



Oct 5: Climate Extremes & Effects

Foci of the Topic

- What are climate extremes?
- How are climate extremes defined and quantified?
- What are the attributes of climate extremes?
- What are the major climate extreme types?
- In class exercises

Reading

- 1) U.S. Climate Extremes Index (CEI): <https://www.ncei.noaa.gov/access/monitoring/cei/>
- 2) Stephenson, D. B. (2008). Definition, diagnosis, and origin of extreme weather and climate events. *Climate Extremes and Society*, 9780521870, 11–23.

Reference

Grant, L., Vanderkelen, I., Gudmundsson, L., Fischer, E., Seneviratne, S. I., & Thiery, W. (2025). Global emergence of unprecedented lifetime exposure to climate extremes. *Nature*, 641(8062), 374-379.



What are climate extremes?

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D. Stephenson

1.2 Definition of extreme events

Extreme events are generally easy to recognize but difficult to define. This is due to several reasons. First, there is no unique definition for what is meant by the word “extreme”: several definitions are in common use. Second, the concept of “extremeness” is relative and so strongly depends on context. Third, the words “severe,” “rare,” “extreme,” and “high-impact” are often used interchangeably.

IPCC (2001): “simple extreme” events to be “individual local weather variables exceeding critical levels on a continuous scale.”

Stephenson, D. B. (2008). *Definition, diagnosis, and origin of extreme weather and climate events. Climate Extremes and Society* 9780521870, 11–23.



What are climate extremes?

Climate extremes: unusually severe or rare weather or climate conditions that differ greatly from the average pattern in a given place (location specific) and time (long term changes). Common ones include:

- **Temperature:** heatwaves, cold snaps (unusually cold periods), Dzuds, etc.
- **Precipitation:** heavy rainfall/snowfall, floods, or prolonged droughts, etc.
- **Storm-related extremes:** hurricanes, typhoons, blizzards, severe thunderstorms, etc.
- **Other:** wildfires, storm surges

Or a combination of multiple events!



- **Tropical cyclones and hurricanes** (e.g., Typhoon Tracy, Hurricane Hugo, etc.). These storms are the major source of global insured catastrophe loss after earthquakes.
- **Extratropical cyclones** (e.g., the “Perfect Storm” that hit the northeast coast of the United States, October 28–30, 1991). These storms are generally referred to as “windstorms” by the reinsurance industry.
- **Convective phenomena** such as tornadoes, waterspouts, and severe thunderstorms. These phenomena can lead to extreme local wind speeds and precipitation amounts on horizontal scales of up to about 10 km. Deep convection often leads to precipitation in the form of hail, which can be very damaging to crops, cars, and property.

- **Mesoscale phenomena** such as polar lows, mesoscale convective systems, and sting jets. These features can lead to extreme wind speeds and precipitation amounts on horizontal scales from 100 to 1,000 km.
- **Floods** of rivers, lakes, coasts, etc., due to severe weather conditions; for example, river floods caused by intense precipitation over a short period (e.g., flash floods) and persistent/recurrent precipitation over many days (e.g., wintertime floods in northern Europe), river floods caused by rapid snowmelt due to a sudden warm spell, or coastal floods caused by high sea levels due to wind-related storm surges.
- **Drought.** Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period. Simple definitions relate actual precipitation departures to average amounts on monthly, seasonal, or annual timescales. However, meteorological



drought also depends on other quantities such as evaporation that depend on variables such as temperature.

- **Heat waves.** Periods of exceptionally warm temperatures can have profound impacts on human health and agriculture. Duration is a key component determining the impact.
- **Cold waves/spells** (e.g., extremely cold days or a succession of frost days with minimum temperatures below 0 °C).
- **Fog.** Extremely low visibility has major impacts on various sectors such as aviation and road transport.



Extreme events have attributes such as:

- rate (probability per unit time) of occurrence frequency
- magnitude (intensity) magnitude
- temporal duration and timing duration/timing
- spatial scale (footprint) extent
- multivariate dependencies



How are climate extremes identified?

1. Threshold-based definitions

Approach: An event is considered “extreme” when a climate variable exceeds a certain threshold (upper or lower percentile) of its historical distribution.

Common thresholds:

Above the **90th or 95th percentile** → hot or wet extremes

Below the **5th or 10th percentile** → cold or dry extremes

Example:

Hot day: daily maximum temperature > 90th percentile of historical daily maxima

Heavy precipitation event: daily rainfall > 95th percentile

An event is typically considered *extreme* if it falls in the **top or bottom 10%** of the historical range (for example, the hottest 10% of days or the wettest 10% of months over a long-term record).



2. Indices from ETCCDI

The **ETCCDI** has standardized a set of 27 indices widely used to compare and monitor extremes globally.

Examples:

Category	Indicator	Description
Temperature	TX90p	% of days when daily max temperature > 90th percentile
	TN10p	% of days when daily min temperature < 10th percentile
	DTR	Daily temperature range
Precipitation	R95p	Total precipitation from days > 95th percentile
	RX1day	Maximum 1-day precipitation
	CDD	Consecutive dry days (precip < 1 mm)

- **Reference:** Alexander et al. (2006), *Journal of Geophysical Research*; Klein Tank et al. (2009), *Climatic Change*.



