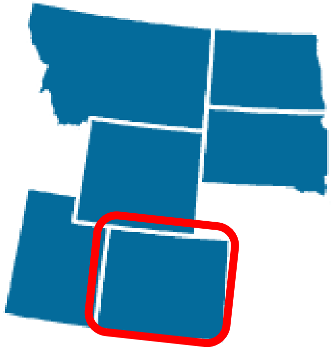
NOT AFFILIATED WITH NWS/NOAA/NHC – CISA ISD Meteorological Engagement Effort

REGION 8



Extreme Weather Events and Impacts – Colorado Focus

Climate Resiliency

08/19/2022

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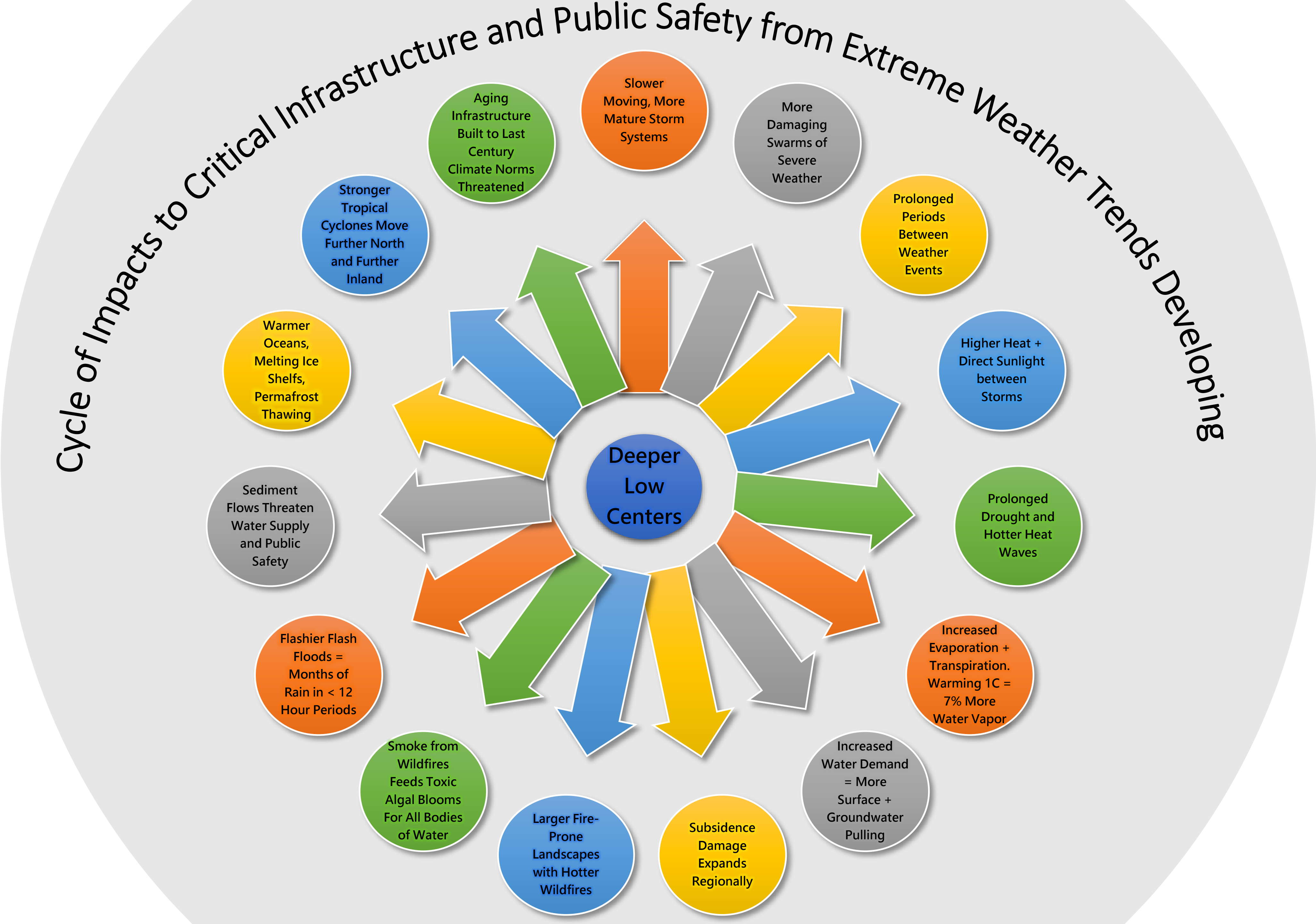


Cycle of Impacts to Critical Infrastructure and Public Safety from Extreme Weather Trends Developing
Deeper Low Centers
Slower Moving, More Mature Storm Systems
More Damaging Swarms of Severe Weather
Prolonged Periods Between Weather Events
Higher Heat + Direct Sunlight between Storms
Prolonged Drought and Hotter Heat Waves
Increased Evaporation + Transpiration. Warming 1C = 7% More Water Vapor
Increased Water Demand = More Surface + Groundwater Pulling
Subsidence Damage Expands Regionally
Larger Fire-Prone Landscapes with Hotter Wildfires
Smoke from Wildfires Feeds Toxic Algal Blooms For All Bodies of Water
Flashier Flash Floods = Months of Rain in < 12 Hour Periods
Sediment Flows Threaten Water Supply and Public Safety
Warmer Oceans, Melting Ice Shelfs, Permafrost Thawing
Stronger Tropical Cyclones Move Further North and Further Inland
Aging Infrastructure Built to Last Century Climate Norms Threatened

Billion-Dollar Weather/Climate Disasters

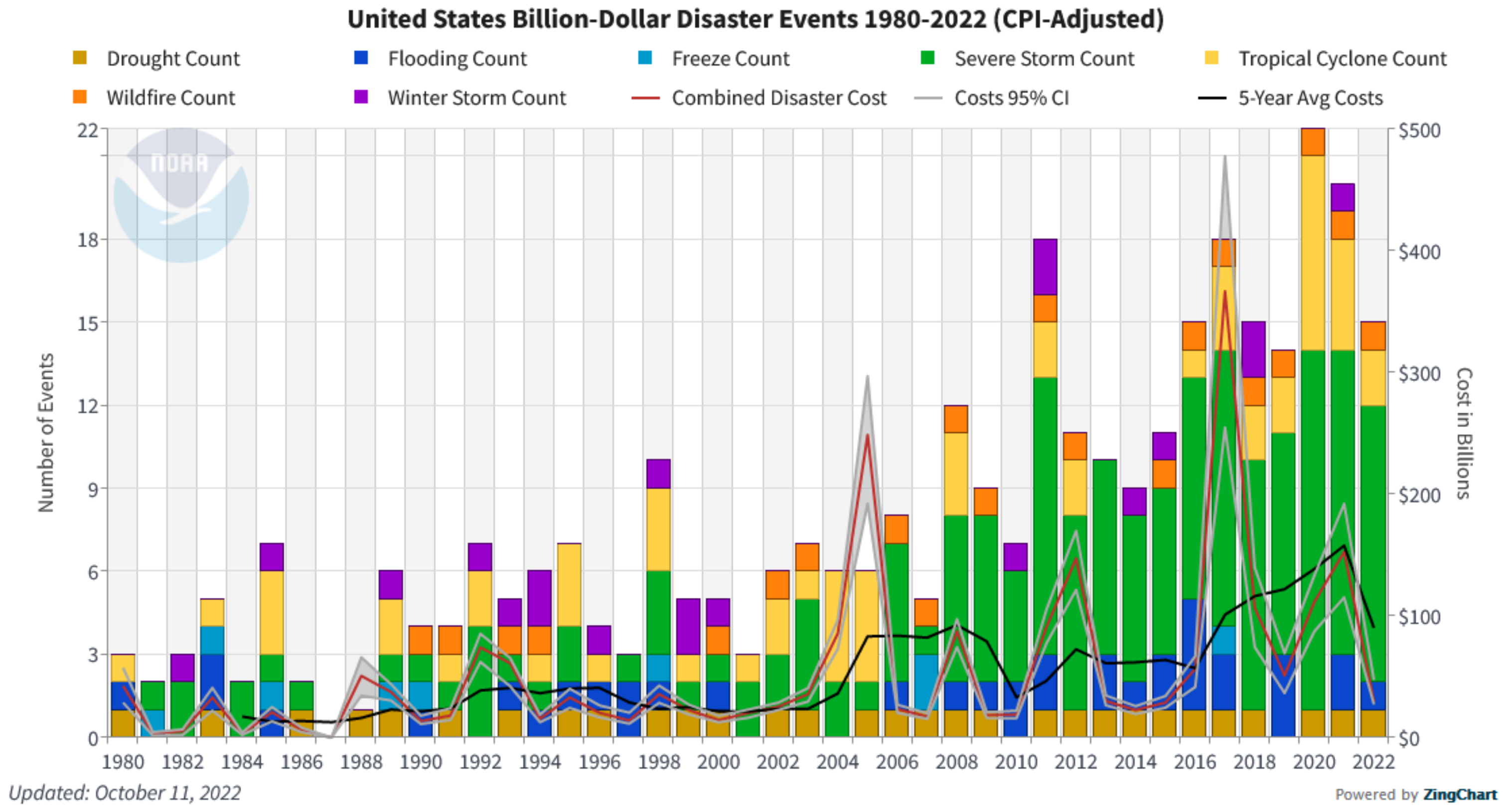
For the July-September period, the average contiguous U.S. temperature was 73.0°F, 2.8°F above average, ranking as warmest on record for this 3-month period.

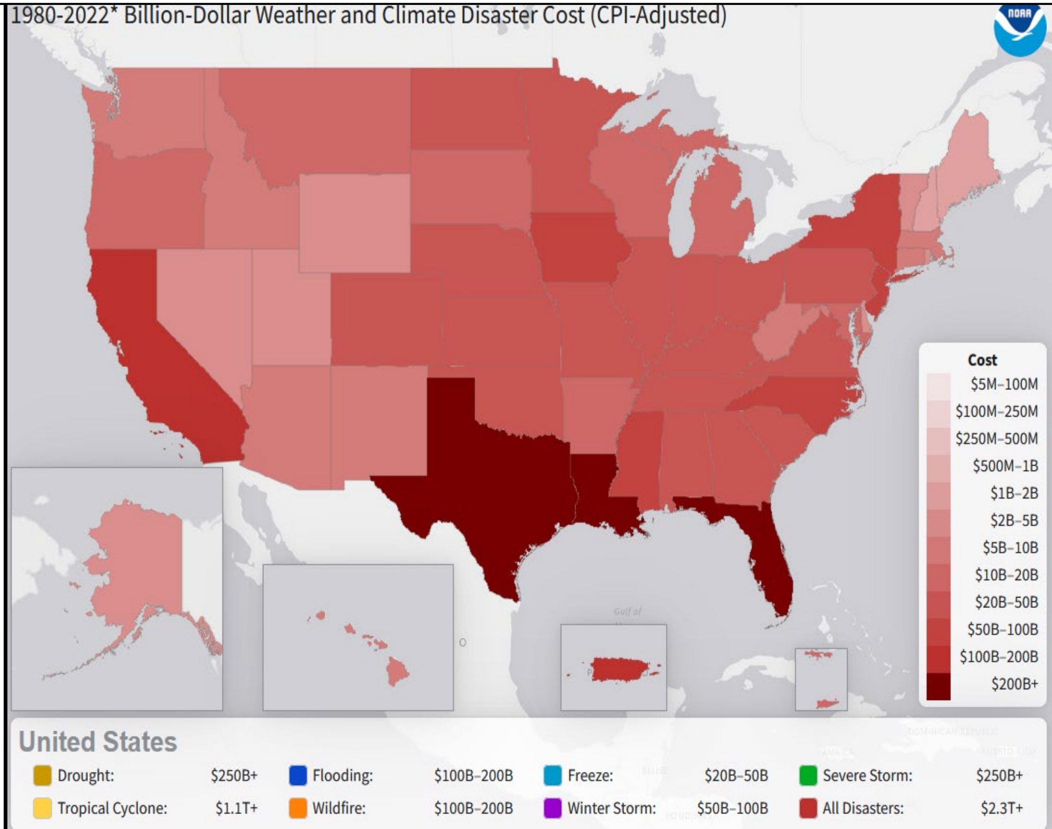
- Temperatures were above average across most of the contiguous U.S. with record warmth blanketing much of the West. California, Nevada, Oregon, Washington, Idaho, Montana, Wyoming, Colorado and Utah each had their warmest July-September period on record.
- Colorado was extremely warm in September as Alamosa averaged 59.9°F to rank warmest, while Denver ranked 3rd. Other locations such as Grand Junction, Pueblo, and Colorado Springs, also ranked in the top 5.
- Colorado has reported their most costly weather events from 1980-2022 have been Severe Storms at 32 events causing $20-50 billion in damages, followed by drought at 15 events causing $5-10 billion in damages, then Wildfires at 12 events causing $5-10 billion in damages. Flooding ranks above freeze and winter storm events by 1 additional costly event.

Billion-dollar events to affect the United States from 1980 to 2022 (CPI-Adjusted)*

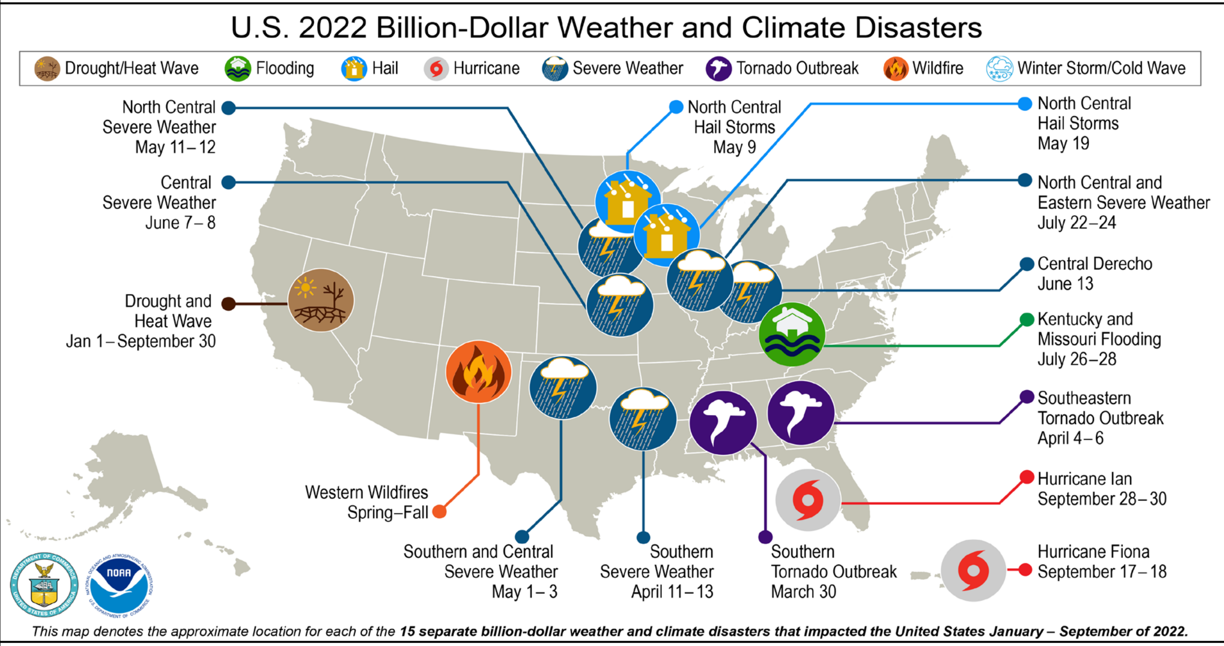
Disaster Type	Events	Events/ Year	Percent Frequency	Total Costs	Percent of Total Costs	Cost/ Event	Cost/ Year	Deaths	Deaths/ Year
Drought	30	0.7	8.9%	$309.4B CI	13.5%	$10.3B	$7.2B	4,256[†]	99[†]
Flooding	37	0.9	10.9%	$174.9B CI	7.6%	$4.7B	$4.1B	676	16
Freeze	9	0.2	2.7%	$34.4B CI	1.5%	$3.8B	$0.8B	162	4
Severe Storm	162	3.8	47.9%	$374.1B CI	16.3%	$2.3B	$8.7B	1,982	46
Tropical Cyclone	59	1.4	17.5%	$1,194.4B[‡] CI	52.0%[‡]	$21.0B[‡]	$27.8B[‡]	6,864	160
Wildfire	21	0.5	6.2%	$126.9B[‡] CI	5.5%[‡]	$6.3B[‡]	$3.0B[‡]	435	10
Winter Storm	20	0.5	5.9%	$83.4B CI	3.6%	$4.2B	$1.9B	1,314	31
All Disasters	**338**	**7.9**	**100.0%**	**$2,297.5B[‡]** CI	**100.0%[‡]**	**$6.9B[‡]**	**$53.4B[‡]**	**15,689**	**365**

[†]Deaths associated with drought are the result of heat waves. (Not all droughts are accompanied by extreme heat waves.)
Flooding events (river basin or urban flooding from excessive rainfall) are separate from inland flood damage caused by tropical cyclone events.
The confidence interval (CI) probabilities (75%, 90% and 95%) represent the uncertainty associated with the disaster cost estimates. Monte Carlo simulations were used to produce upper and lower bounds at these confidence levels (Smith and Matthews, 2015).

