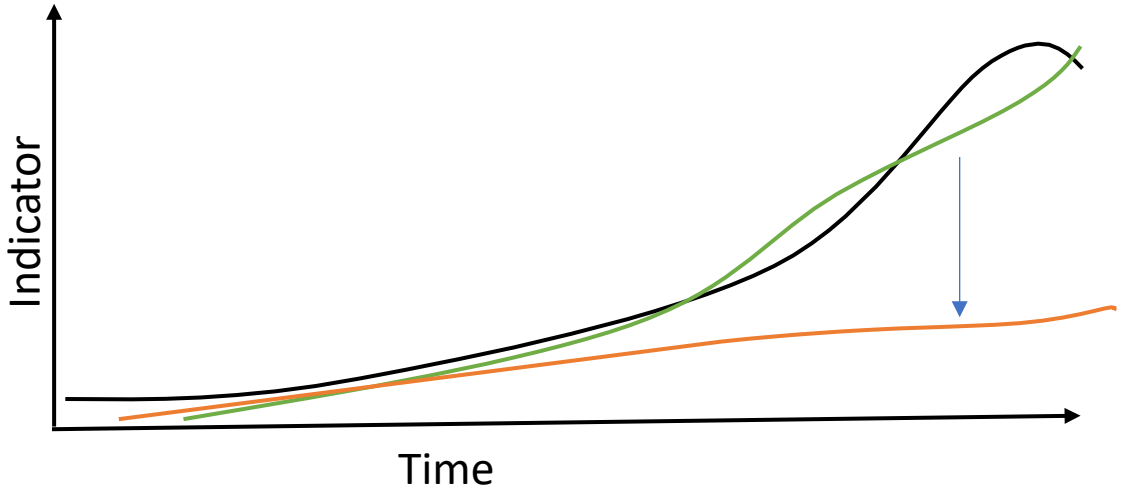
Historic event data

Recipe for an event (detectable to climate models)

For Tornadoes ~ Frequency of violent storm formation:
Climate model indicators = Wind Shear + Unstable Moist Warm Air

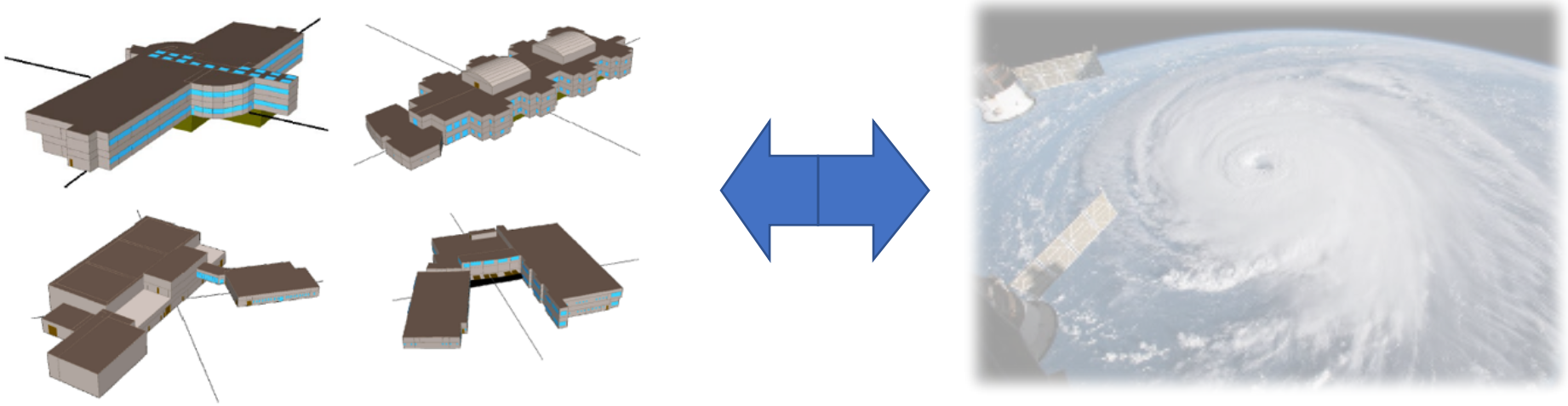
Indirect attribution





Analogy

Attribution science is similar to energy savings calculations where many uncontrolled changes are made to a building at the same time. For example, perhaps a new air handler is installed at the same time as a new chiller. Also the controls are updated and thermostat levels are adjusted to new values. The before and after clearly shows that energy is being saved but a more detailed study is needed if an energy engineer is going to separate how much of the savings belongs to the thermostat adjustment in comparison to the new air handler or controls. The energy engineer can use a building energy model to aid in separating the effects (ASHRAE Guideline 14, Standard 100). Climate scientists are doing the same thing except with earth systems and for negative impacts instead of positive impacts.