Heatwaves



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Heatwave

● NATURAL HAZARDS

A heatwave can be defined as a period where local excess heat accumulates over a sequence of unusually hot days and nights.

Heatwaves amplify many risks, such as health-related or economic risks, including increased human mortality, drought and water quality, wildfire and smoke, power shortages and agricultural losses.



Heatwaves (<https://wmo.int/topics/heatwave>)

Overview

Heatwaves consist of period of abnormally hot weather that can last from a few days to months where the maximum and minimum temperatures are unusually high to a location. The minimum temperature is as important as the maximum temperature as cooler nights allow the body to recover and if the nights are unusually hot, higher temperatures will be reached earlier in the day and last for longer.

Heatwaves have spread rapidly into new regions of the globe and occurring at unseasonable times of the year. The [IPCC](#) states that with further global warming, we can expect an **increase in the intensity, frequency and duration of heatwaves**.

Multiple risks interact with heatwaves such as **droughts, fire weather, flash flooding and air pollution** which have compounding impacts for people and nature.

70 days

In 2022, a heatwave in China lasted over 70 days, making it the country's worst on record.

30x

Devastating heatwaves in India and Pakistan in 2022 were made 30 times more likely due to climate change.

40.3 °C

In 2022, heatwaves across the UK broke the previous national record of 38.7°C.

UK Met Office

220 million

In 2018, more than 220 million vulnerable people were exposed to heatwaves.

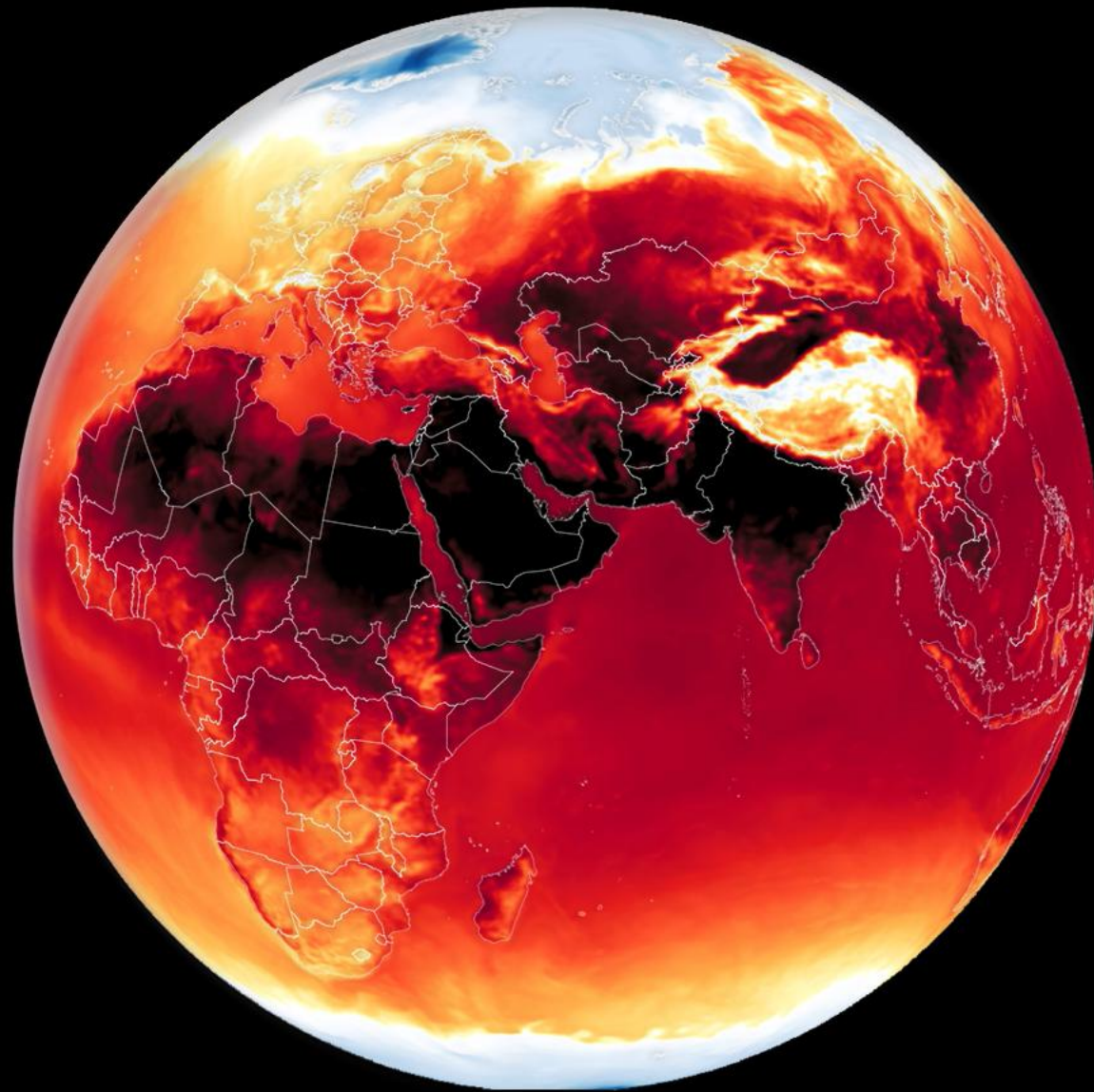
65+

Heat is dangerous for vulnerable people, the elderly and infirm, pregnant women, infants, outdoor workers and athletes.