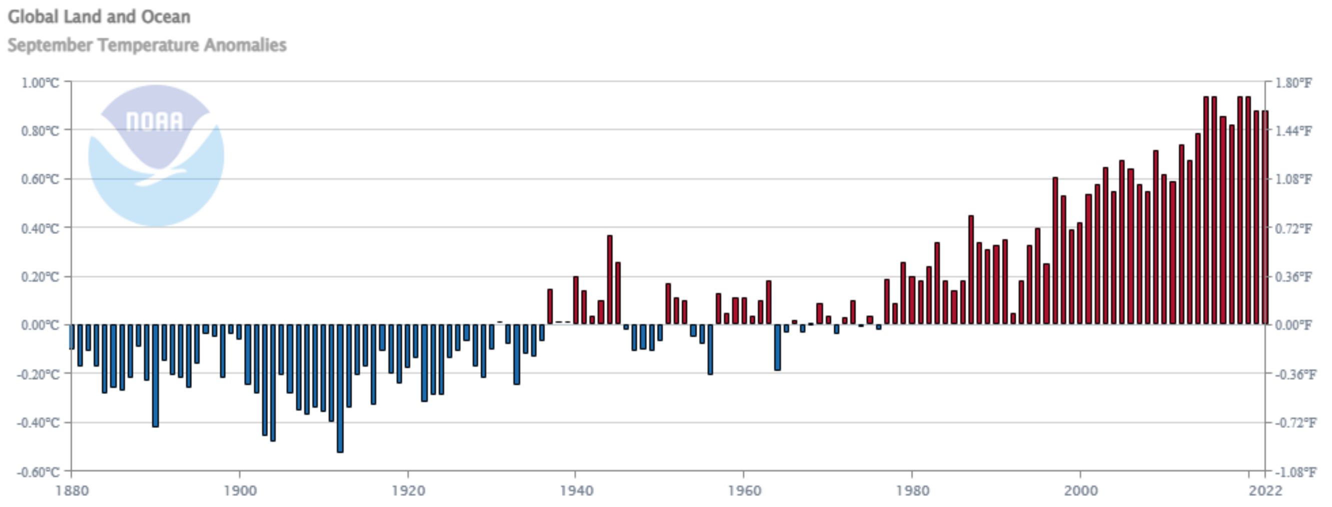


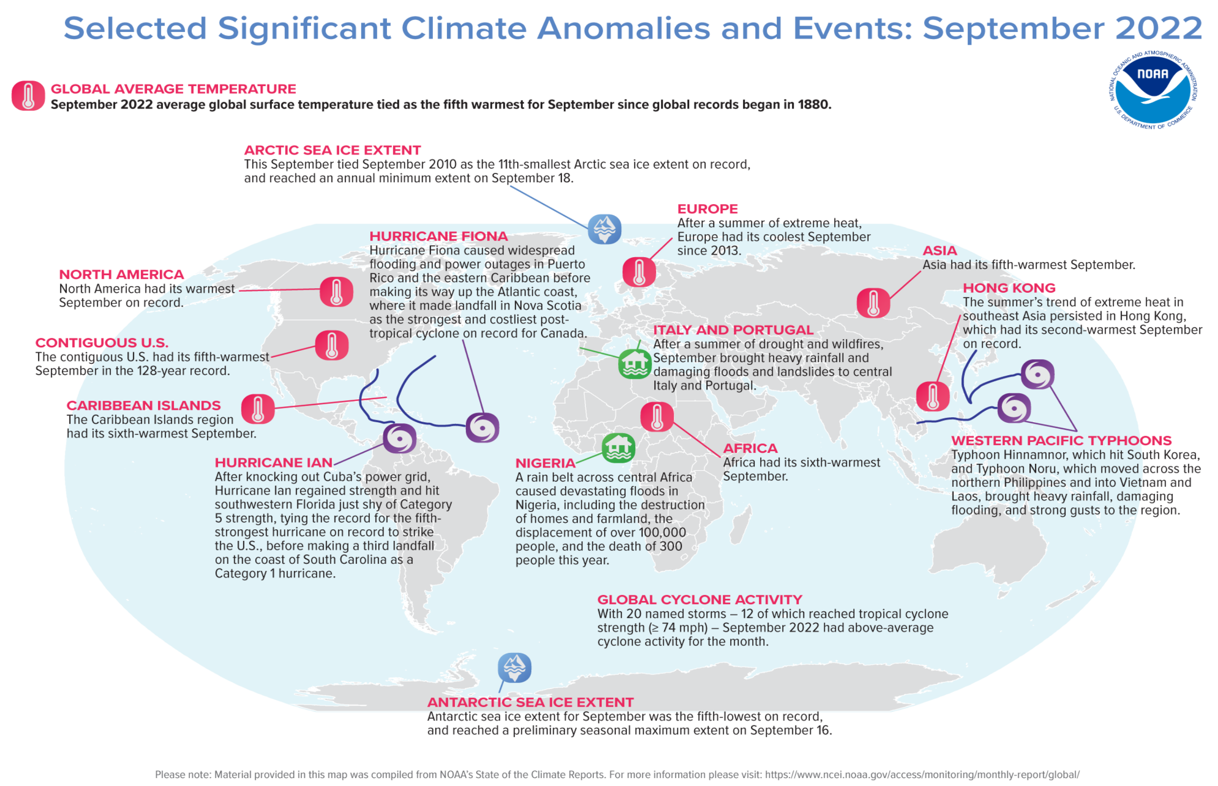


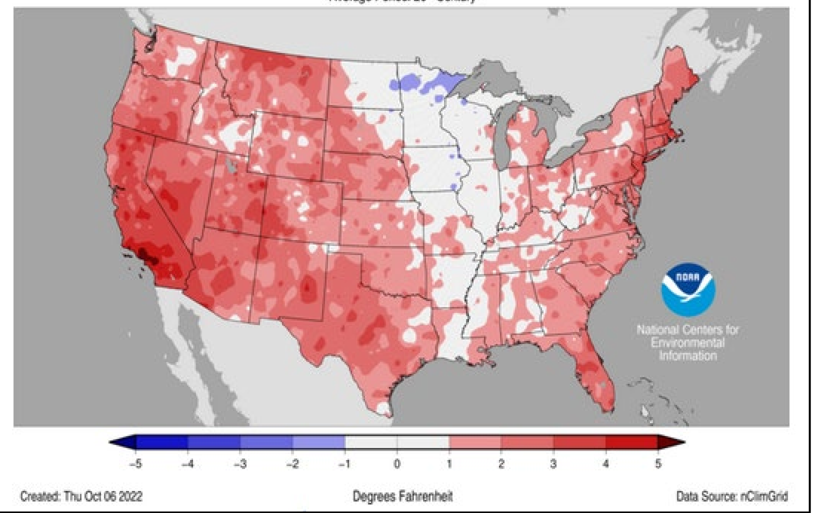
2022 Climate



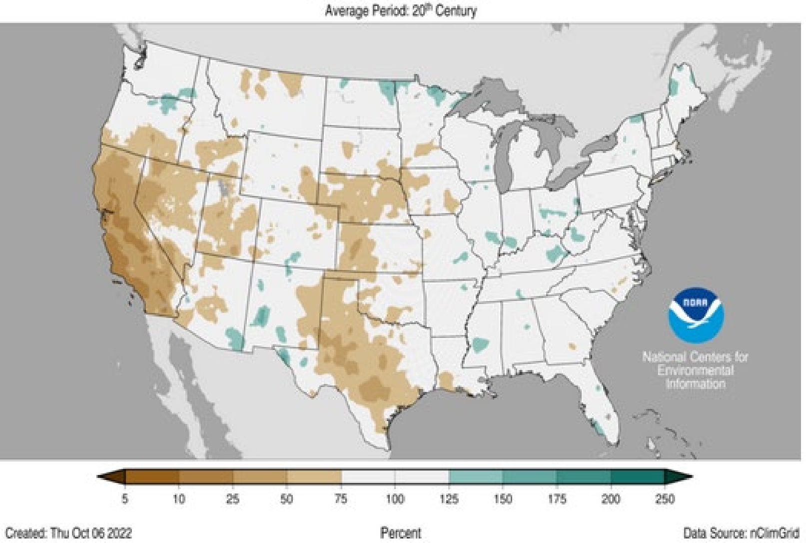
The September 2022 global surface temperature departure tied September 2021 as the fifth highest for September in the 143-year record at 1.58°F above the 20th century average of 59.0°F. The ten warmest Septembers on record have all occurred since 2012. September 2022 also marked the **46th consecutive September** and the **453rd consecutive month** with temperatures, at least nominally, above the 20th century average.



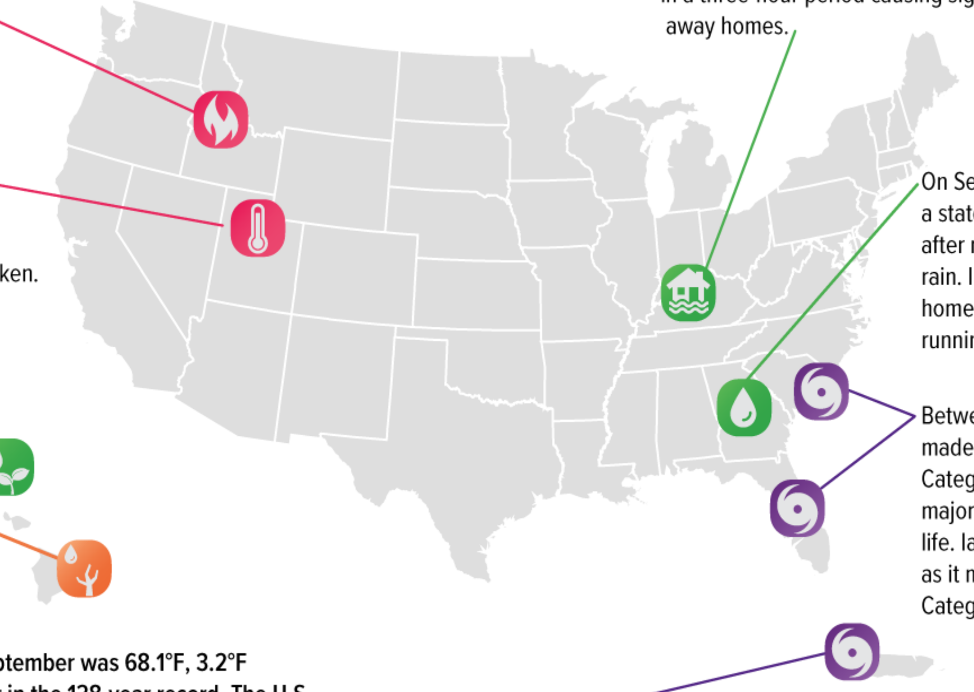




Based on [NOAA's Residential Energy Demand Temperature Index (REDTI)](), the contiguous U.S. temperature-related energy demand during July was 211% of average and the 5th-highest value in the 128-year period of record. January-September was 113% of average, 48th-highest value on record.



U.S. Selected Significant Climate Anomalies and Events for September 2022



The powerful remnants of Typhoon Merbok pounded Alaska's western coast on Sep 17, pushing homes off their foundations and tearing apart protective berms as water flooded communities. This was the strongest storm to enter the Bering Sea during Sep in 70 years.

On Sep 27, about 50.9% of the CONUS was in drought, up about 5.4% from the end of Aug. Drought conditions expanded or intensified across portions of the MS Valley, central and northern Plains, Northwest, Southeast and parts of the Great Lakes. Drought contracted or was eliminated across portions of the Southwest, southern Plains, Northeast, Florida and Puerto Rico.

On Sep 4, torrential rains caused flooding in parts of IN and KY. Parts of southern IN were drenched by an excess of 9 in. of rain in a three-hour period causing significant flooding and washing away homes.

As of Oct 5, there were 57 active wildfires in the Pacific Northwest (ID, MT and OR) that burned over 660,000 acres to date.

A heatwave settled over the West the first week of Sep and brought scorching temperatures that set all-time record highs. On Sep 9, nearly 1,000 heat records were broken.

On Sep 4, the GA governor declared a state of emergency in two counties after receiving an estimated 12 in. of rain. In Summerville, GA, some 8,000 homes and businesses lost access to running water due to flooding.

As of Sep 27, drought coverage reduced slightly over HI but intensified on the windward side of the Big Island over the month.

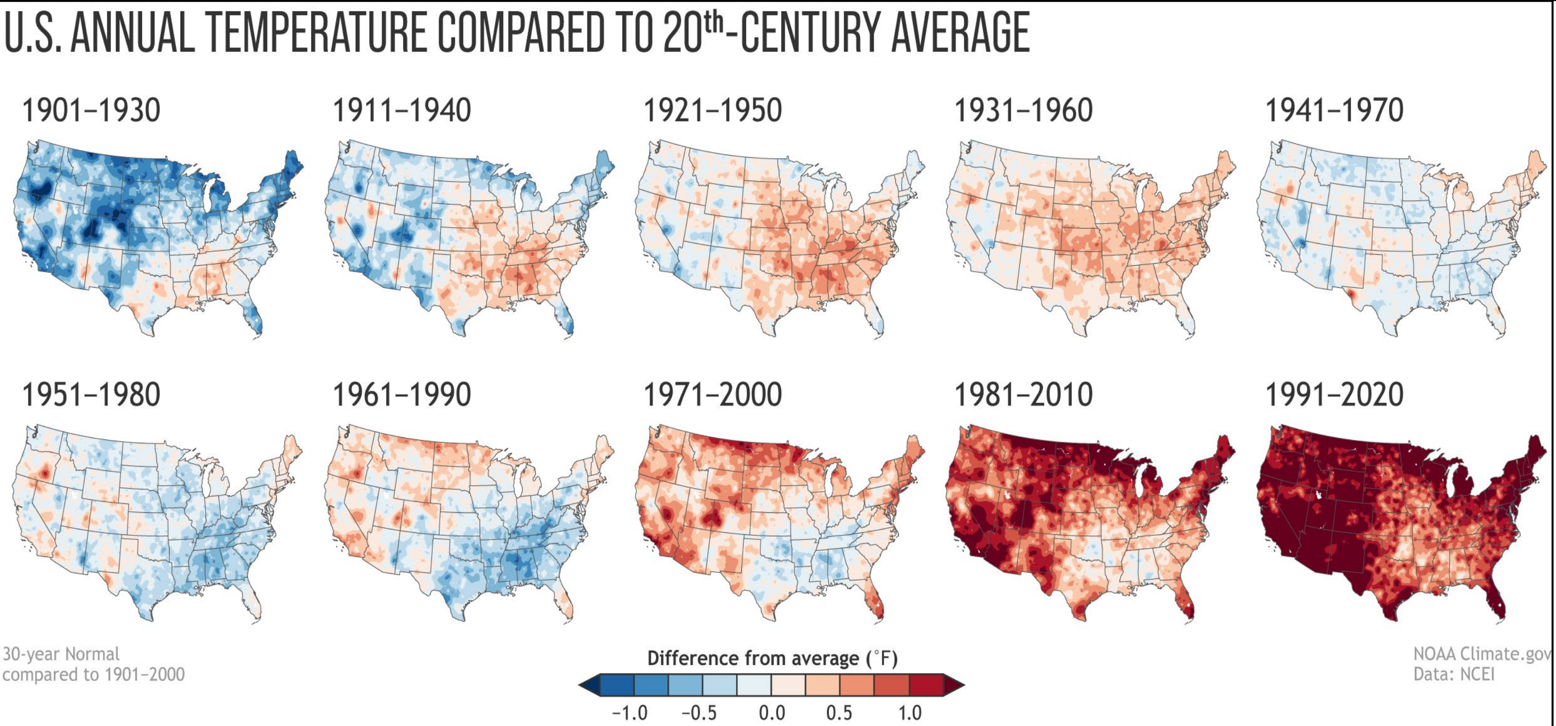
Between Sep 28-30, Hurricane Ian made landfall in FL as a strong Category 4 hurricane, resulting in major flooding, damage and loss of life. Ian created additional damage as it made landfall in SC as a Category 1 hurricane.