Further Reading

An overview of attribution science is available by van Oldenborgh et. al. (2021)

A detailed look at methods is available by Philip et. al. (2020)

Extreme Event Asymmetry

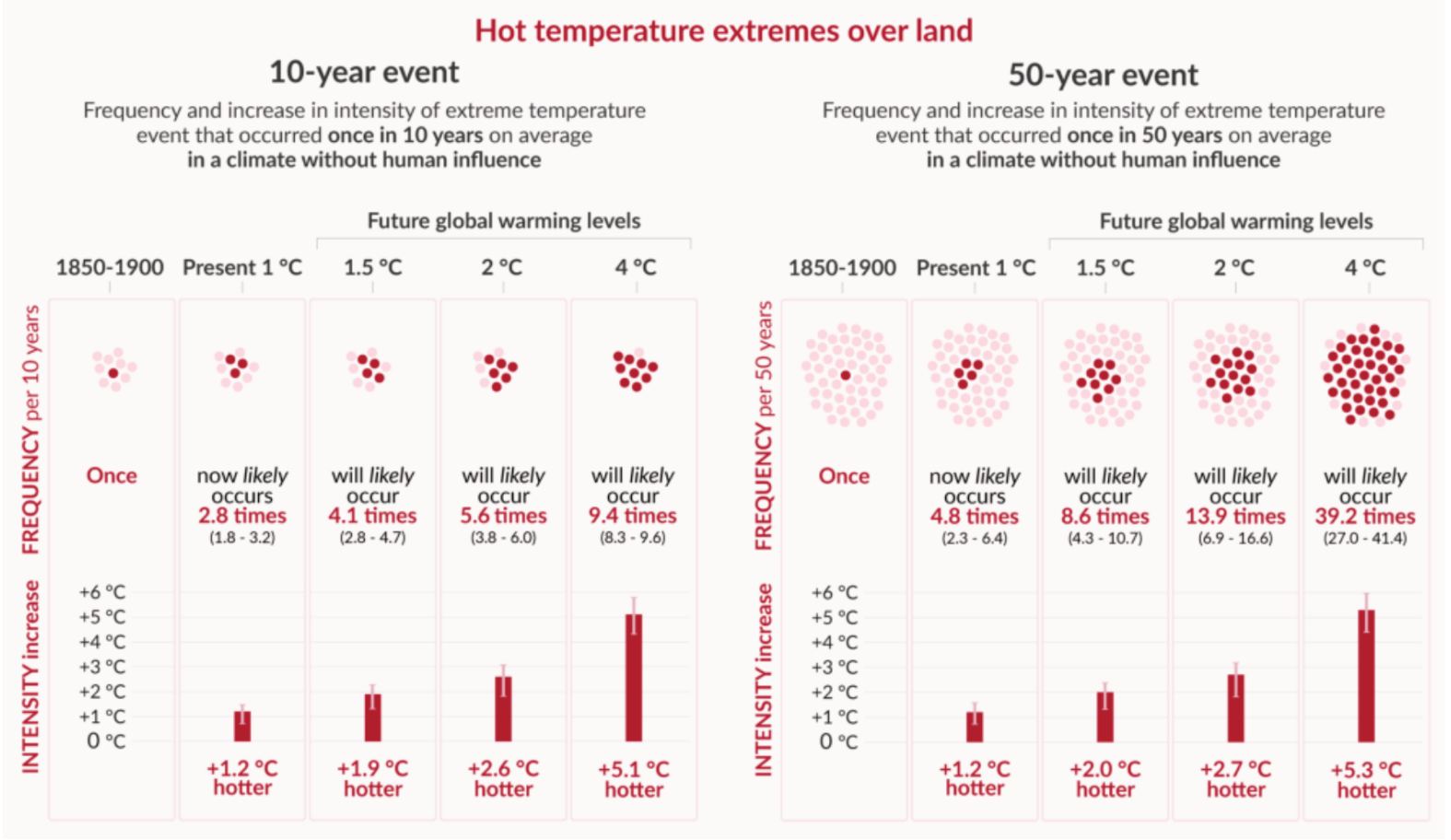
The Intergovernmental Panel on Climate Change (IPCC) physical basis report states that even relatively small global temperature changes cause statistically significant changes in extremes on the global scale for large regions (high confidence) (IPCC, 2021 Chapter 11)

- Temperature extremes (very likely)
- Heavy Precipitation (likely)
- Worsening of droughts (high confidence)
- Tropical cyclones (medium confidence)

Note: No event type has reached “virtually certain” likelihood and some are still based on confidence instead of likelihood.

Heat Waves

Very likely: The first attribution science study “We estimate that it is very likely that human influence has at least doubled the risk of heatwaves exceeding this threshold magnitude.” (Stott, Stone, and Allen, 2004)



(IPCC,2021 Technical Summary Figure SPM.6)

How great will the consequences be?