5°C to 10°C

Urban areas can be up to 5°C to 10°C warmer than surrounding areas, increasing the heatwave intensity and associated risks.





June 15
Air Temperature (°C)

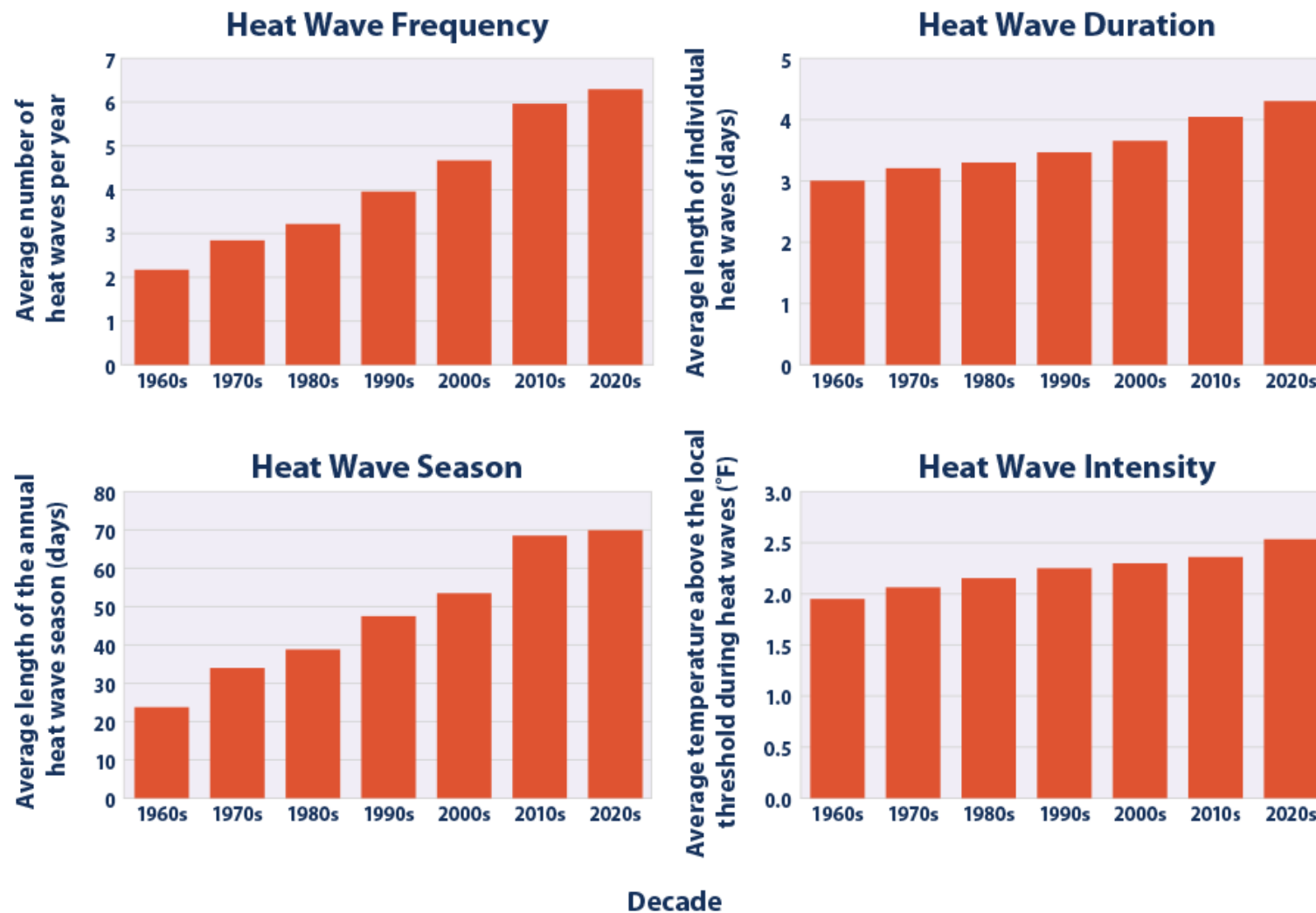




Climate Change Indicators: Heat Waves

(<https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves>)