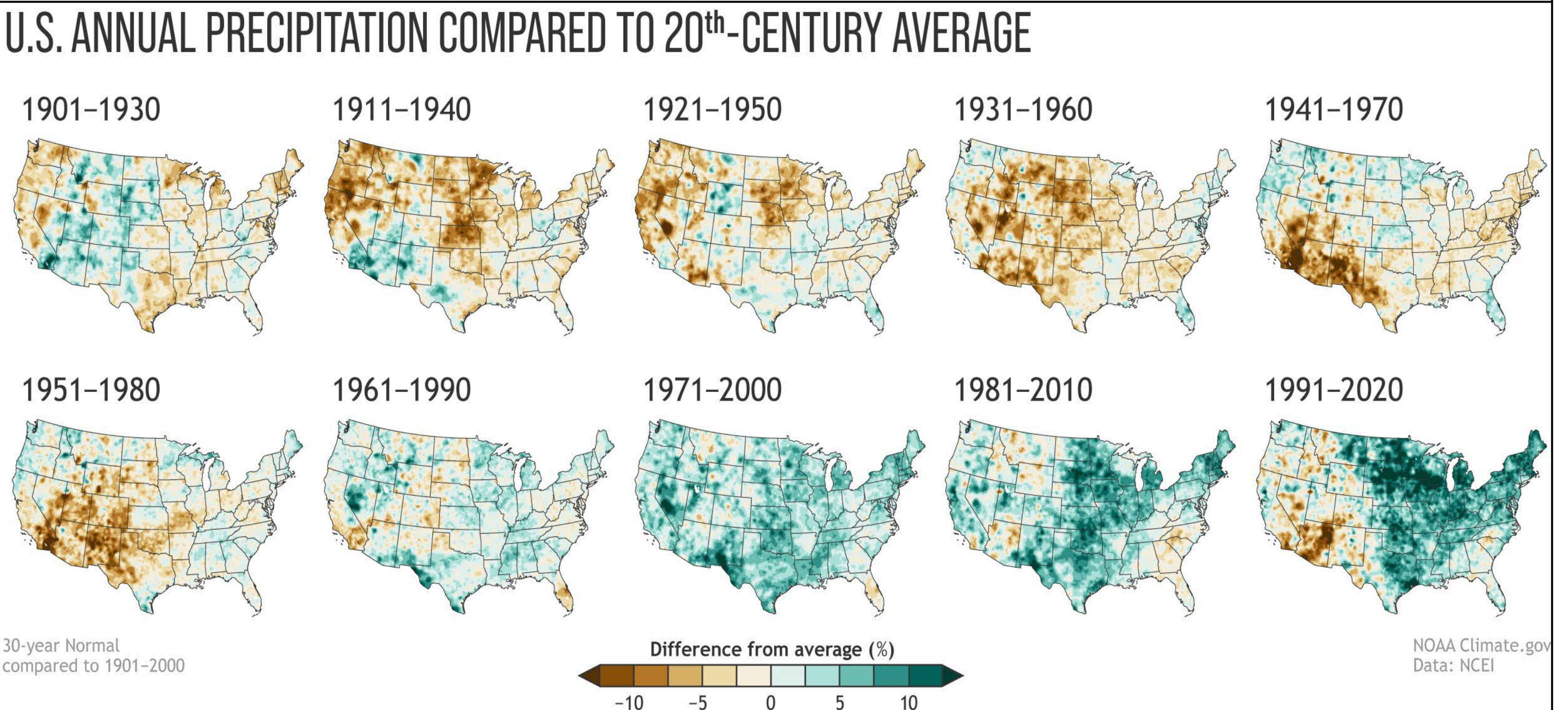
The average U.S. temperature for September was 68.1°F, 3.2°F above average, ranking fifth warmest in the 128-year record. The U.S. precipitation average for September was 1.83 in., 0.66 in. below average, ranking 10th driest in the historical record.

Hurricane Fiona brought massive flooding to Puerto Rico. One station reported 27.14 in. of rain in 24 hrs while other locations reported 12–18 in.

Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: https://www.ncei.noaa.gov/access/monitoring/monthly-report/

The [U.S. Climate Extremes Index (USCEI)]() for the year-to-date period was 26% above average and ranked in the highest one-third of the 113-year period of record. The USCEI is an index that tracks extremes (occurring in the upper or lower 10% of the record) in temperature, precipitation and drought across the contiguous United States (NOAA NCEI).





By 2050, about 63% of the US population could be forced to endure temperatures over 100 degrees. For areas where triple-digit temperatures are seasonal already, the baseline temperature and the frequency of high heat events will increase.

As average temperatures at the Earth's surface rise, **more evaporation occurs**, which increases overall precipitation. For every 1.8°F of warming, the atmosphere can hold about 7% more moisture.

- Warmer air holds more water because the water vapor molecules it contains move faster than those in colder air making them less likely to condense back to liquid.
  - Sea surface temperatures have risen by 0.5–0.6 °C since the 1950s, and over the oceans this has led to 4% more atmospheric water vapor since the 1970s.
- Heat is released when water vapor condenses to form rain. When the rain falls, it brings the warm air down to the surface raising the temperature throughout the area.
- As temperatures increase at the surface, short-burst heavy rainfall events will increase.
  - The air is on average warmer and moister than it was prior to about 1970 and in turn has likely led to a 5-10% effect on precipitation and storms that is amplified in extreme downpours.

Wet bulb conditions occur when heat and humidity are too high for sweat to evaporate. Such conditions can be fatal for humans if the temperature and humidity both exceed 95.

- Extreme heat and humidity are growing more common due to the growing distance between major low-pressure centers crossing the US, allowing for direct sunlight heating the surface and a larger presence of greenhouse gases trapping that heat for prolonged periods.

In cities, the air, surface and soil temperatures are almost always warmer than in rural areas. This effect is known as the Urban Heat Island.

Trend Analysis: Heat and Mortality

Some statistical approaches estimate that more than 1,300 deaths per year in the United States are due to extreme heat. Heat was a contributing factor in 1,577 deaths in 2021. Early estimates from the CDC indicate that heat deaths jumped 56% between 2018 and 2021. Data centers generate large amounts of heat, making cooling systems critical.

- **Heat deaths have outpaced hurricane deaths by more than 15-to-1 over the past decade, according to data tracked by the National Weather Service.**
  - The 10 hottest years on record in the US have all occurred between 2005-2021.
- During cooler months, outside air is directly supplied to the data center without using any water also known as adiabatic cooling. During warmer months, the warm air is drawn through water-moistened pads and as the water in the pads evaporates, the air is chilled and pushed into the server halls. In hotter climates, cooling towers and chillers use more water. There are three main types of cooling towers that are defined by how water or air pass through them. These types include crossflow, counterflow, and hyperbolic.
- The data center industry is responsible for 1% of the global electricity consumption. On average, a data center uses 1.8 L of freshwater per kWh of IT power consumed. In comparison, it takes 57 L of water to produce 1 kWh of electricity in the US.

Rank	State	Deaths
1	Nevada	571
2	Arizona	1,298
3	Oregon	132
4	Washington	162
5	New Mexico	42
6	Louisiana	85
7	Arkansas	54
8	Maryland	104
9	Texas	378
10	Mississippi	36
11	Alabama	60
12	Oklahoma	46
13	California	421
14	South Carolina	55
15	Missouri	55
15	Tennessee	60
17	Pennsylvania	97
18	Florida	130
19	Indiana	39
20	Ohio	63

The wet bulb temperature is used to determine the relative humidity, which changes throughout the day. The relative humidity is found by comparing the temperature of a dry thermometer with the temperature of a wet bulb thermometer.

- The wet bulb thermometer has water placed on its bulb, air is passed over it, the water evaporates, and the temperature is recorded. Most of the time the two thermometers will have different temperature readings, however, if the air is completely saturated with water the readings will be the same.
- When 100% relative humidity is reached the air can no longer accept water, the water on the bulb cannot evaporate, and the temperature will be the same as the dry bulb. So, the lower the wet bulb reading, the lower the humidity, the more moisture the air can accept, the more heat a cooling tower can be expected to reject.

Heat Index is a measure indicating the level of discomfort the average person is thought to experience as a result of the combined effects of temperature and humidity of the air. When the body gets too hot, it begins to perspire or sweat to cool itself off. The ability for this to occur refers to the wet-bulb limit.

Heat-related deaths (by the year)	
2018	1,012
2019	911
2020	1,156
2021	1,577

Source: ValuePenguin analysis of Centers for Disease Control and Prevention (CDC) Provisional Mortality Statistics data

If the perspiration is not able to evaporate, the body cannot regulate its temperature. Evaporation is a cooling process. When perspiration is evaporated off the body, it effectively reduces the body's temperature. When the atmospheric moisture content (relative humidity) is high, the rate of evaporation from the body decreases. This same concept applies to electronics, surface water, and all living animals capable of sweat.

The human body feels warmer in humid conditions and cooler in arid conditions dependent on the relative humidity variations because the rate of perspiration is increasing or decreasing.

There is a direct relationship between air temperature, relative humidity, and the heat index. As the air temperature and relative humidity increase the heat index increases and vice versa.

Humans typically stay cool by sweating. As sweat droplets form on the skin, they evaporate in the heat and cool the skin, bringing down the body temperature. As the wet-bulb temperature approaches your core temperature, you lose the ability to cool down.

- Sweat can only evaporate if the air is dry enough to take up moisture. Once the relative humidity surpasses 95%, sweat will collect on the skin and increase heat.
- According to a 2020 study, wet bulb conditions are becoming increasingly common.

If the wet bulb temperature exceeds the human body's skin temperature of around 95°F perspiration can no longer act as a cooling mechanism and the body will quickly overheat, which can result in death

- **Air conditioning removes humidity from the air and is the best solution when wet-bulb temperatures get too high**.
- Fans can help sweat evaporate more efficiently, but they're less effective. People die of heat stress at wet-bulb temperatures much lower than 95°F.

A sustained wet-bulb temperature **exceeding 95°F** is likely to be fatal even to fit and healthy people, unclothed in the shade next to a fan; at this temperature human bodies switch from shedding heat to the environment, to gaining heat from it.

- At *wet-bulb* temperatures above 95°F , it is thought that even young, healthy people will *die* in about six hours.
- At an internal temperature of **109.4°F** serious brain damage, continuous convulsions, shock, and death are possible results for humans. Cardio-respiratory collapse will likely occur.
- During a heat stroke the body temperature increases to over 104°F. The acute overheating causes a brain edema, that evokes symptoms such as cramps, clouding of consciousness, headache, and sickness. In the worst cases heat stroke ends with lasting brain damages or with death.
- “If there's enough moisture in the air, it's thermodynamically impossible to prevent the body from overheating, even if there is an endless supply of water available, shade, and light clothing.”
- People die of heat stress at wet-bulb temperatures lower than 95°F. The wet-bulb temperatures during the June 2021 Pacific Northwest heatwave were closer to 77°F.

Within 50 years, states like **Arkansas, Missouri, and Iowa** will likely hit the critical wet-bulb temperature limit (NASA). https://climate.nasa.gov/ask-nasa-climate/3151/too-hot-to-handle-how-climate-change-may-make-some-places-too-hot-to-live/

LOW-INCOME FAMILIES ARE DISPROPORTIONATELY AFFECTED BY HIGH HOME ENERGY COSTS.

16.3%	3.5%
OF A LOW-INCOME FAMILIES' GROSS ANNUAL INCOME IS SPENT ON HOME ENERGY COSTS	OF OTHER HOUSEHOLDS' ANNUAL INCOME IS SPENT ON HOME ENERGY COSTS COMPARATIVELY

Heat Affects Health in Many Ways

Warmer temperatures increase the risk for a diverse range of health risks. For example:

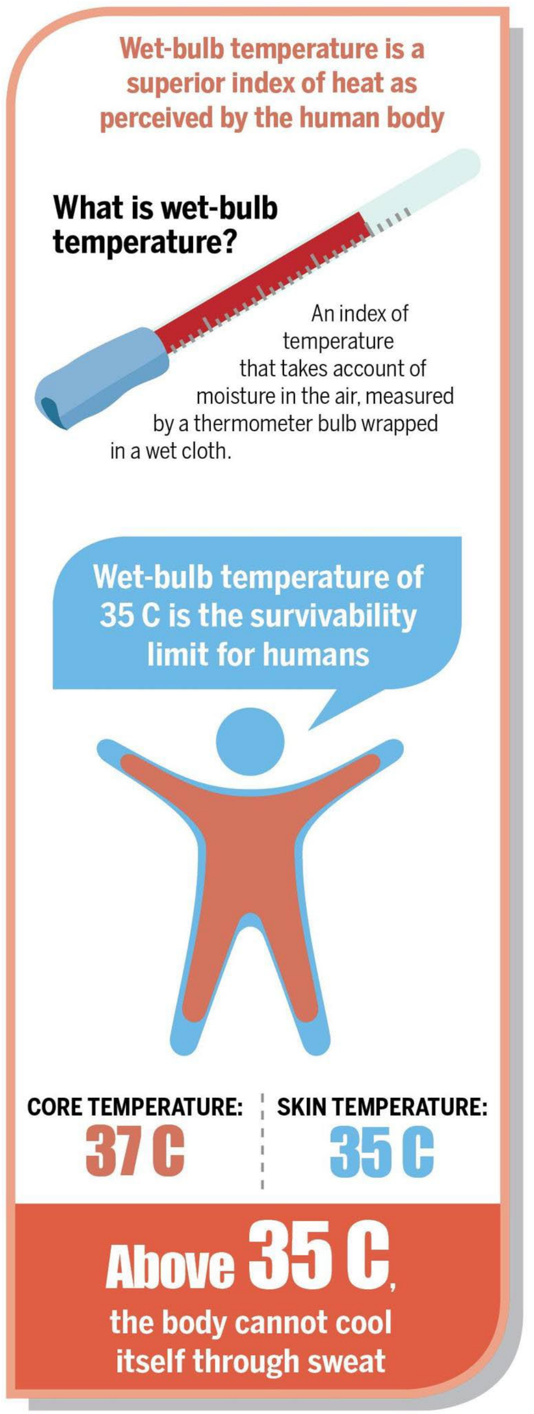
An increased risk of **hospitalization for heart disease**.

Heat exhaustion, which can lead to **heat stroke** if not treated, can cause critical illness, brain injury, and even death.

Worsening **asthma** and **chronic obstructive pulmonary disease (COPD)** as heat increases the production of ground-level ozone.

Dehydration, which can lead to **kidney injury** and blood pressure problems. Some kidney damage can become irreversible with repeated or untreated injury.

Violence, **crime**, and **suicide** may increase with temperature, adding to the rates of depression and anxiety already associated with climate change.



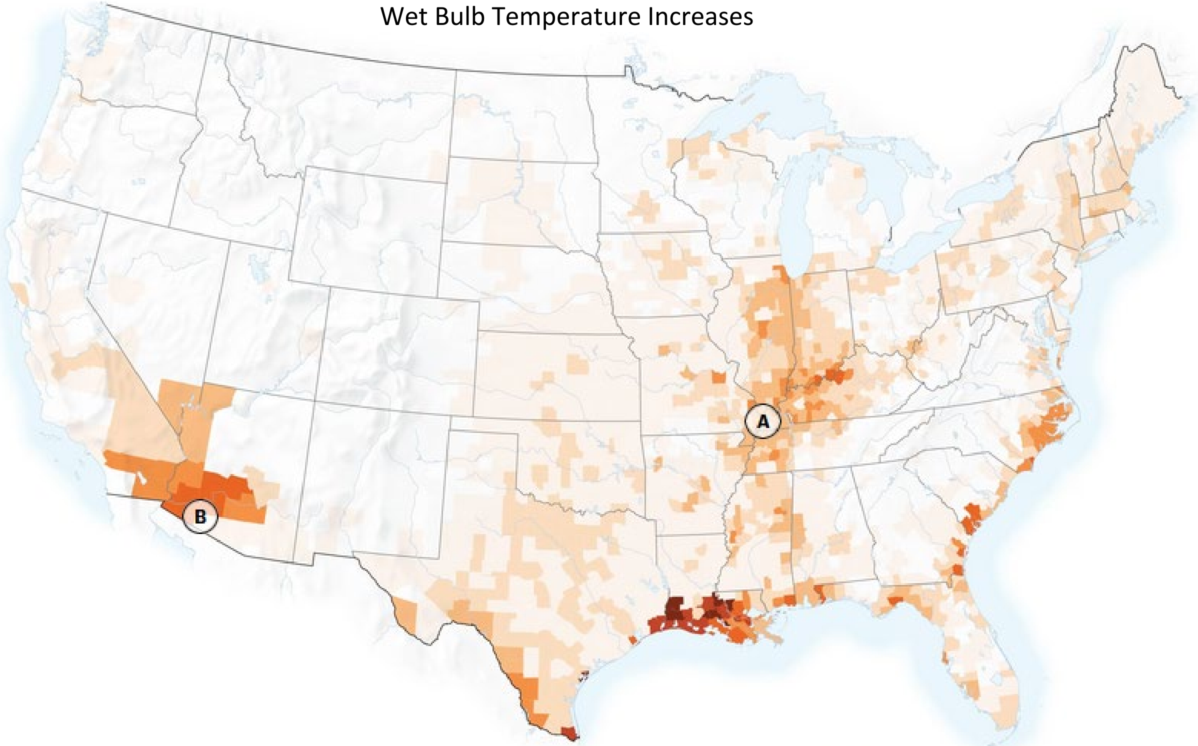
https://nca2014.globalchange.gov/highlights/overview/climate-trends

High Emissions | **Moderate Emissions**

0 1 5 10 15 25 40 70

Days with high wet bulb temperatures

Wet Bulb Temperature Increases



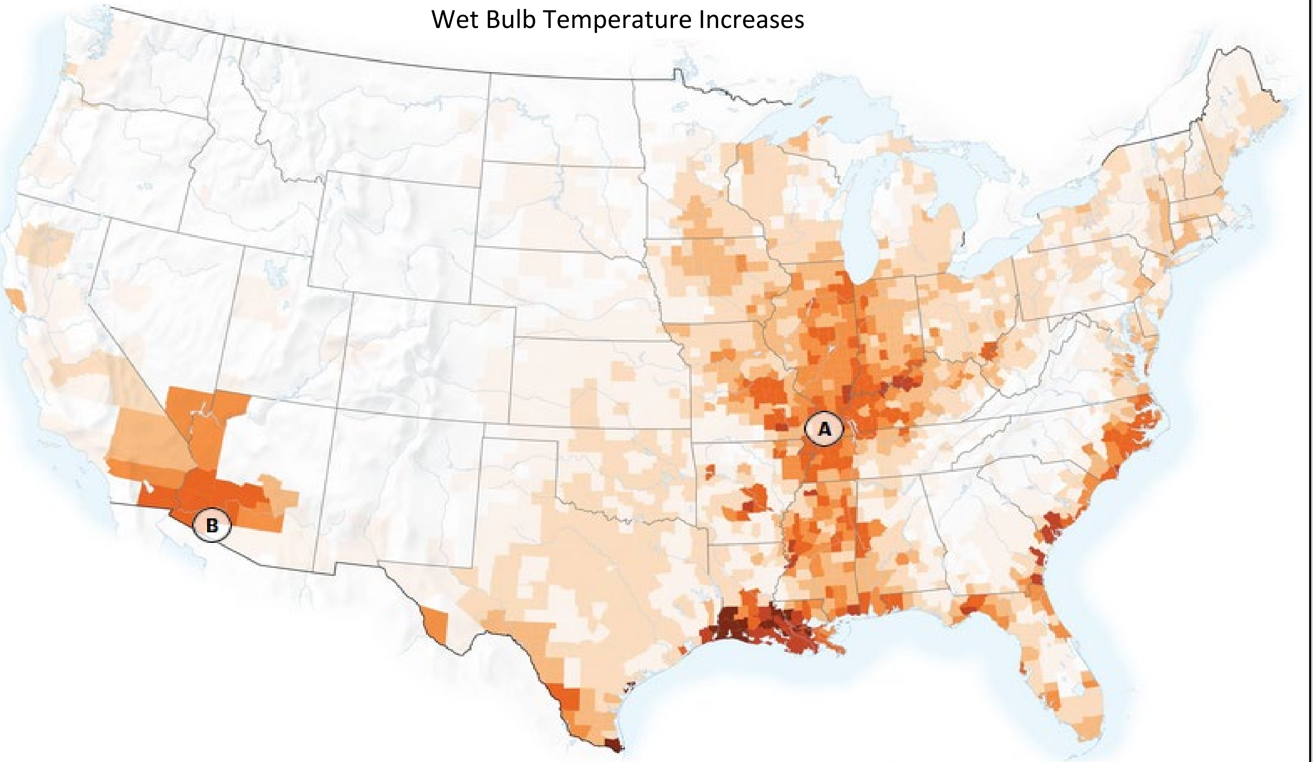
By midcentury, heat and humidity in Missouri (A) will feel like Louisiana does today, while some areas we don't usually think of as humid, like southwestern Arizona (B), will see soaring wet bulb temperatures because of factors like sun angle, wind speed and cloud cover reacting to high temperatures, according to Hannah Hess of the Rhodium Group.