To the north

- Higher rates of change for temperature
- Population not adapted to extreme heat

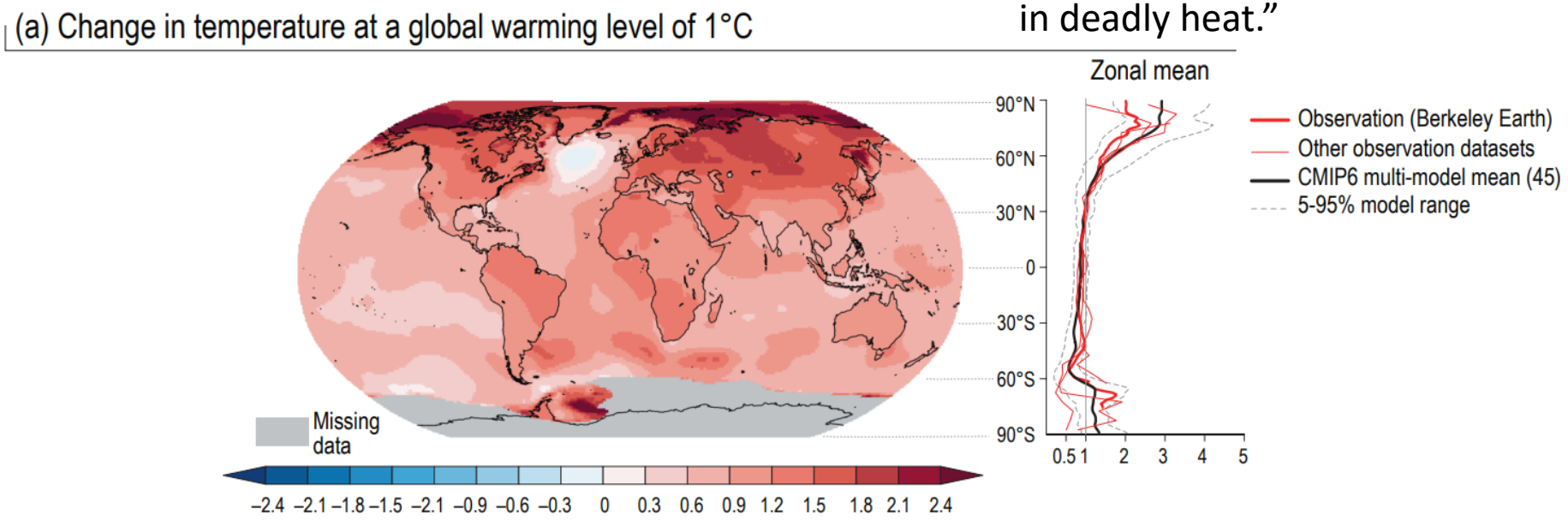
Nearer the equator

- Lower rates of change in temperature
- Population adapted to extreme heat
- Emergence of deadly ambient conditions (Raymond et. al. 2020)

If Humanity prepares and mitigates climate change: low-consequences → its pretty easy to survive in a controlled HVAC environment

Do we want HVAC to be life support??

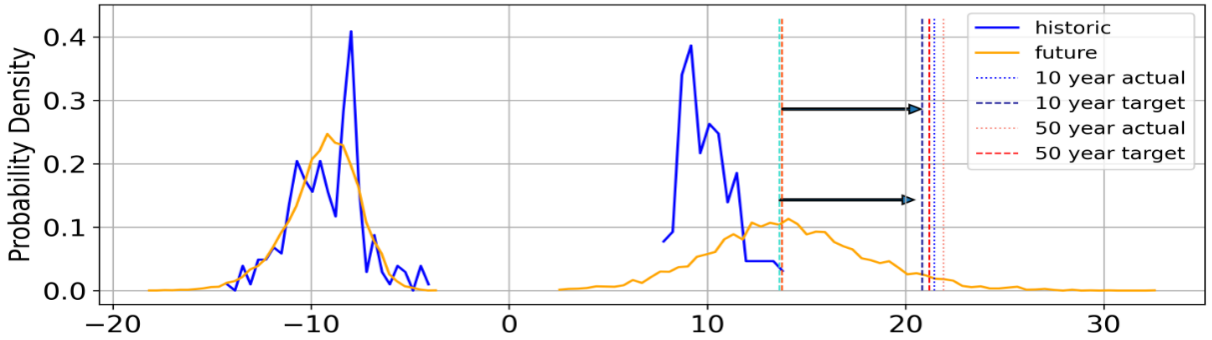
If Humanity does not prepare or mitigate climate change: high-consequences → Future headlines could be:
"City X loses power for several days and 300,000 people perish in deadly heat."