Heat Wave Characteristics in the United States by Decade, 1961–2023

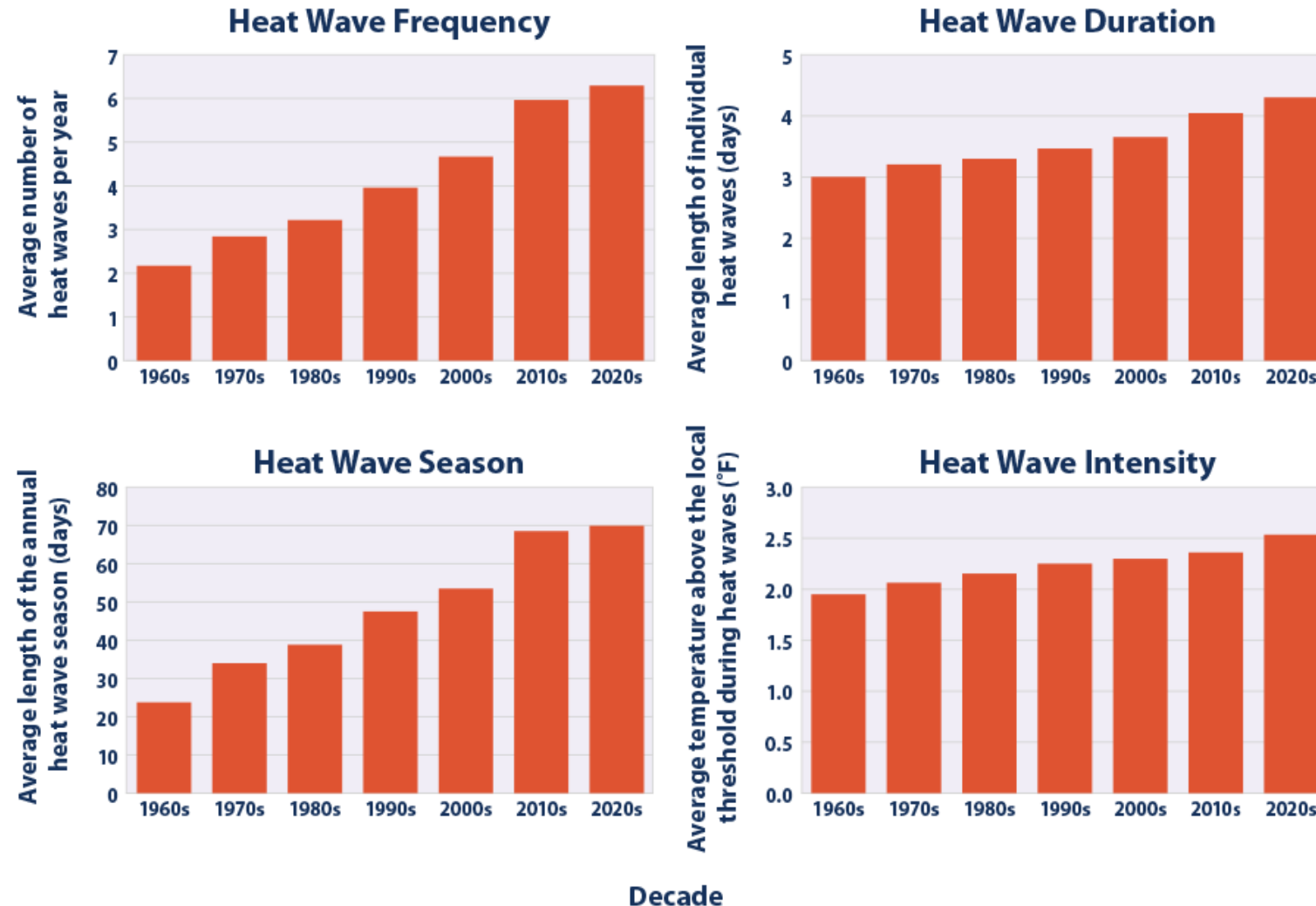




Climate Change Indicators: Heat Waves

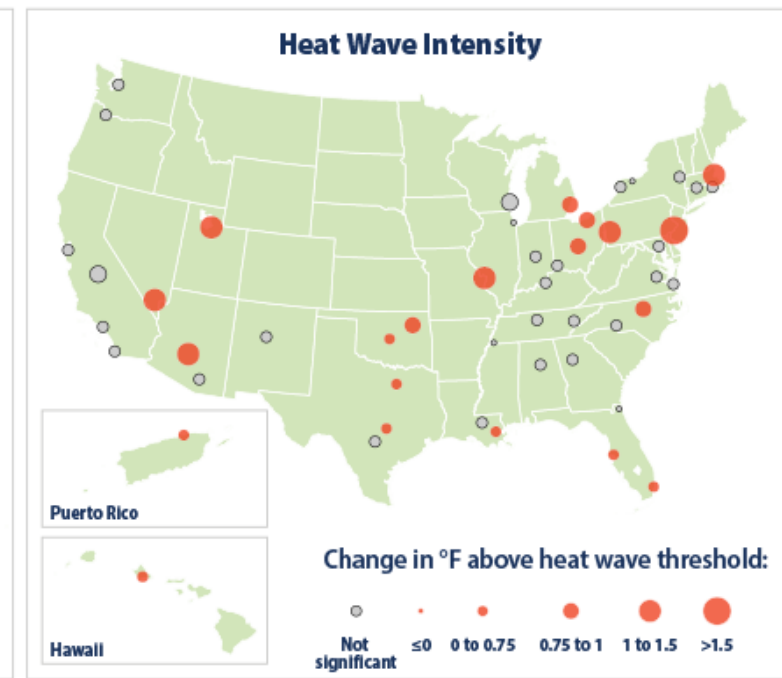