High Emissions | Moderate Emissions

0 1 5 10 15 25 40 70

Days with high wet bulb temperatures

Wet Bulb Temperature Increases



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Regarding high heat and high humidity, the higher the wet bulb temperature the lower the cooling tower capacity for powerplants and data centers. High temperatures and humidity levels can damage IT equipment, causing them to fail. This could lead to uncomfortable conditions for anyone working inside the data center. The size of the cooling tower is determined by the max wet bulb reading. Wet bulb temperature, along with cooling tower size and flow rate, determine inlet and outlet water temperatures.

RADIATIVE HEAT THREATS

In the 1980s, concurrent heat waves only occurred for 20-30 days each summer. Global warming has driven a sixfold increase in the frequency of simultaneous heat waves over the last 40 years. The study also found that concurrent heat waves covered about 46% more space and reached maximum intensities that were 17% higher than 40 years ago.

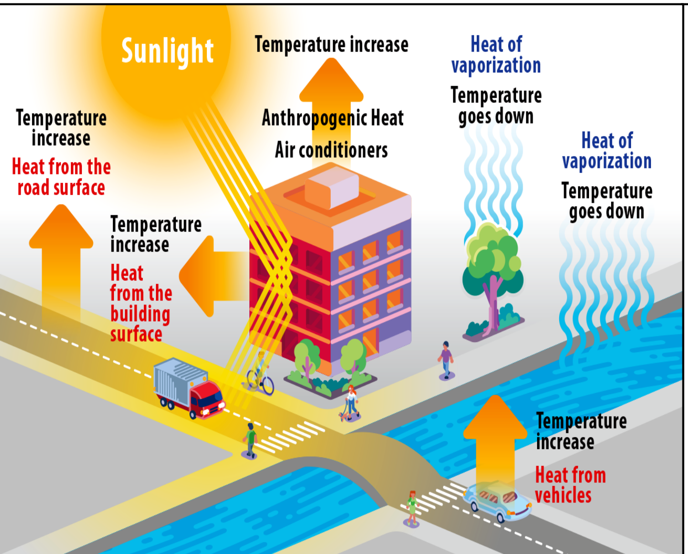
Heat transfer from a body with a high temperature to a body with a lower temperature, when bodies are not in direct physical contact with each other or when they are separated in space, is called heat radiation. Thermal radiation is one of three mechanisms which enables bodies with varying temperatures to exchange energy.

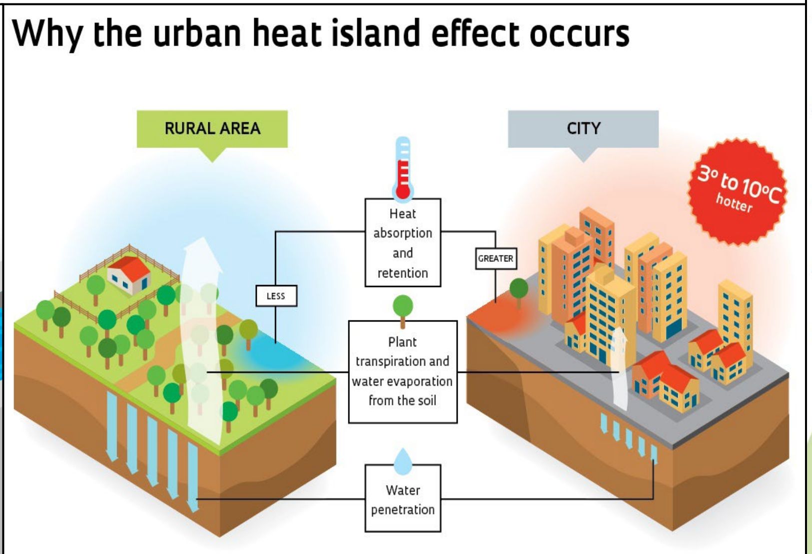
- Sunshine, or solar radiation, is thermal radiation from the extremely hot gasses of the sun, and this radiation heats the earth.
- The entire body acts as an emission source of continuous thermal radiation, and as a continuous receiver of radiation originating even from far-field bodies.
- Concrete is a great material for absorbing and storing heat from the sun. Concrete has a very high capacity for storing heat. Meaning it can warm to higher temperatures then most other materials and releases that heat more slowly. On a hot summer day, even concrete that’s in the shade can easily average 70°F, however, concrete that’s in direct sunlight can reach 135°F. Builders test this with a device called an infrared thermometer. Concrete **has a very high heat capacity.**
- Grass rarely exceeds 80°F, wood peaks around 90°F, composite decking about 100°F, but concrete can reach a peak of 175°F.

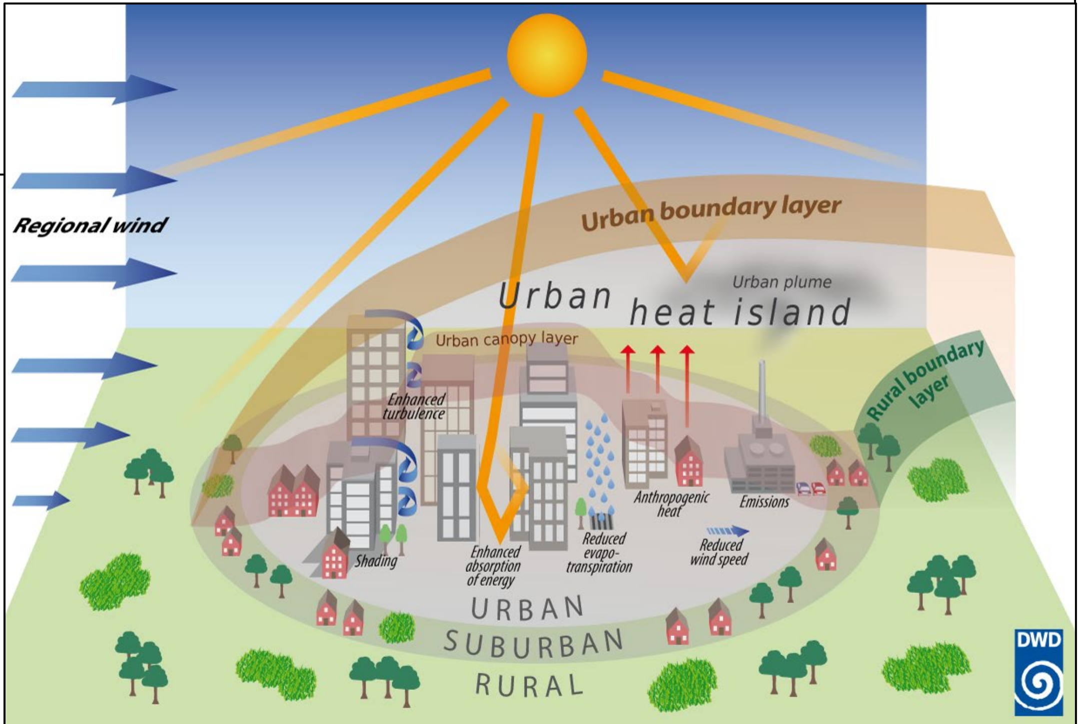
Heat islands form as a result of reduced natural landscapes in urban areas and increases in heat-retentive materials. Trees, vegetation, and water bodies tend to cool the air by providing shade, transpiring water from plant leaves, and evaporating surface water, respectively.

When asphalt heats it becomes more malleable, making it soft and able to compress under weight and become disformed. High heat also rapidly ages the material, making infrastructure on or near it weaker.

At the current rate of heating, the expansion buffer will not stop the material from buckling more often.







How Does This Impact CI?

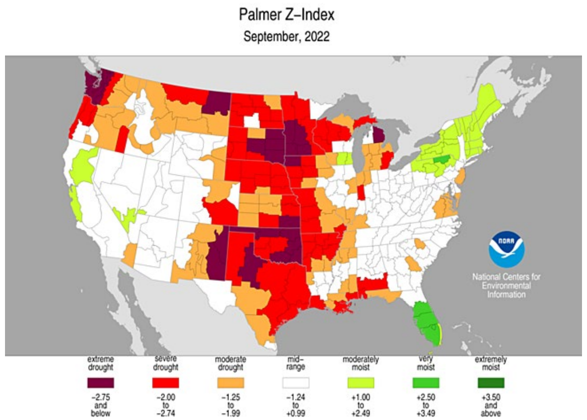
Global average surface temperature has risen at an average rate of **0.17°F per decade since 1901** like the rate of warming within the contiguous 48 states.

Buckling Roadways
Warping Railways
Runway Defects
Energy Infrastructure Impacts
Permanently Damaged Crops
Widespread Algal Blooms
Depleted Water Oxygen
Livestock/Fishery Deaths
Deadly Ambient Air Temperatures
Wildlife Incursions Increasing
Cement/Concrete/Tar Degradation

Building Insect Swarms
Decreased Hibernation Periods
Increasing Longevity of Insects
Migration Pattern Shifts
Wildfire Climate Growth
Flash Drought Amplification
Wet-Bulb Days Increasing
Roofing/Insulation Damage
Cast Iron Bridge Support Cracking
Decreased Surface Water
Exposed Structural Support

Earthen Dam Damages
Decreased Transportation
Lack of Adhesion Materials
Strain on Medical Services
Overwhelmed Morgues
Military Operations Impact
Readiness Degradation
Contaminated Water Sources
Loss or Lack of Critical Staff
Heat Creates More Ozone
Increased Human Mortality Rates

2009-2020, drought and extreme heat have caused $63 billion in damages and 271 deaths across the Southwest.



Currently, 31% of Coloradans, or 1,577,000 people, inhabit places in abnormal drought conditions.

EPA United States Environmental Protection Agency

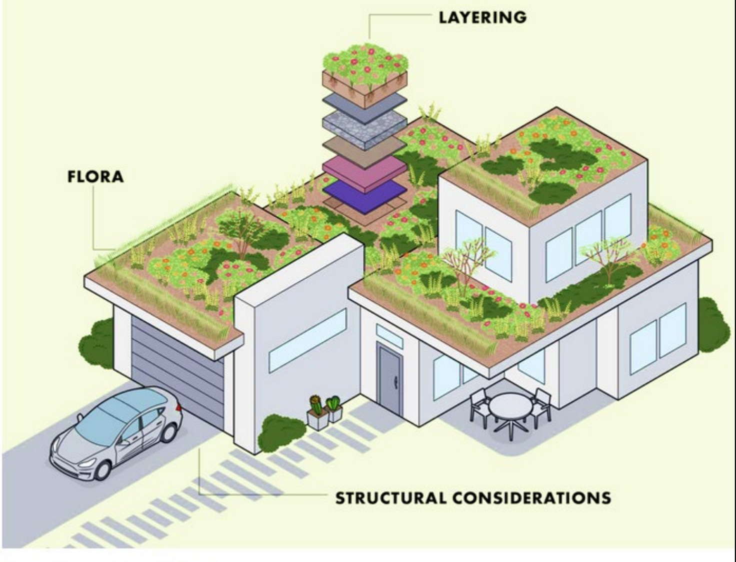
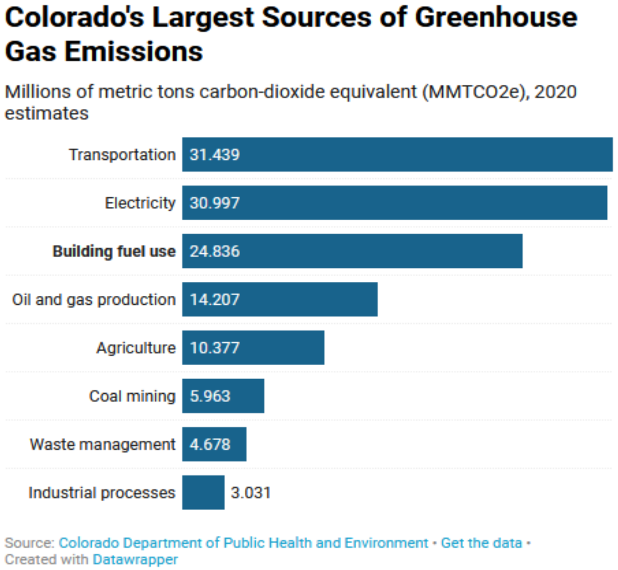
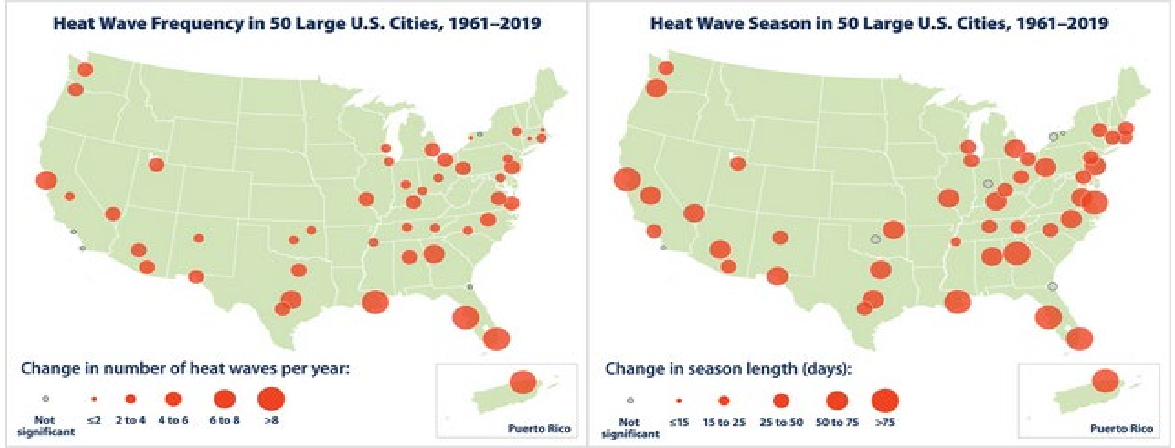
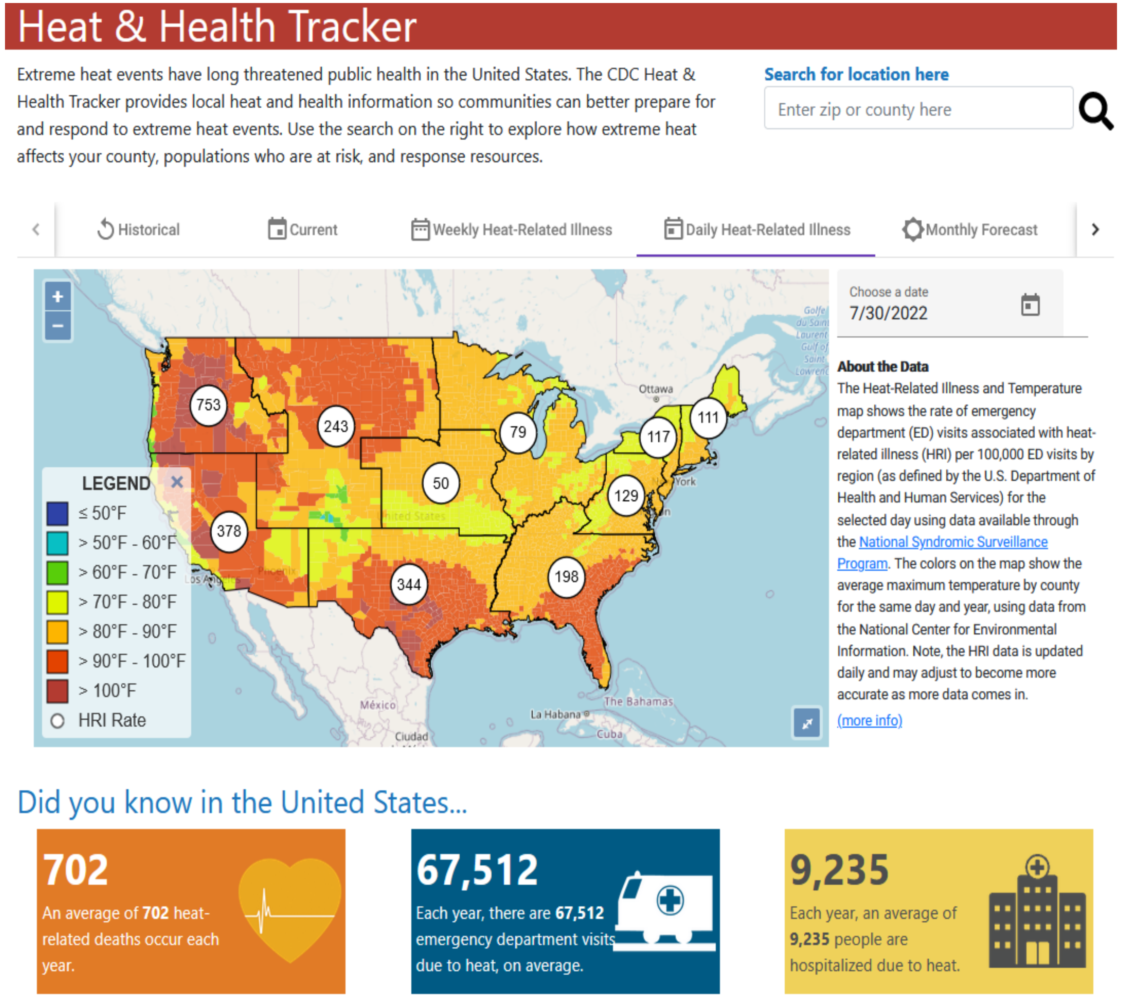