(Seneviratne et. al., 2021 – Technical Summary Figure TS.3)

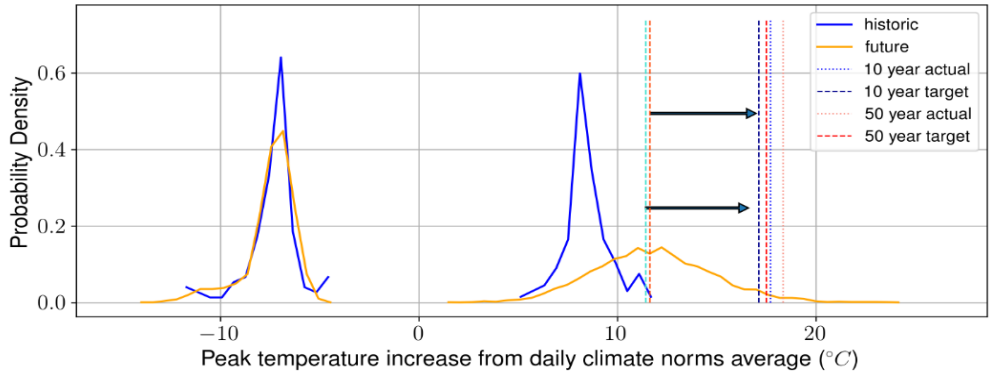
North-South Differences

42.2626° N



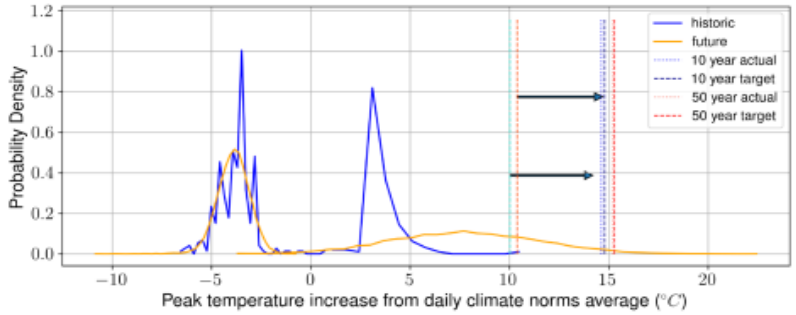
Worcester, MA
(Villa, 2023(2))

29.7499° N



Houston, TX
(Villa, 2023 (3))

21.6090° N



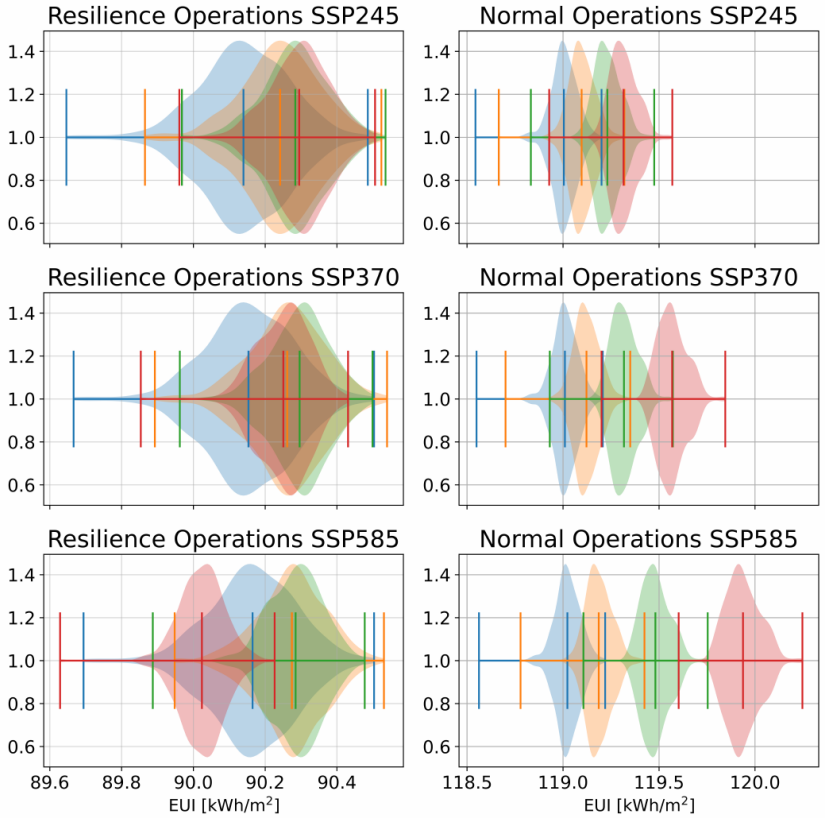
Hau'ula, HI (2080)
(Villa et. al., 2023 (1))

An asymmetric future for extreme heat!