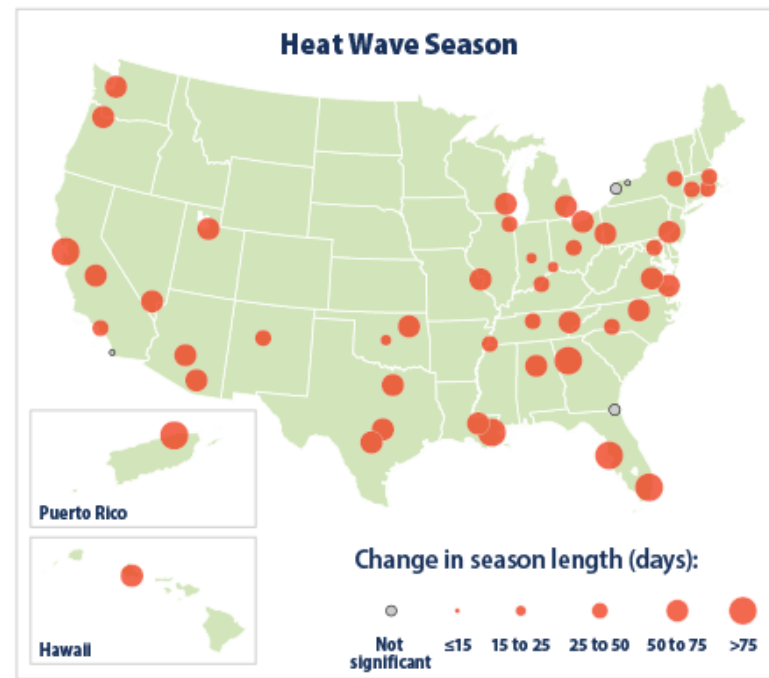
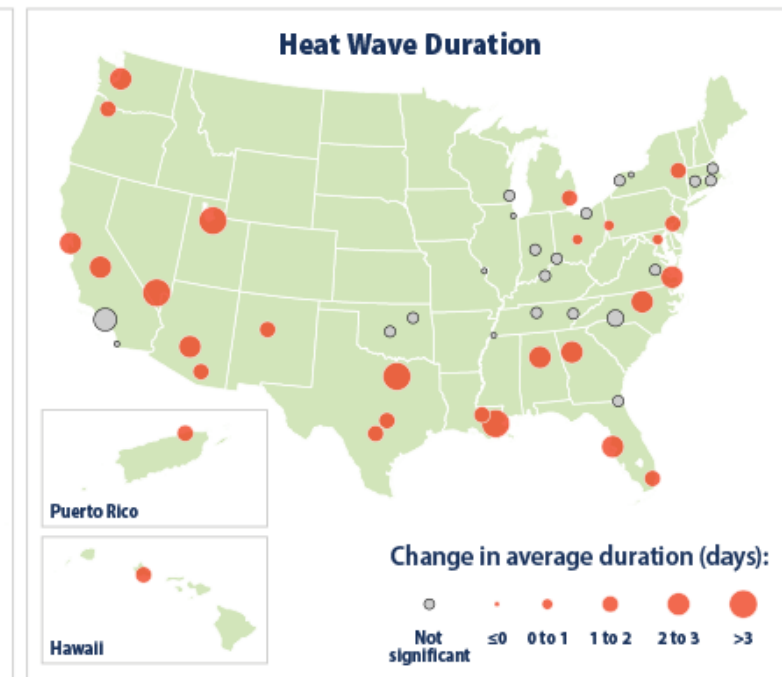
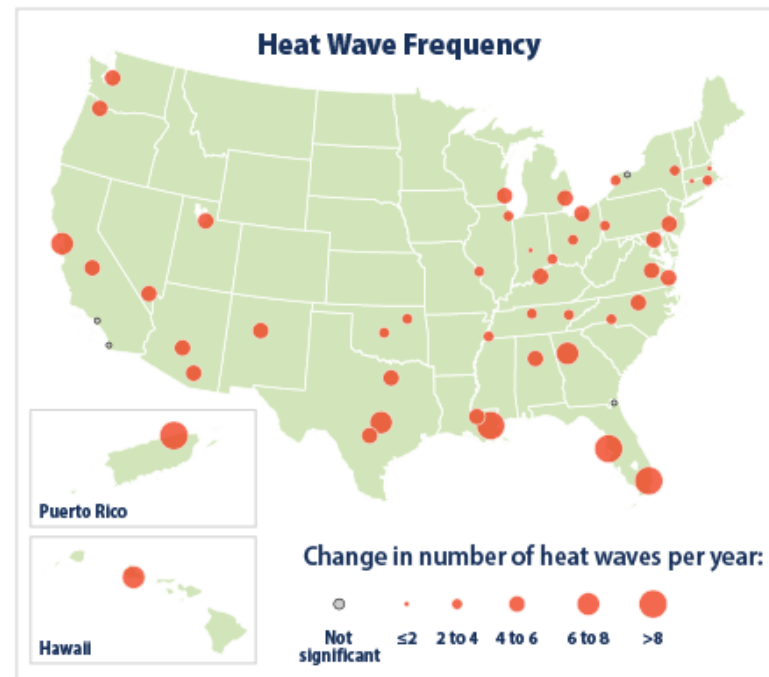
(<https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves>)