Illustration by Chris Philpot

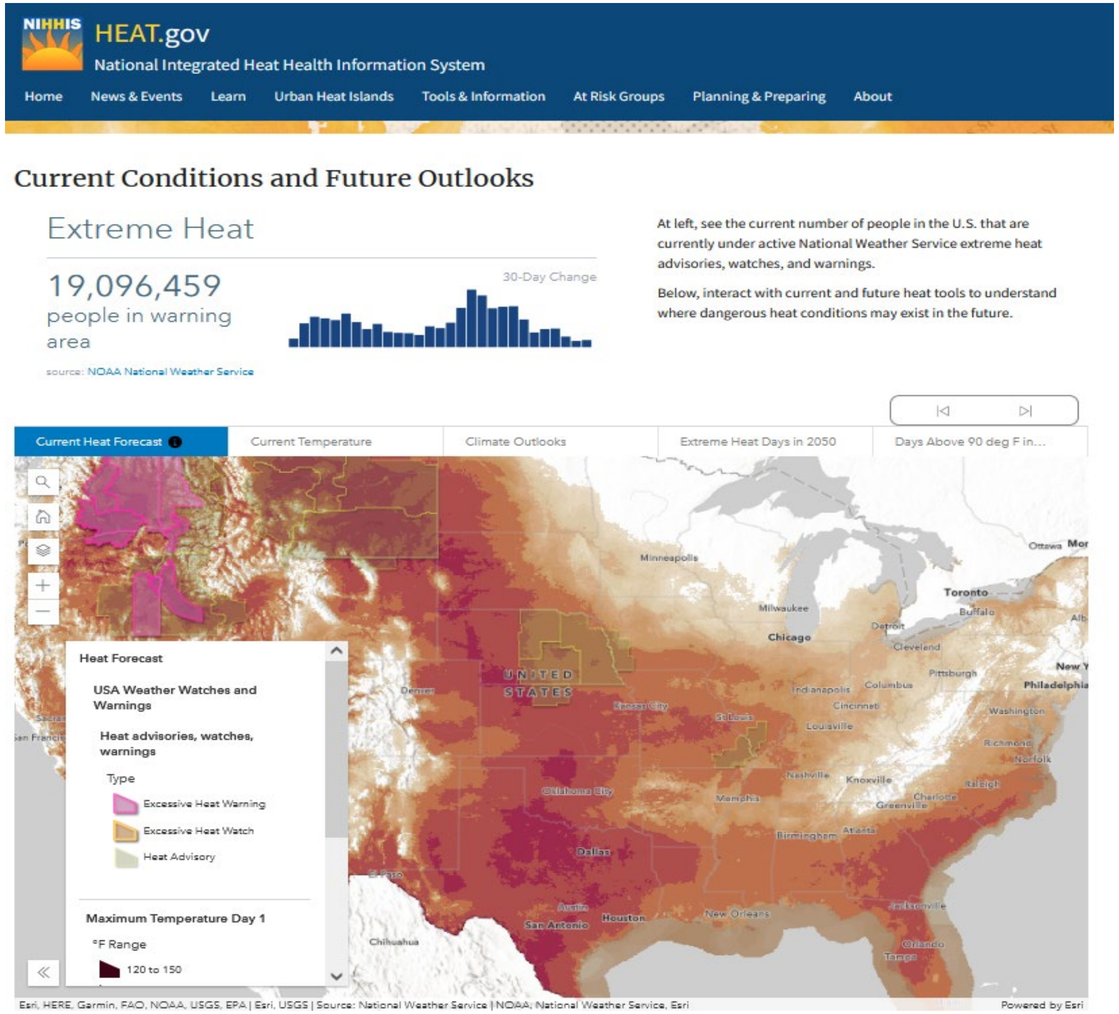




These maps represent the number of heat waves per year (frequency) and the number of days between the first and last heat wave of the year (season length) compared with the local temperature threshold for defining a heat wave across 50 U.S. metropolitan areas https://ephtracking.cdc.gov/Applications/heatTracker/



https://www.heat.gov/



FIRE WEATHER

***About 30%** of Denver homes do not have air conditioning, most of which are older homes or those in low-income communities, according to the city. As temperatures continue to climb, those Denver's residents will be vulnerable to health risks brought on by the excessive heat.*

A study from the University of Colorado states wildfires have become larger, more frequent, and more widespread since the year 2000.

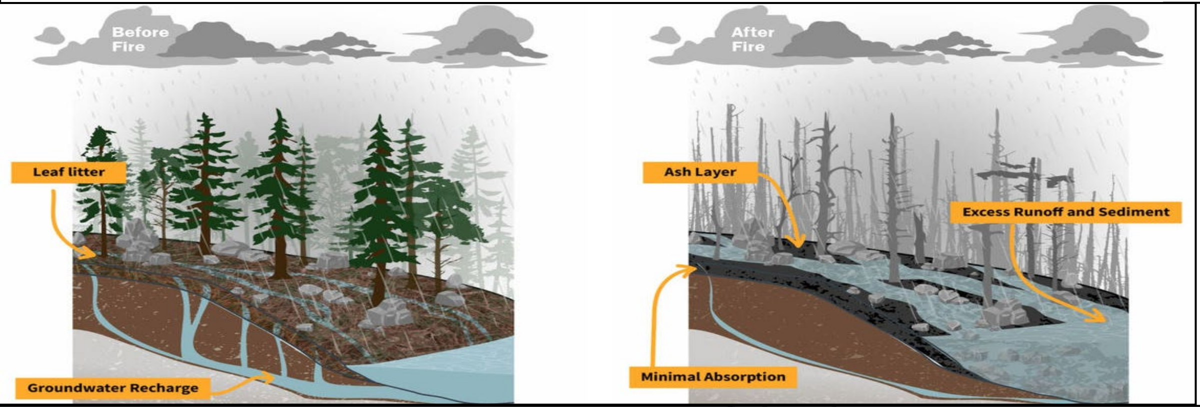
- Analysis of coincident 1000-hour fuel moistures indicated that as fuels dried out, satellites detected increasingly larger and more intense wildfires with higher probabilities of nighttime burns.

A new study from the University of Montana highlights burn scar impacts to tree regrowth across various regions, indicating new tree seedlings are unable to survive in hotter climates where parent trees remain.

- The study indicated that if large areas of the forested parts of the Rocky Mountains burned, only 50% would recover.

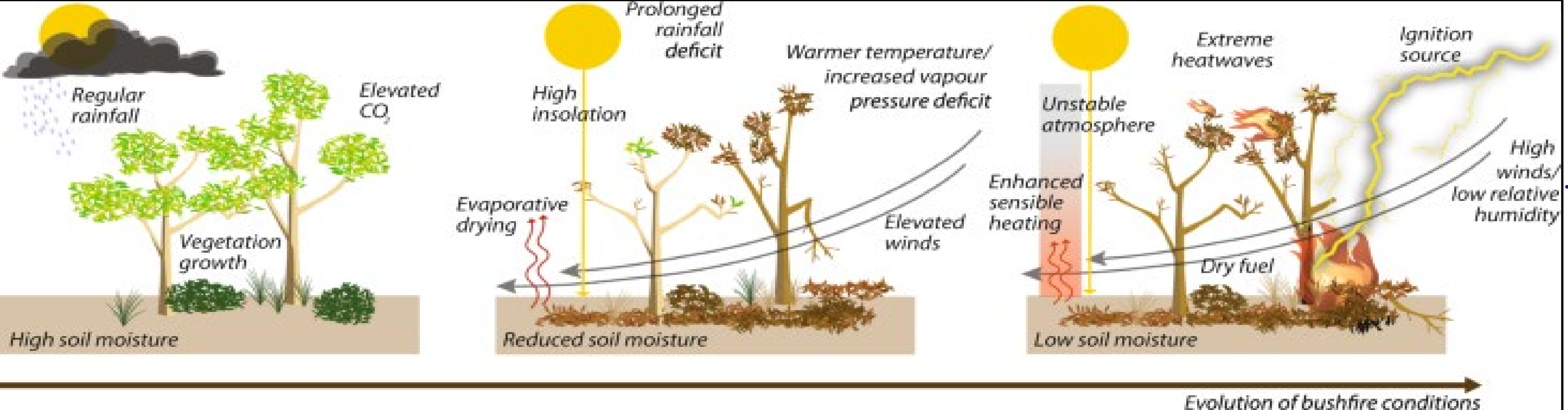
Satellite imagery and state/federal fire history records from 28,000 fires in 1984-2018 showed more fires occurred in the past 13 years than the previous 20 years. On the West and East coasts, fire frequency **doubled**. In the Great Plains, fire frequency **quadrupled**.

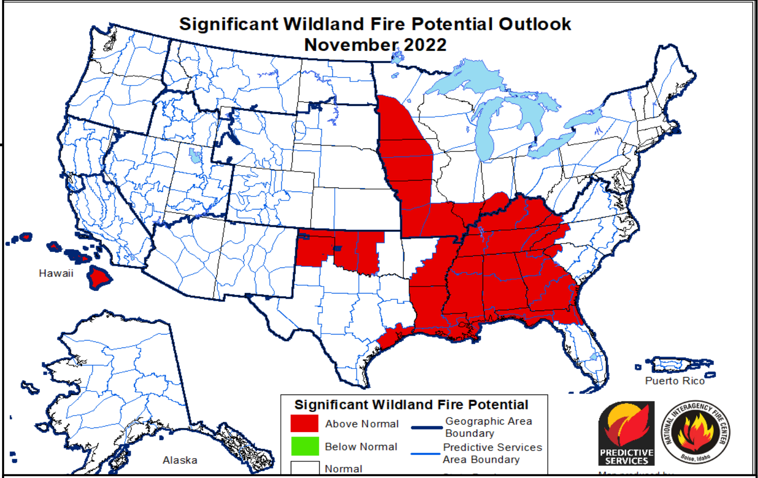
Burned vegetation/charred soil form a water repellent layer which blocks water absorption along with compacted soil from prolonged drought which reduces absorption, too. These major soil changes cause short rainfall events to be less beneficial for long-term recovery.

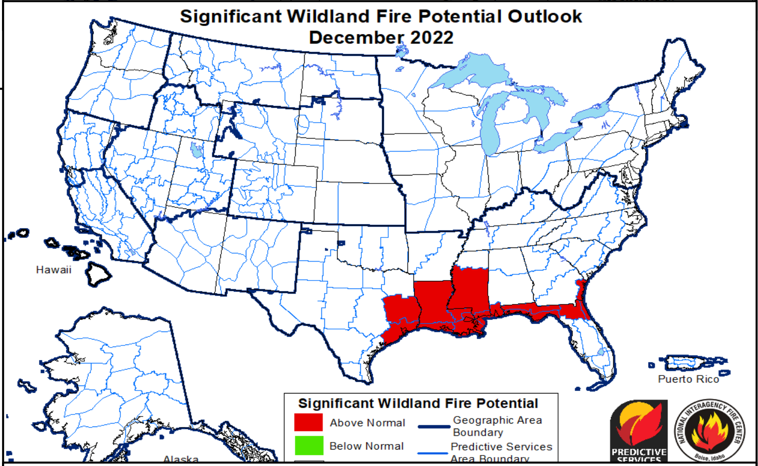


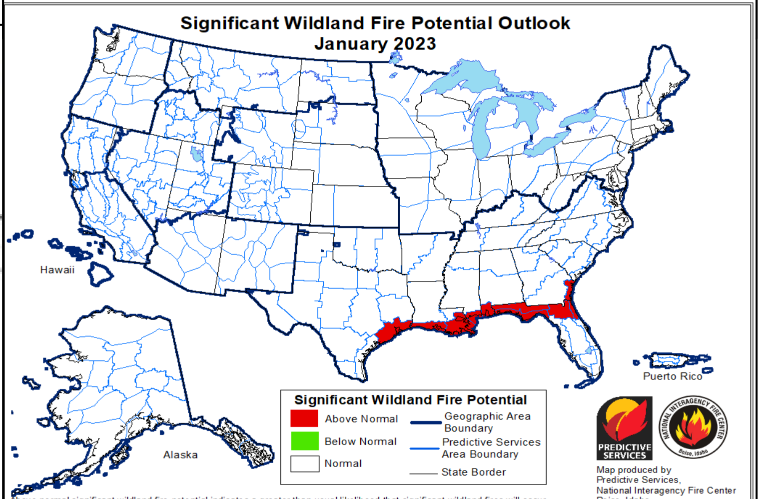
Disasters related to weather, climate, or water hazards happen five times more often now than they did in the 1970s. Droughts that may have occurred only once every decade or so now happen 70% more often.

- The IPCC states heavy rainfall that used to occur once every 10 years now occur 30% more often.
- 61% of western wildfires have occurred since 2000 with a steady increase in the number of wildfires the last 60 years.









Decreasing relative humidity was a driver of over 75% of significant increases in the fire weather and initial spread indexes while increasing temperature was a driver for 40% of increased trends.

Reburns occur about every 7 years in the areas studied, potentially from the type of vegetation growing back in the burn scar versus the more robust, naturally fire-resistant mature plants which studies indicate are creeping to higher elevations where cooler temperatures and rain/snow runoff persists.