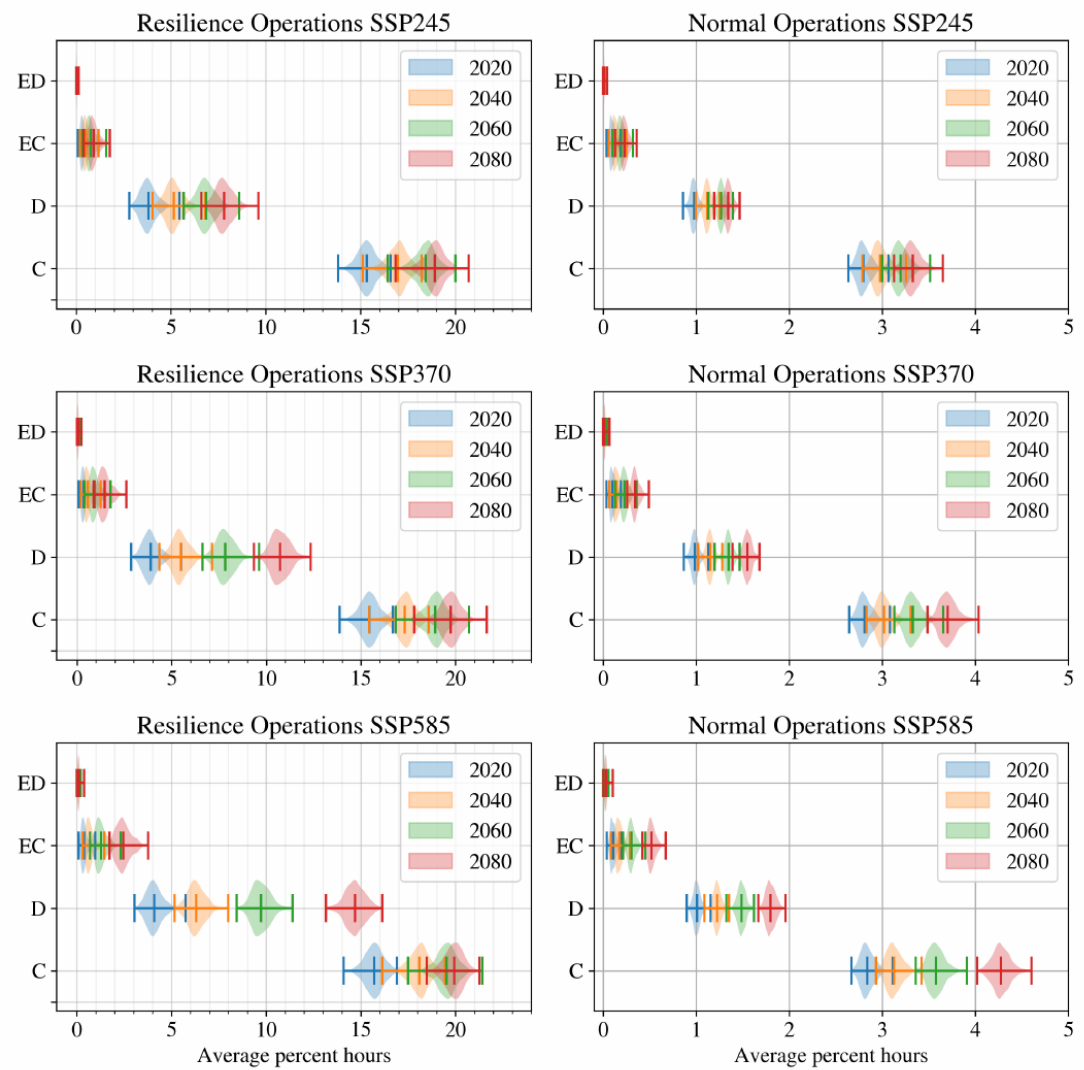
SSP5-8.5
95% IPCC CI, 2075
July

The Built Environment: Hau'ula Hawaii study

Changes in future temperature extremes are significant to the built environment but not consequential for a resilience center design in Hau'ula Hawaii which has adequate preparation through a microgrid (Villa et. al., 2023 (1))