Heat Wave Characteristics in the United States by Decade, 1961–2023



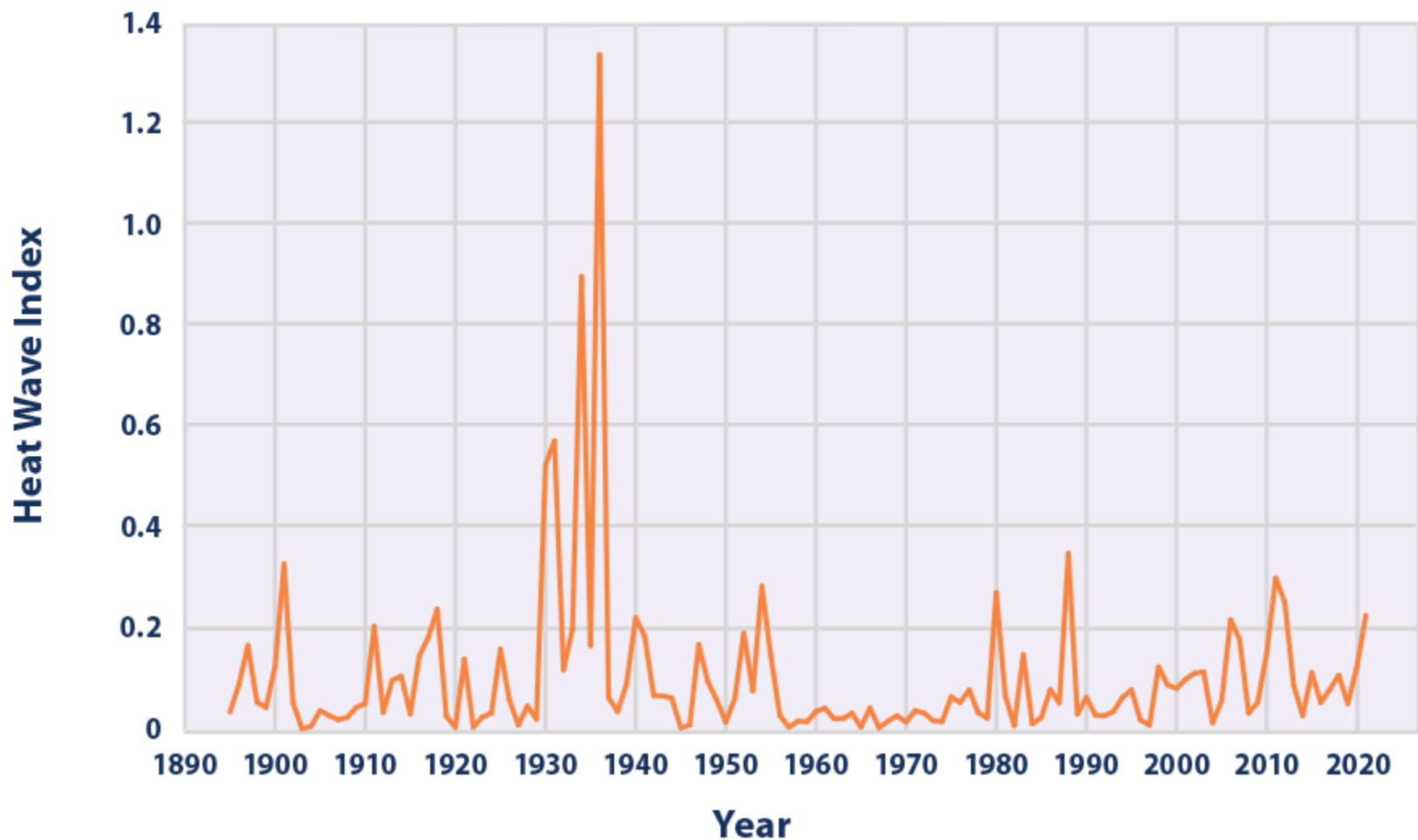


Heat Wave Characteristics in 50 Large U.S. Cities, 1961–2023





U.S. Heat Wave Index for 1895-2021 in the contiguous 48 states. An index value of 0.2 could mean that 20% of the country experienced one heat wave, 10% of the country experienced two heat waves, or some other combination of frequency and area.





Photos: 8/1/2003, Yosemite, CA



River Floods

Significant trends in peak streamflow have been observed in some regions over the past decades

From May through September of 1993, major and/or record flooding occurred across North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, and Illinois. Fifty flood deaths occurred, and damages approached \$15 billion. Hundreds of levees failed along the Mississippi and Missouri Rivers.