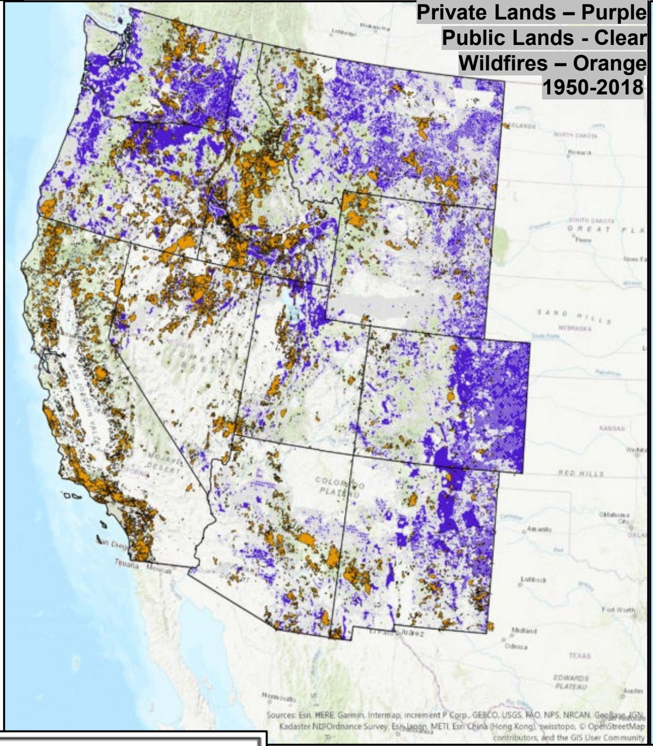
- 11% of the Western US had burned as of 2018 and 3% of that burned land has seen repeat fire activity since the initial burn period (see graphics to the right →).
    - 16 years after the Peppin Fire in Lincoln National Forest, NM the pine trees did not grow back, instead scrubby oaks which live in hotter conditions appeared.
- The 2021 Dixie Fire burned brush areas which came from the 2007 Moonlight Fire regrowth

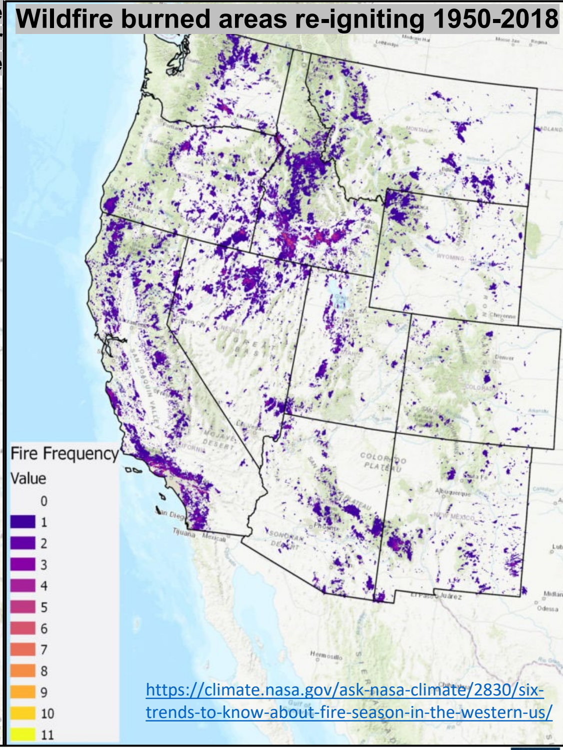
Since 2000, an annual average of 70,072 wildfires has burned an annual average of 7.0 million acres. The acreage figure is over double the average annual acreage burned in the 1990s (3.3 million acres), while a greater number of fires occurred annually in the 1990s (78,600 average).

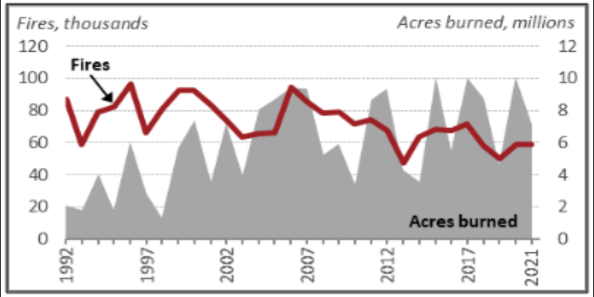
Researchers analyzed a total of 74,069 forest plots across nine states in the western United States, looking at the distances between mature trees and new seedlings to estimate how fast tree species were migrating away from fire climates. **The study concluded trees retreat ~five feet annually.**

As relative humidity decreases globally with temperatures increasing, fire risk will focus on explosive heat at the surface from abundant dried fuels causing hotter, geographically larger fires with more soil and root damage from combustible fuels igniting.

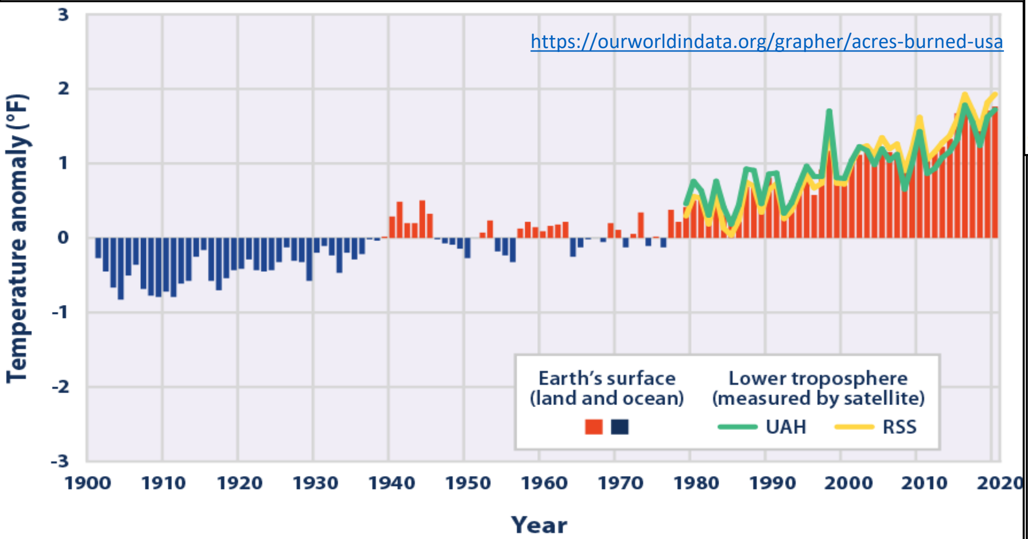
Satellite heat sensing data showed significant increasing trends in nighttime wildfire fire activity as temperatures have remained high overnight.

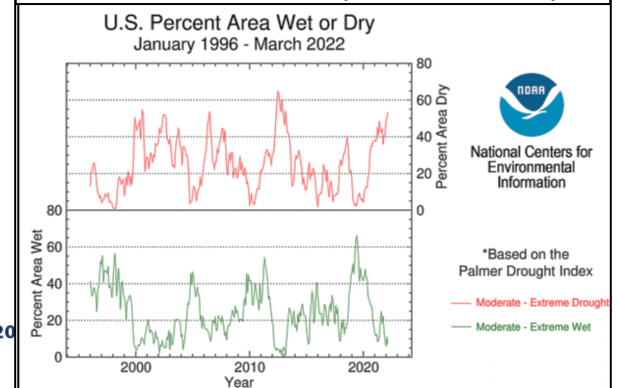


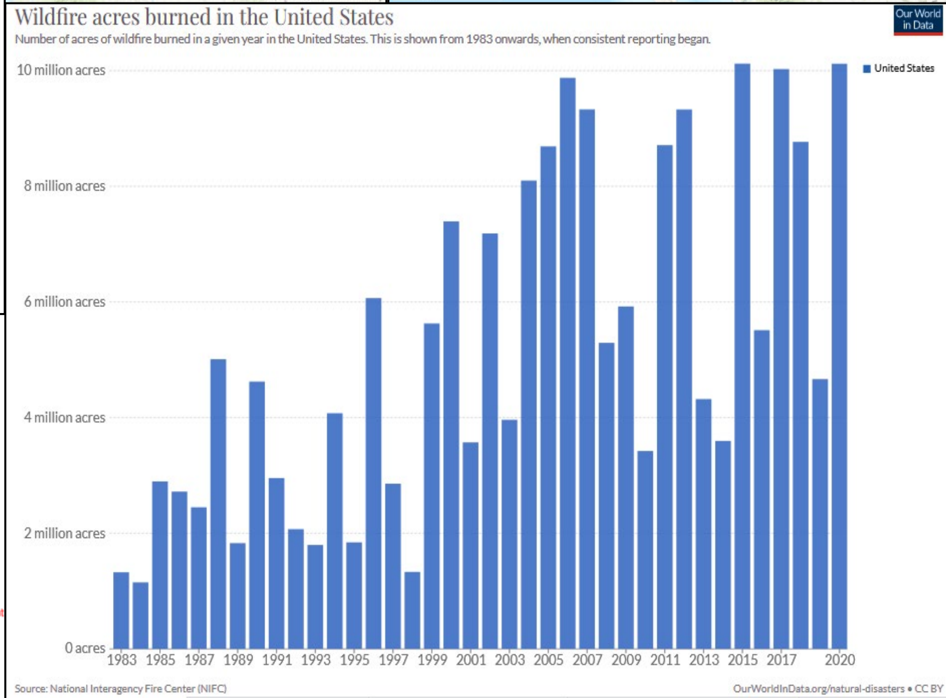




Source: NICC Wildland Fire Summary and Statistics annual reports.







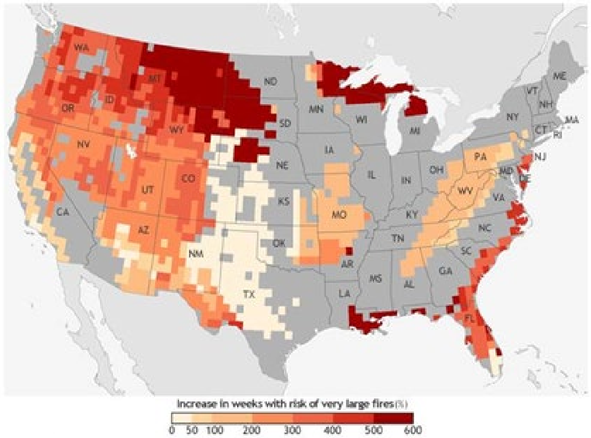
INCREASING FIRE THREATS

More than 7 million American homes currently have a “major” risk of wildfire damage, increasing to 13 million over the next 30 years, according to a national wildfire assessment by the First Street Foundation in May 2022.

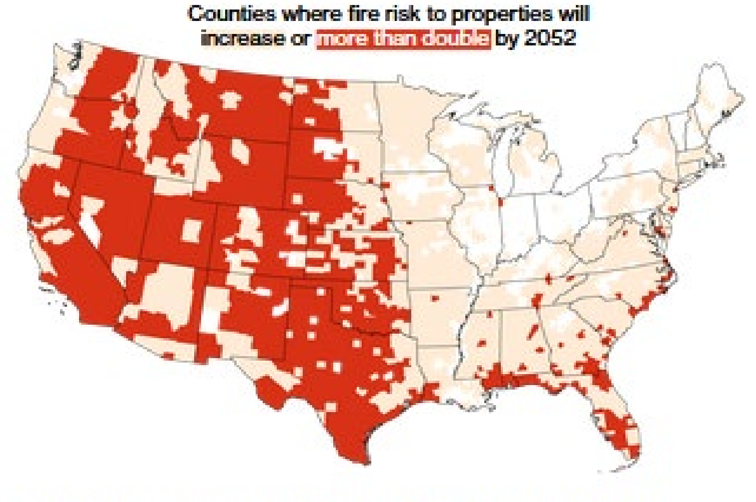
- Fire Factor is the First Street Foundation Fire Model.
- First Street’s data covers the contiguous US, depicting the uneven fire risk spread across the country.

33% of those in the West today face a significant chance of wildfire exposure, which is expected to reach 39% by 2052.

The map below shows the projected increase in the number of “very large fire weeks” —periods where conditions will be conducive to very large fires—by mid-century (2041-2070) compared to the recent past (1971-2000). The projections are based on scenarios where carbon dioxide emissions continue to increase.

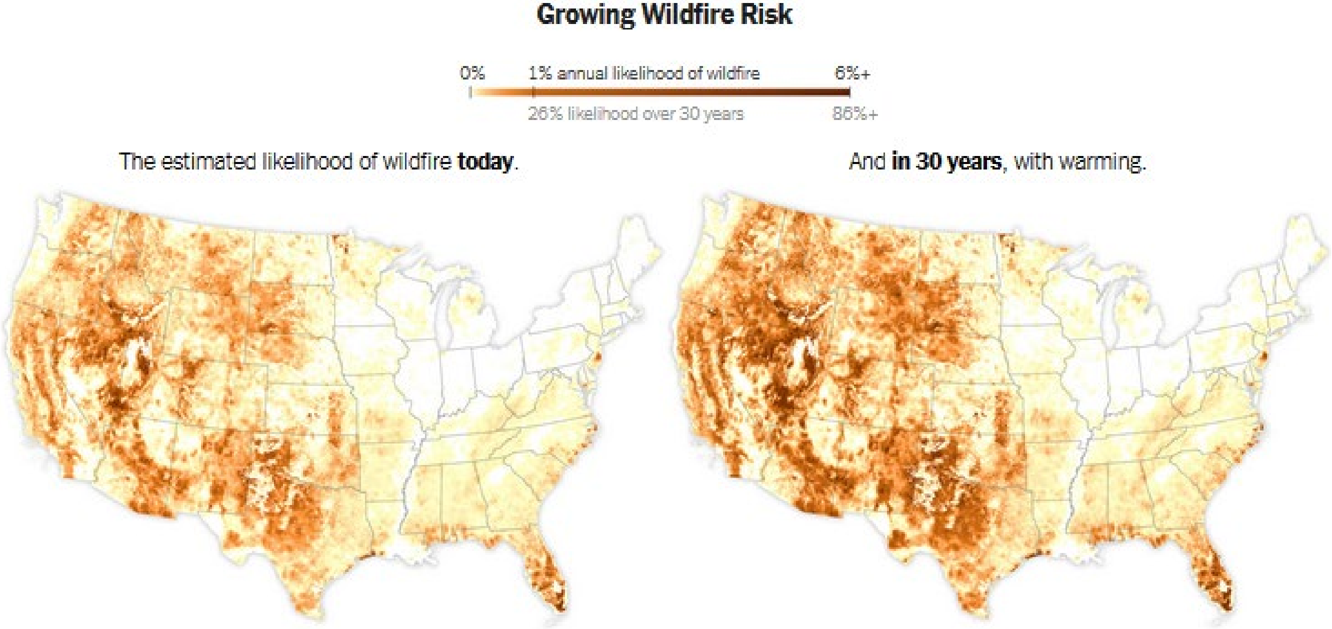


Source: NOAA Climate.gov map, based on data from Barbera et al, 2015.

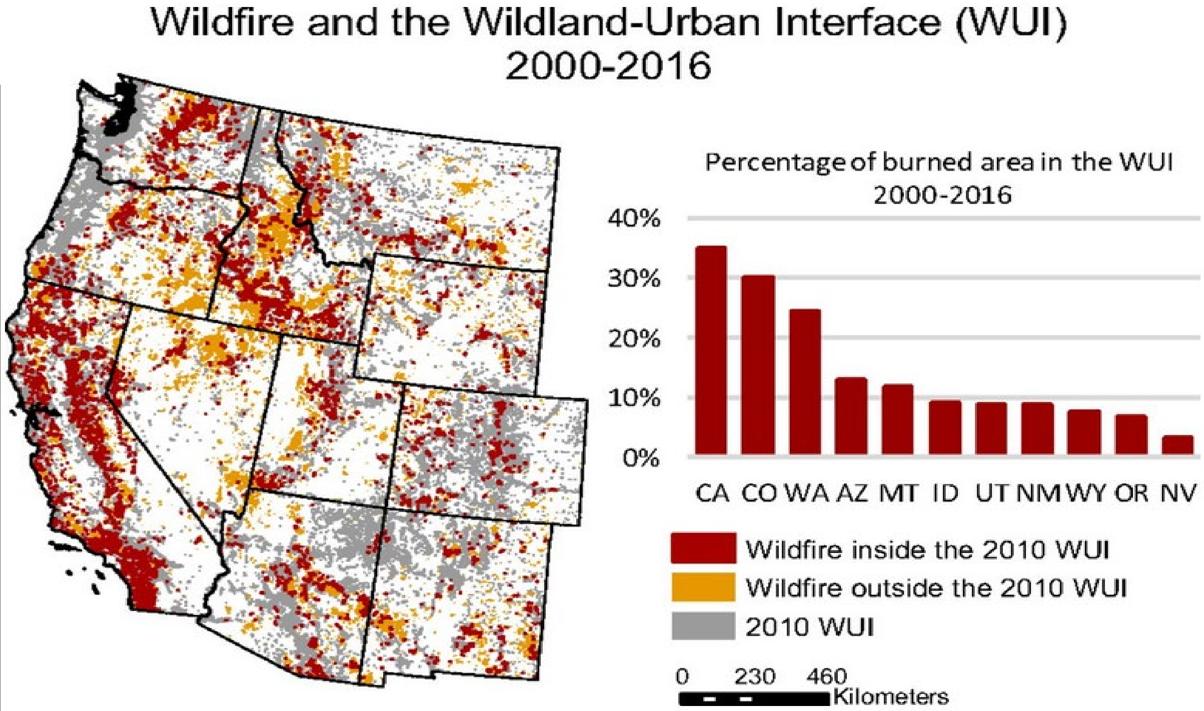


Note: Map shows percent change in annual likelihood of wildfire among properties with risk
Source: First Street Foundation

Nationwide, the number of existing properties facing at least a 1% risk will almost quadruple, to 2.5 million by 2050; not accounting for subdivisions to be built in the intervening years.



Source: First Street Foundation • The future projection reflects a warming scenario in which countries take measures to curb emissions over the next 30 years roughly in line with pledges under the Paris climate agreement. The future risk map reflects changes in temperature, precipitation and other climatic factors, but the model relies on historical weather, development patterns and other inputs.



(Left) Area burned by wildfires between 2000 and 2016 across the western United States inside and outside the 2010 WUI including a 2.5-km community protection zone (27). (Right) About 15% of the WUI burned during this period, with largest proportions of the WUI burning in California, Colorado, and Washington.