ED = Extreme danger
EC = Extreme Caution
D = Danger
C = Caution



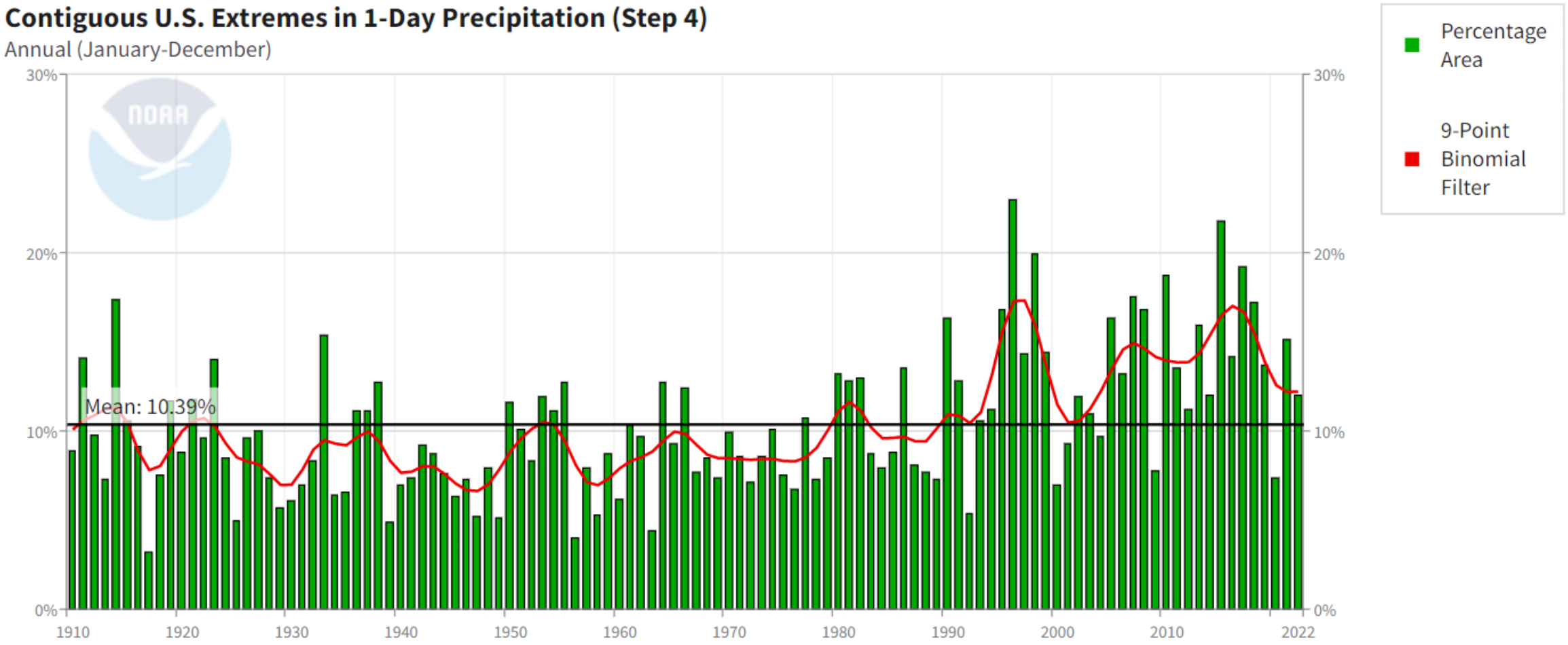
Extreme Precipitation

Frequency and Intensity increase on a continental scale is ***likely*** *(i.e., 66-100%)* for North America, Europe, and Asia

Human influence, in particular greenhouse gas emissions, is ***likely*** to be the primary cause

IPCC The Physical Basis Chapter 11 section—Heavy Precipitation and Pluvial Floods (Seneviratne et al, 2021)

Extreme Precipitation



National Oceanic and Atmospheric Association U.S. Climate Extremes (NOAA, 2023)

Hawaii – Drought with more extreme rainfall

PETTY OFFICER 3RD CLASS BRANDON VERDURA/U.S. COAST GUARD VIA ASSOCIATED PRESS

Flooding along Kauai's Hanalei Bay, April 15, 2018 after 24-hour record of 49.69'' (126.21 cm)

Can extreme event attribution science show this is a man-made problem?