Photos: Toledo, 4/7/2003





Photos: Evening downpour floods parts of East Lansing, 7/10/2024

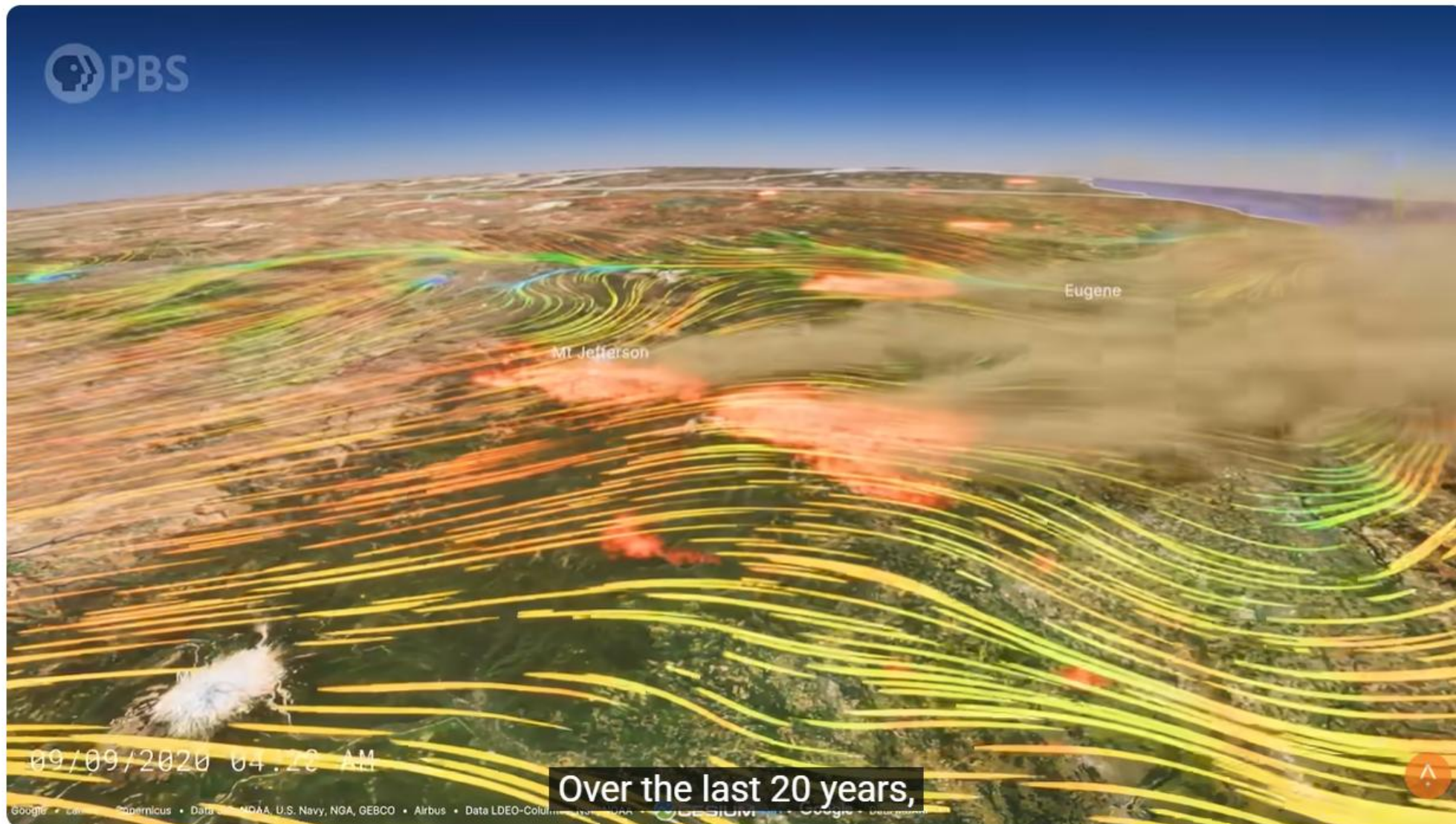
(<https://www.youtube.com/watch?v=A6jknOimaVA>)