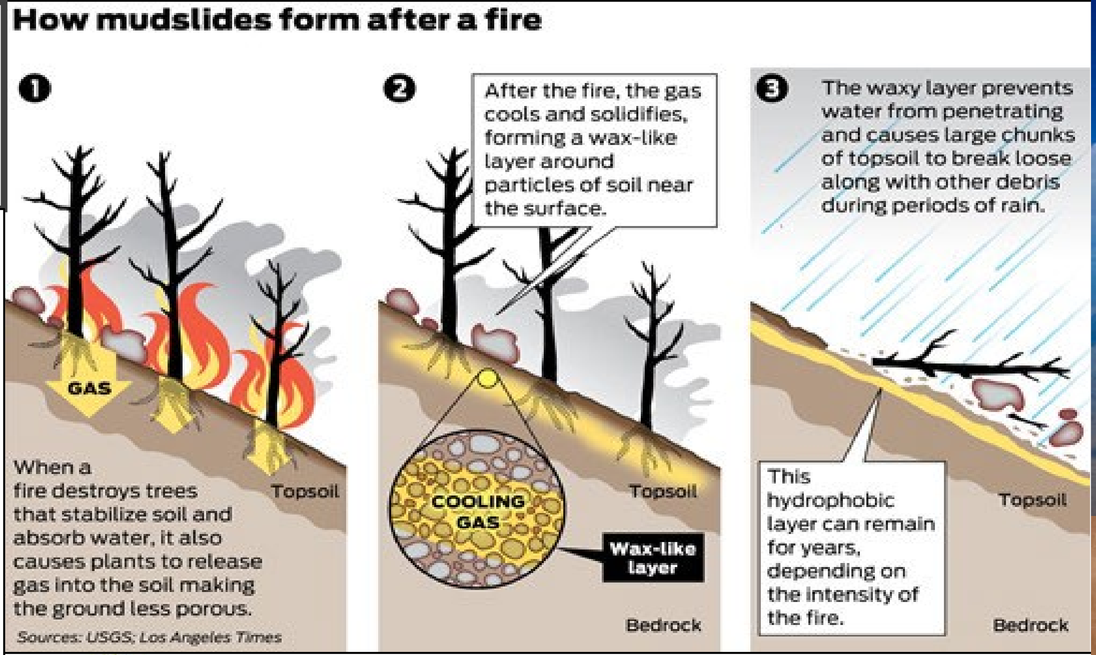
WILDFIRE CASCADING IMPACTS

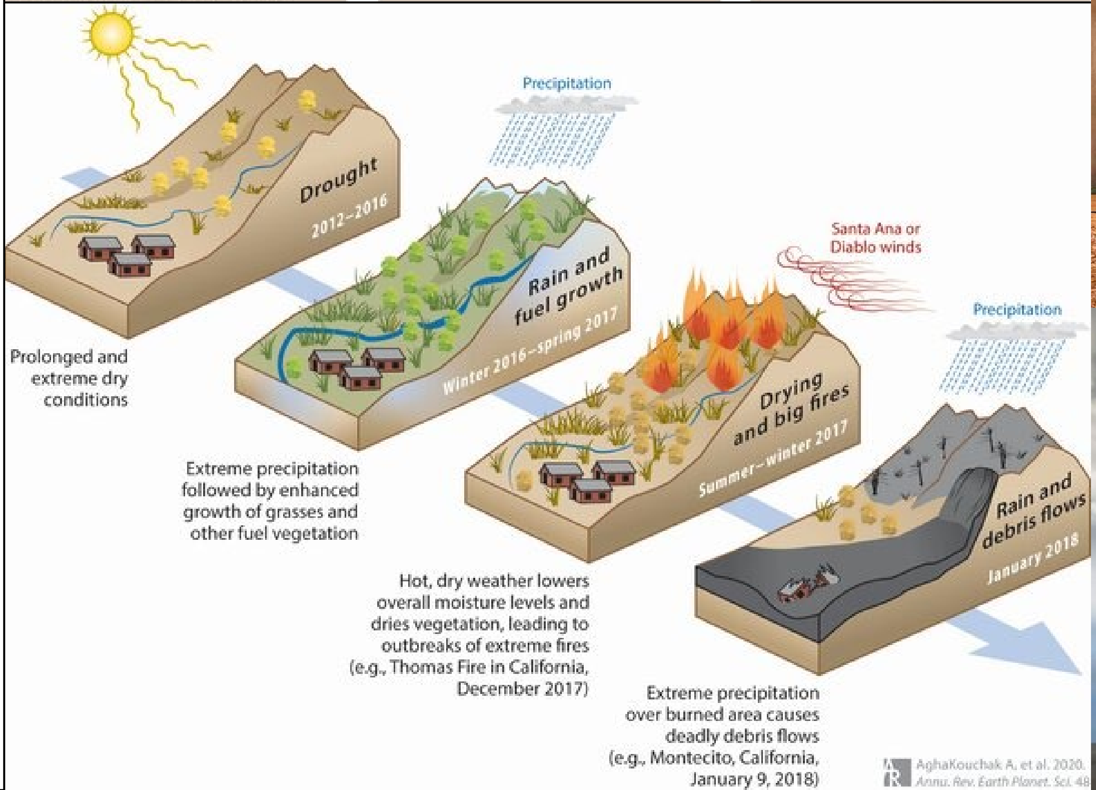
Wildfire damage is often seen as a spontaneous development with immediate threats from the ignition and spread of fire. The development of larger and hotter burning fires is causing larger areas of wax-like layers in soil to contribute to debris-flows and destroys soil nutrients necessary for healthy plant return to the region impacted.

Wildfire damage can amplify the drought impacts at the surface by removing trees and exposing soils to direct sunlight, stronger winds due to a lack of blocking, and loose, dried soil causing an increase in large dust storms called throughout the West.

A haboob is an extreme dust storm that can last for up to three hours. Dust storms of this size can take down trees, power lines, bury equipment, fill reservoirs and rivers, damage buildings, and cause 'dust-pneumonia' in livestock and people.

Haboobs and Debris Flows are expected to increase annually.





Fire intensity is a term that is used to describe the rate at which a fire produces thermal energy. Fire intensity is most frequently quantified in terms of Fireline intensity because this measure is related to flame length, which is easily measured.

Fire severity is a more qualitative term that is used to describe ecosystem responses to fire and is useful for describing the effects of fire on the soil and water system. Severity reflects the amount of energy (heat) that is released by a fire and the degree that it affects the soil and water resources. It is classified according to postfire criteria on the site burned and has been classified into *low*, *moderate*, and *high* fire severity.

- Heat transfer in the soil during the combustion of aboveground fuels and surface organic layer.
- High intensity fires can produce high severity changes in the soil.
- Combustion is the rapid physical-chemical destruction of organic matter that releases the large amounts of energy stored in fuels as heat.

Three components are necessary for a fire to ignite and initiate the combustion process.

✓ Burnable fuel must be available.

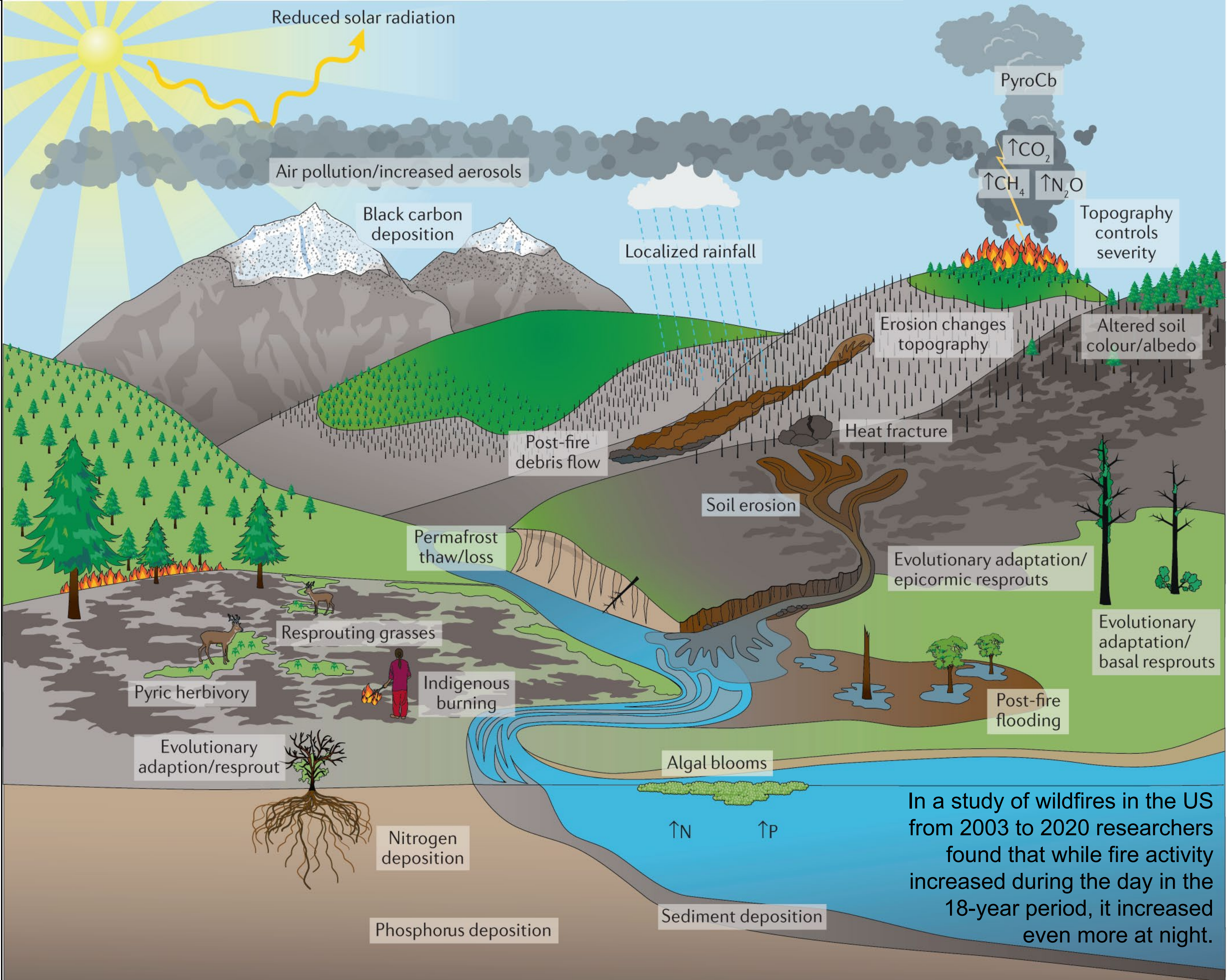
✓ Sufficient heat must be applied to the fuel to raise its temperature to the ignition point.

✓ Sufficient oxygen (O2) is necessary to keep the combustion process going and to maintain the heat supply needed for igniting unburned fuel.

As heat is transferred downward into the soil, it raises the temperature of the soil.

- The greatest increase in temperature occurs at/near the soil surface.

Fires are getting larger and harder to extinguish…



In a study of wildfires in the US from 2003 to 2020 researchers found that while fire activity increased during the day in the 18-year period, it increased even more at night.

https://www.fs.fed.us/rm/pubs/rmrs_gtr042_4.pdf

AIR QUALITY IMPACTS

Recent studies have identified correlation in 18 regions of California during heavy smoke periods showing the positive relationship between the smoke days and growth in hospitalizations for respiratory and cardiac illnesses.

- The number of claims asthma medication ‘Albuterol’ increased by 240,000 between 2013-2018 according to the Centers for Medicare/Medicaid.
- California found that children who breathed the smoky air during wildfires had more coughing, wheezing, bronchitis, colds, and were more likely to medical care for respiratory causes, especially from asthma.
- BlueSky is a modeling framework designed to predict cumulative impacts of smoke from forest, agricultural, and range fires. The smoke modeling combines emissions, meteorology, and dispersion models to create possible predictions of smoke impacts across regions. https://tools.airfire.org/websky/v2/#status

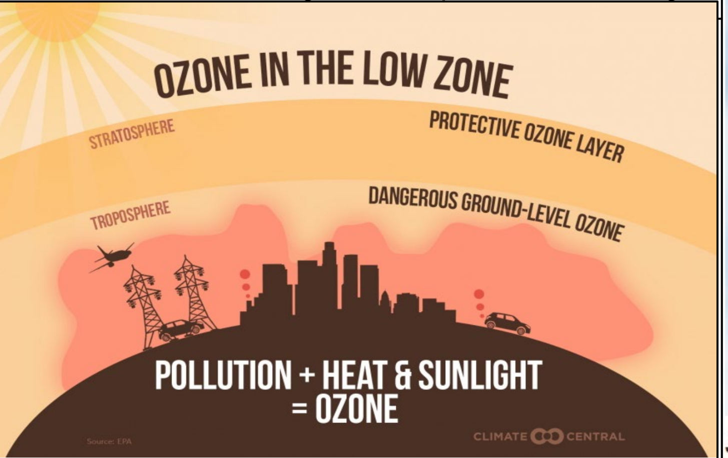
Short term exposure can cause:

Coughing, phlegm, wheezing, bronchitis reduced lung function, breathing issues heart failure, heart-attack, stroke, and increased risk of premature death.

Long term exposure can cause:

Reduced lung capacity, accelerated lung aging, and possibly cancer.

Most ground-level ozone is the result of reactions of man-made Volatile Organic Compounds and Nitrogen.



0-50	Good	Enjoy your usual outdoor activities.
51-100	Moderate	Extremely sensitive children and adults should refrain from strenuous outdoor activities.
101-150	Unhealthy for Sensitive Groups	Sensitive children and adults should limit prolonged outdoor activity.
151-200	Unhealthy	Sensitive groups should avoid outdoor exposure and others should limit prolonged outdoor activity.
201-300	Very Unhealthy	Sensitive groups should stay indoors and others should avoid outdoor activity.
301-500	Hazardous	Everyone should avoid all outdoor exertion.

GREEN: Air quality is good.

YELLOW: Air quality is acceptable, but there may be some health concerns.

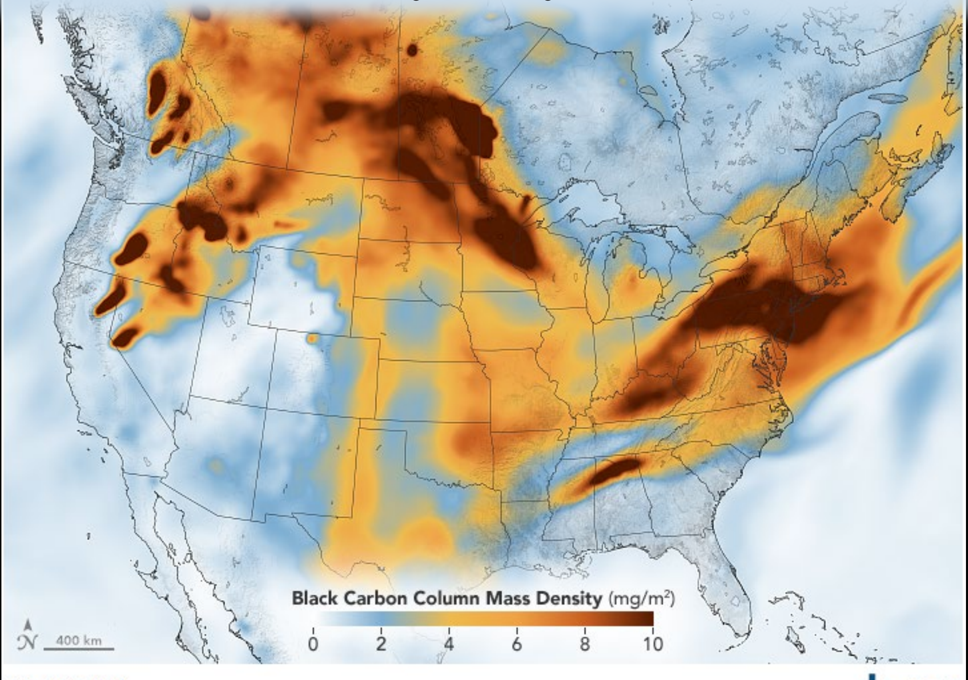
ORANGE: Air quality is unhealthy for sensitive groups — people with lung or cardiac disease, children, outdoor athletes and older adults.

RED: Air quality is bad. Outdoor activity should be limited for all children, and sensitive individuals should stay indoors.

CN

Information from Arizona Department of Environmental

Ozone is formed when heat and sunlight cause chemical reactions between oxides of nitrogen (NOX) and Volatile Organic Compounds (VOC), which are also known as Hydrocarbons. This reaction can occur both near the ground and high in the atmosphere.