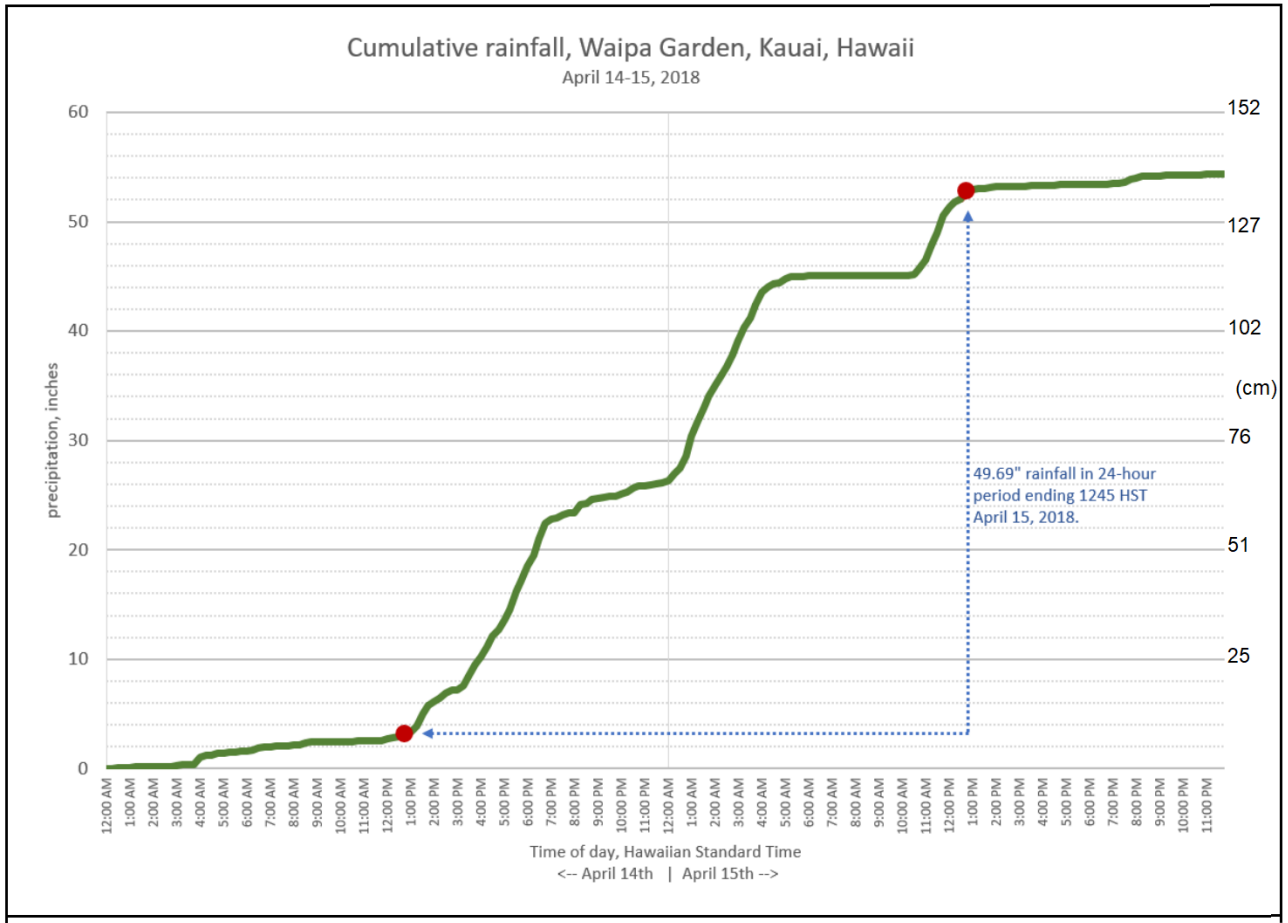


Fig. 2. Rainfall accumulation at Waipā Garden during 14-15 April 2018. The observations bracketing the 24-hour period in question are noted in red. Data courtesy of the Waipā Foundation.

NATIONAL CLIMATE EXTREMES COMMITTEE (NCEC, 2018)

Drought/Rainfall changes due to Human induced climate change: *Inconclusive*

Heavy rainfall is happening less but is more intense. Number of consecutive dry days is increasing in dry regions but decreasing in already wet ones. (Kruk et. al., 2015)

Hawaii is getting dryer, is it due to climate change? Overall, Multi-linear regression and pattern correlation coefficients results give weak and inconclusive evidence for detection of anthropogenic signals in the observed rainfall trends. (Frazier et. al., 2018)

It is perhaps surprising to see that atmospheric fluctuations alone, unconstrained by boundary forcing changes, could yield centennial-scale Hawaiian rainfall changes on the order of 20%. It is thus entirely possible to reconcile the observed severity of the recent Hawaiian decadal rainfall deficits with unforced internal variability alone. (Eischeid et. al., 2022)