Photos: LA Firestorm in 2025

(https://www.youtube.com/watch?v=PiX9t_wovEY) – 5:00 to 12:00



Weather and Climate Extreme Events in a Changing Climate

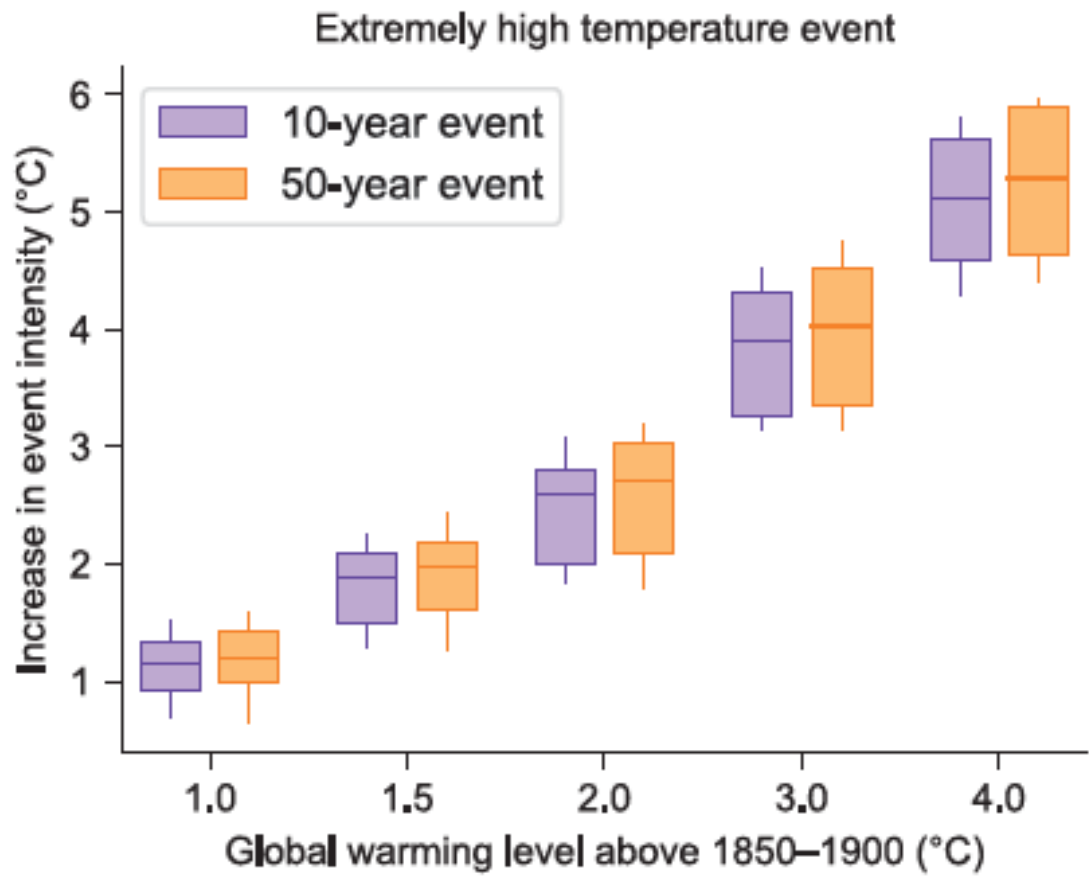


Figure 11.12 | Projected changes in the intensity of extreme temperature events under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. Extreme temperature events are defined as the

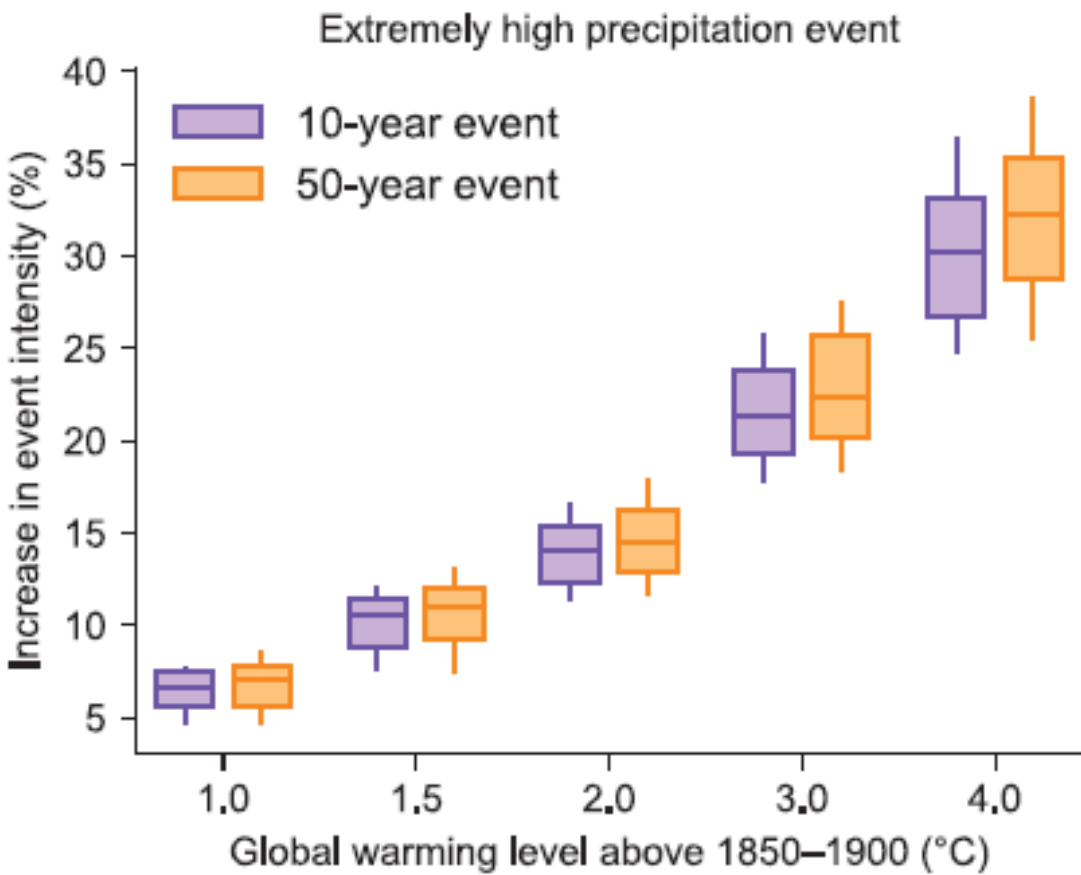


Figure 11.15 | Projected changes in the intensity of extreme precipitation events under 1°C, 1.5°C, 2°C, 3°C, and 4°C global warming levels relative to the 1850–1900 baseline. Extreme precipitation events are defined as the annual

<https://www.ncei.noaa.gov/access/monitoring/cei/>

- 1) Each group will select a **region, time period, and indicator.**
- 2) Examine the plots and tables, and report **three major findings.**
- 3) Enter your findings in the **table on the right.**

[illegible]



Oct 7 & 12: Carbon Cycle and Climate Change

- Q&A for Quiz 2

Foci of the Day

- Terminology and basics
- Recap: Greenhouse Gas Effects and Changes
- Global carbon budget

Reading

[Executive summary \(Pages 968-969\) of](#)

Friedlingstein, P., O'sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Landschützer, P., ... & Zeng, J. (2024). Global carbon budget 2024. *Earth System Science Data Discussions*, 2024, 1-133.