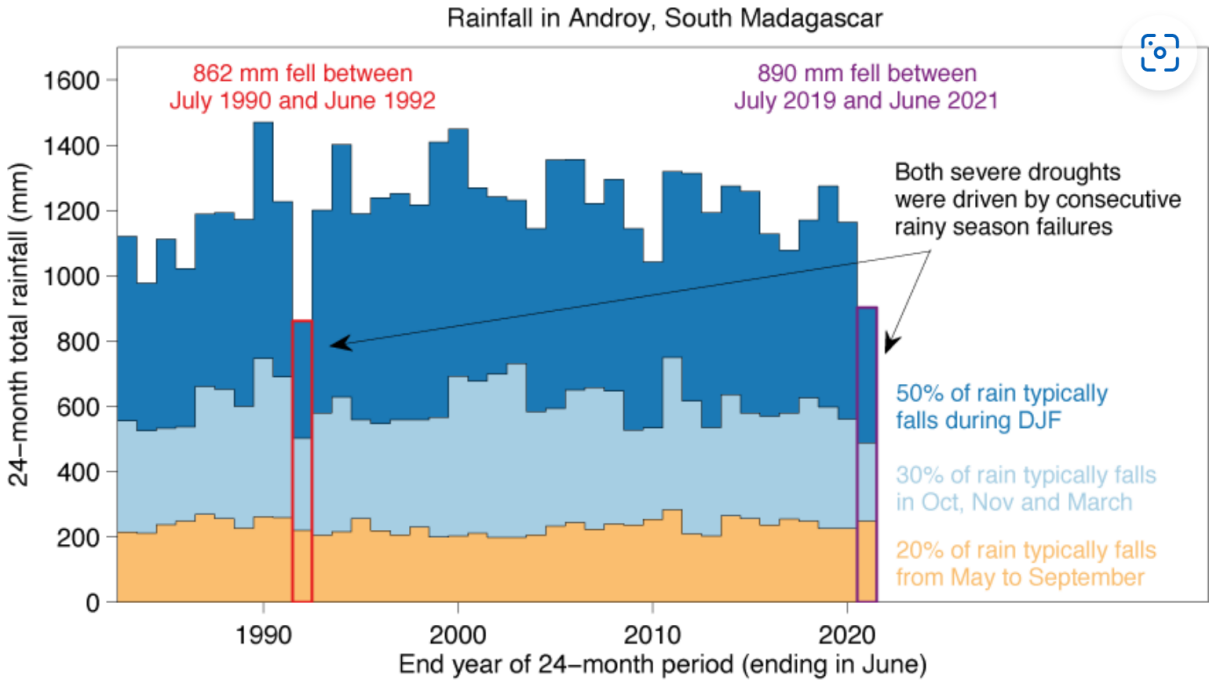
Inconclusive =

1. Correlation does not equal causation!

2. Failure to attribute does not mean there is no connection

Drought due to climate change: NO

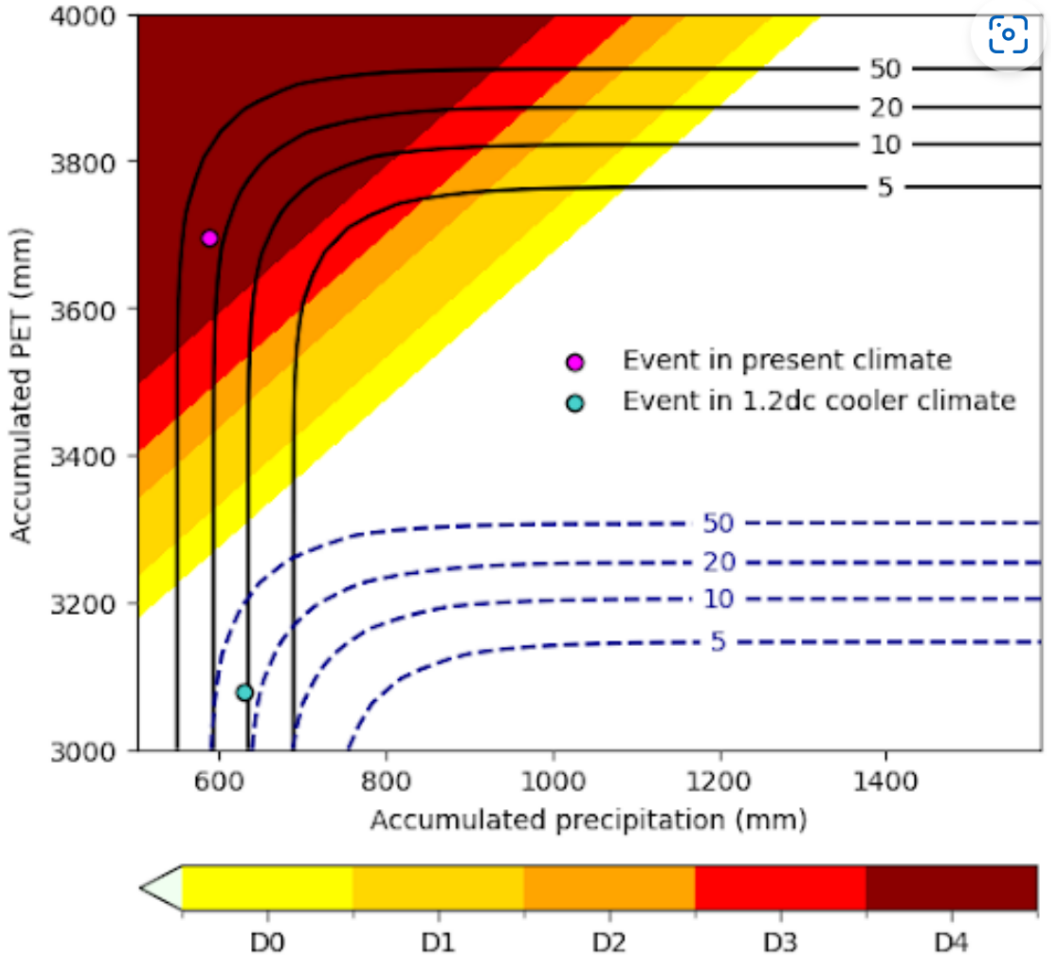
"Factors other than climate change are the main drivers of recent food insecurity in Southern Madegascar" (WWA, 2021)



USGS (2023)

Drought due to climate change: Yes

"Human-induced climate change increased drought severity in Horn of Africa" (WWA, 2023)



Engineering Resilience to an Extreme Future

Bullet proof

?

Sustainable

Tornado proof

The TIV (Tornado Intercept Vehicle) built from a Ford F-450 (2006) Creative commons Wikimedia Creative Commons Attribution 2.0 Generic license.

Flood proof

License: Creative Commons Attribution 2.0 Generic

Idealism: “Future proofing”

Reality: Choose carefully: Balance efficiency, equity, and risk with limited resources

Conclusion

- There is an overwhelming amount of evidence showing extreme weather events are increasing in frequency, intensity, and duration.
- Attribution Science seeks to make this abundantly clear
  - Extreme weather phenomena have been shown to be:
    - Attributable to climate change
    - Strengthened by climate change
    - Not due to climate change
    - Inconclusive – neither climate change nor natural variation explain a change in extreme events well
  - An authentic record of “Yes”, “No”, and “Inconclusive” exists for hundreds of studies
- Much work is needed in this area to extend climate-based results to the built environment – especially for extreme heat where results are *very likely* (90-100%)

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Questions

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