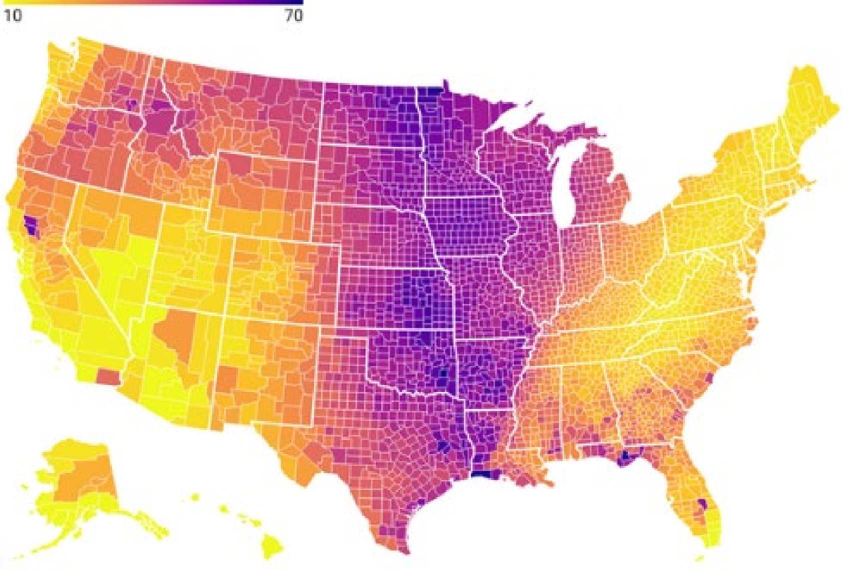


July 21, 2021

JPEG

Wildfire smoke exposure across U.S. counties, 2009-2013

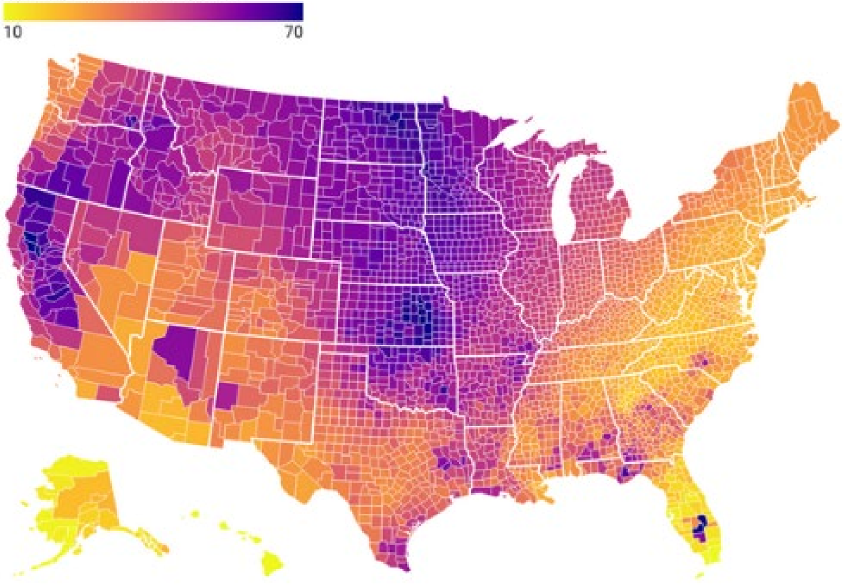
Average days per year by county



Map: Alison Saldanha • Source: Analysis of National Oceanic and Atmospheric Administration satellite imagery by NPR's California Newsroom and Stanford University's Environmental Change and Human Outcomes Lab • Created with Datawrapper

Wildfire smoke exposure across U.S. counties, 2016-2020

Average days per year by county

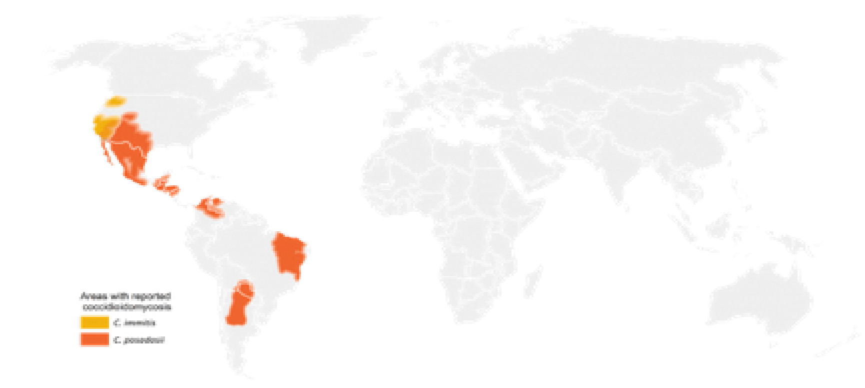


Valley fever, also called coccidioidomycosis, is an infection caused by the fungus *Coccidioides*. The fungus is known to live in the soil in the southwestern United States and parts of Mexico and Central and South America.

Coccidioides spores circulate in the air after contaminated soil and dust are disturbed by humans, animals, or the weather. The spores are too small to see without a microscope. When people breathe in the spores, they can develop Valley fever. The fungus was originally discovered in 1892 in Buenos Aires and San Joaquin Valley.

- The fungus was also recently found in south-central Washington. People can get Valley fever by breathing in the microscopic fungal spores from the air, although most people who breathe in the spores don't get sick. Usually, people who get sick with Valley fever will get better on their own within weeks to months, but some people will need antifungal medication.
- *Coccidioides* lives in dust and soil in some areas in the southwestern United States, Mexico, and South America. In the United States, *Coccidioides* lives in Arizona, California, Nevada, New Mexico, Texas, and Utah.

Coccidioides is thought to grow best in soil after heavy rainfall and then disperse into the air most effectively during hot, dry conditions. There are about 15 thousand cases of Valley fever in the U.S. each year, and approximately 200 deaths, according to the U.S. CDC. Only 40% of people infected have symptoms, and 8% of those go to the hospital. https://www.nasa.gov/feature/dust-storms-and-valley-fever-in-the-american-west



Estimated areas with coccidioidomycosis (Valley fever) worldwide

"There's no vaccine – the fungus lives with you for the rest of your life. Those infected are paying about US $50,000 per hospital visit, and a quarter of those people must go ten times or more" (NASA Research Team and the CDC).

Pregnant people, immunocompromised, African Americans, and Filipinos are especially at risk.

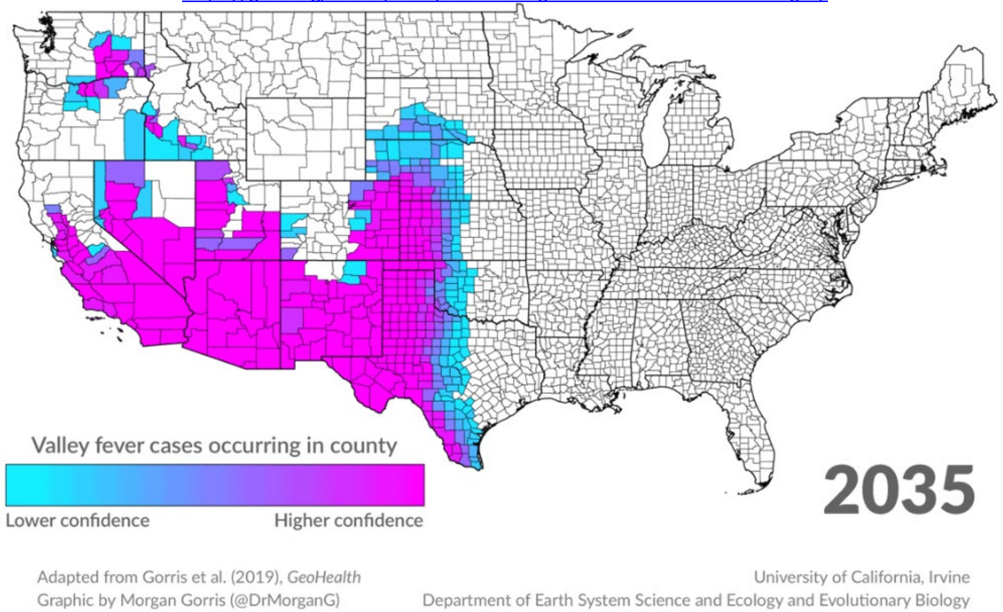
The CDC states about 150,000 cases of Valley fever go undiagnosed annually.

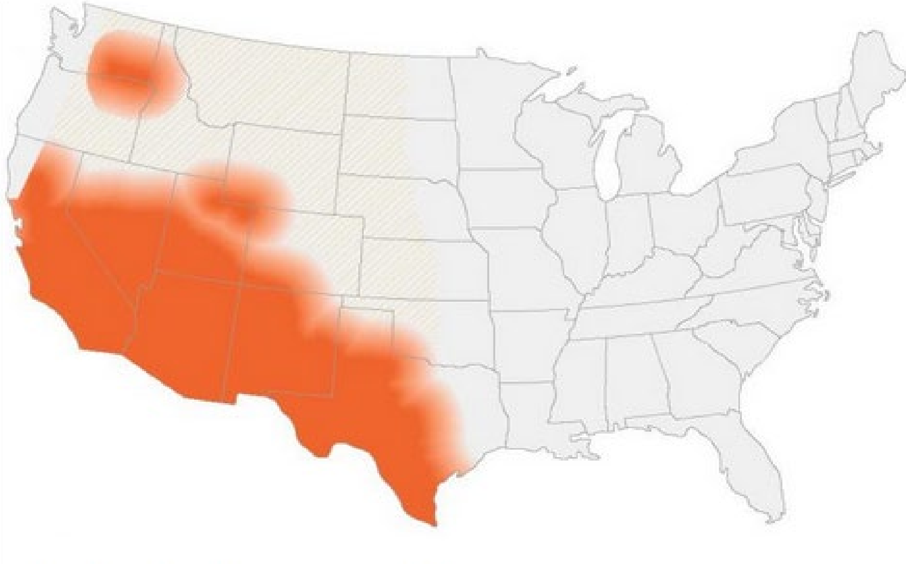
Valley fever cases in the US increased 32% between 2016-2018. Cases in California rose *800%* from 2000-2018.

The disease's morbidity rate in the endemic region is comparable to polio, measles, and chicken pox

Expansion of Valley fever in the western US in response to high climate warming (RCP8.5)

https://grist.org/health/valley-fever-rising-us-west-wildfires-cocci-fungus/

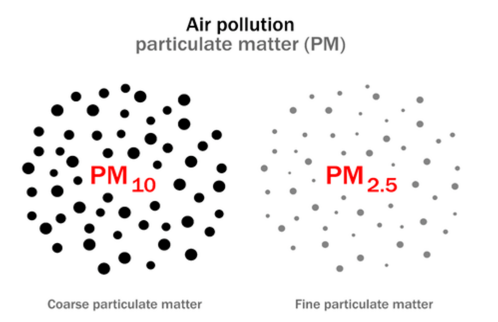


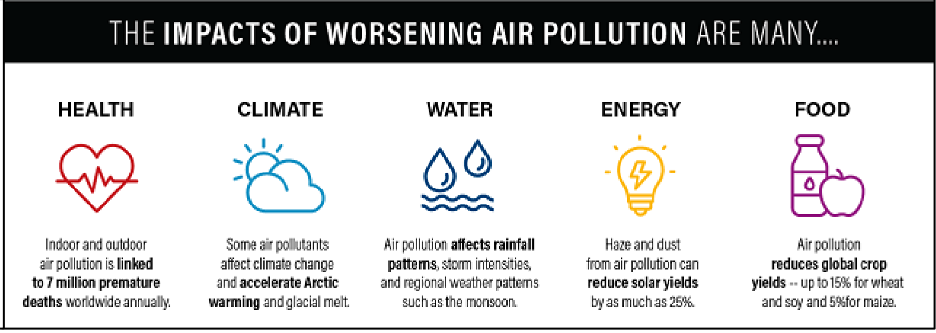


Estimated areas with coccidioidomycosis (Valley fever) in the United States

Dust Damage

World Meteorological Organization: Airborne Dust – Summary and Bulletin's:
https://public.wmo.int/en/our-mandate/focus-areas/environment/sand-and-dust-storms





Sand and dust storms usually occur when strong winds lift large amounts of sand and dust from bare, dry soils into the atmosphere. They are usually caused by thunderstorms – or strong pressure gradients associated with cyclones – which increase wind speed over a wide area. Some 40% of aerosols in the troposphere (the lowest layer of Earth's atmosphere) are dust particles from wind erosion.

- The main sources of these mineral dusts are the arid regions of Northern Africa, the Arabian Peninsula, Central Asia and China. Comparatively, Australia, America and South Africa make minor, but still important, contributions.
- Global estimates of dust emissions, mainly derived from simulation models, vary between one and three Gigatons per year.
- The ability of dust particles to absorb solar radiation depends on their size, shape and mineralogical and chemical composition.

Airborne dust presents serious risks for human health. Dust particle size is a key determinant of potential hazard to human health. Particles larger than 10 μm are not breathable and can only damage external organs – mostly causing skin and eye irritations, conjunctivitis and enhanced susceptibility to ocular infection.

- Inhalable particles, those smaller than 10 μm, often get trapped in the nose, mouth and upper respiratory tract, thus can be associated with respiratory disorders such as asthma, tracheitis, pneumonia, allergic rhinitis and silicosis.
- Finer particles may penetrate the lower respiratory tract and enter the bloodstream, where they can affect all internal organs and be responsible for cardiovascular disorders. A global model assessment in 2014 estimated that exposure to dust particles caused about 400 000 premature deaths by cardiopulmonary disease in the over 30 population.

Meningococcal meningitis, a bacterial infection of the thin tissue layer that surrounds the brain and spinal cord, can result in brain damage and, if untreated, death in 50% of cases. Outbreaks occur worldwide, yet the highest incidence is found in the "meningitis belt", a part of sub-Saharan Africa with an estimated population of 300 million.

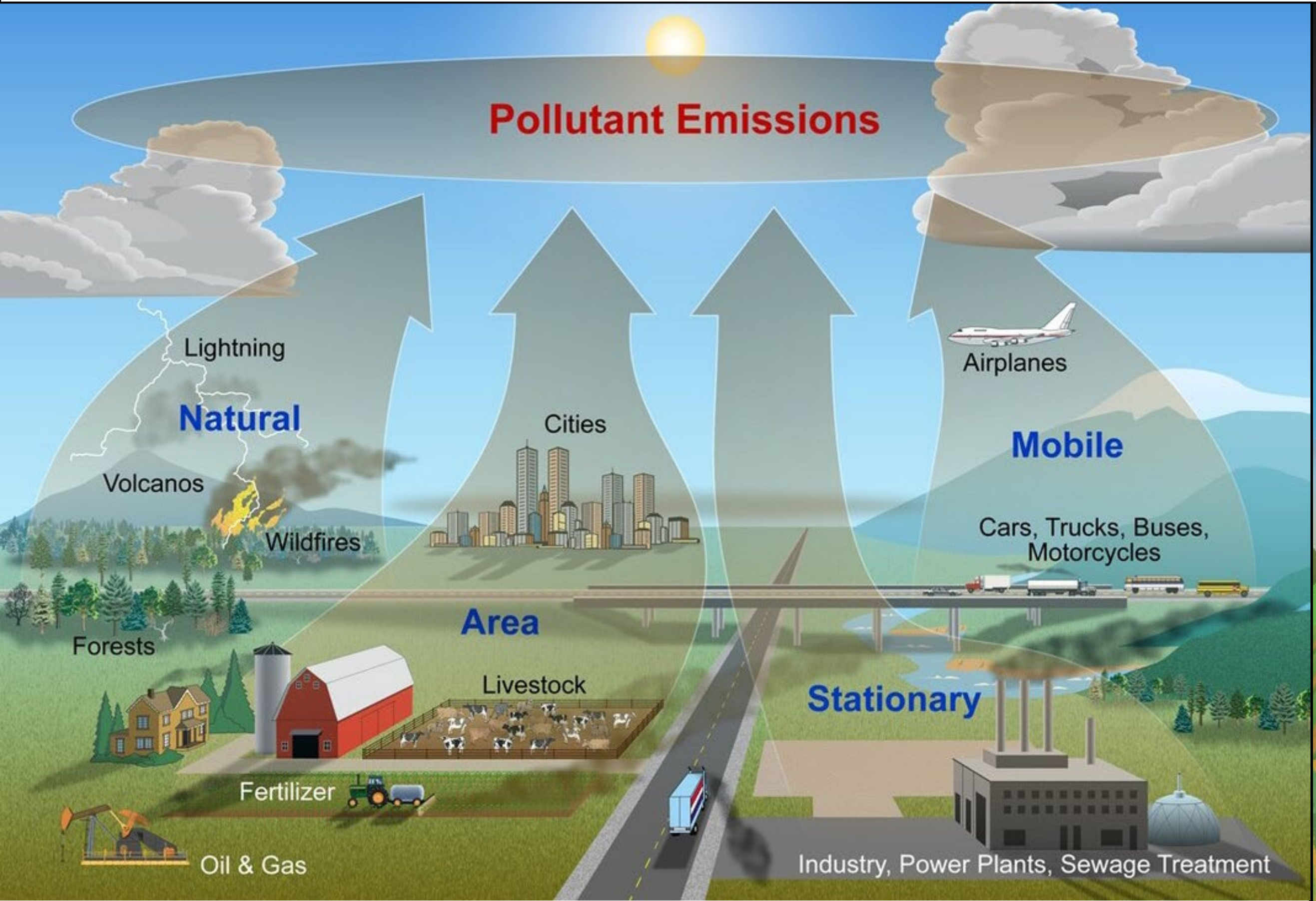
- These outbreaks have a strong seasonal pattern – many studies have linked environmental conditions, such as low humidity and dusty conditions, to the time and place of infections. Researchers believe that the inhalation of dust particles in hot dry weather may damage nose and throat mucosa creating favorable conditions for bacterial infection. Iron oxides embedded in dust particles may enhance the risk of infection.
  - Saharan dust is thought to fertilize the Amazon rainforest, and dust transports of iron and phosphorus are known to benefit marine biomass production in parts of the oceans suffering from the shortage of such elements.
- Dust also has many **negative** impacts on agriculture, including reducing crop yields by burying seedlings, causing loss of plant tissue, reducing photosynthetic activity and increasing soil erosion.
  - Indirect dust deposit impacts include filling irrigation canals, covering transportation routes and affecting river and stream water quality. Dust can impact on the output of solar power plants, especially those that rely on direct solar radiation.

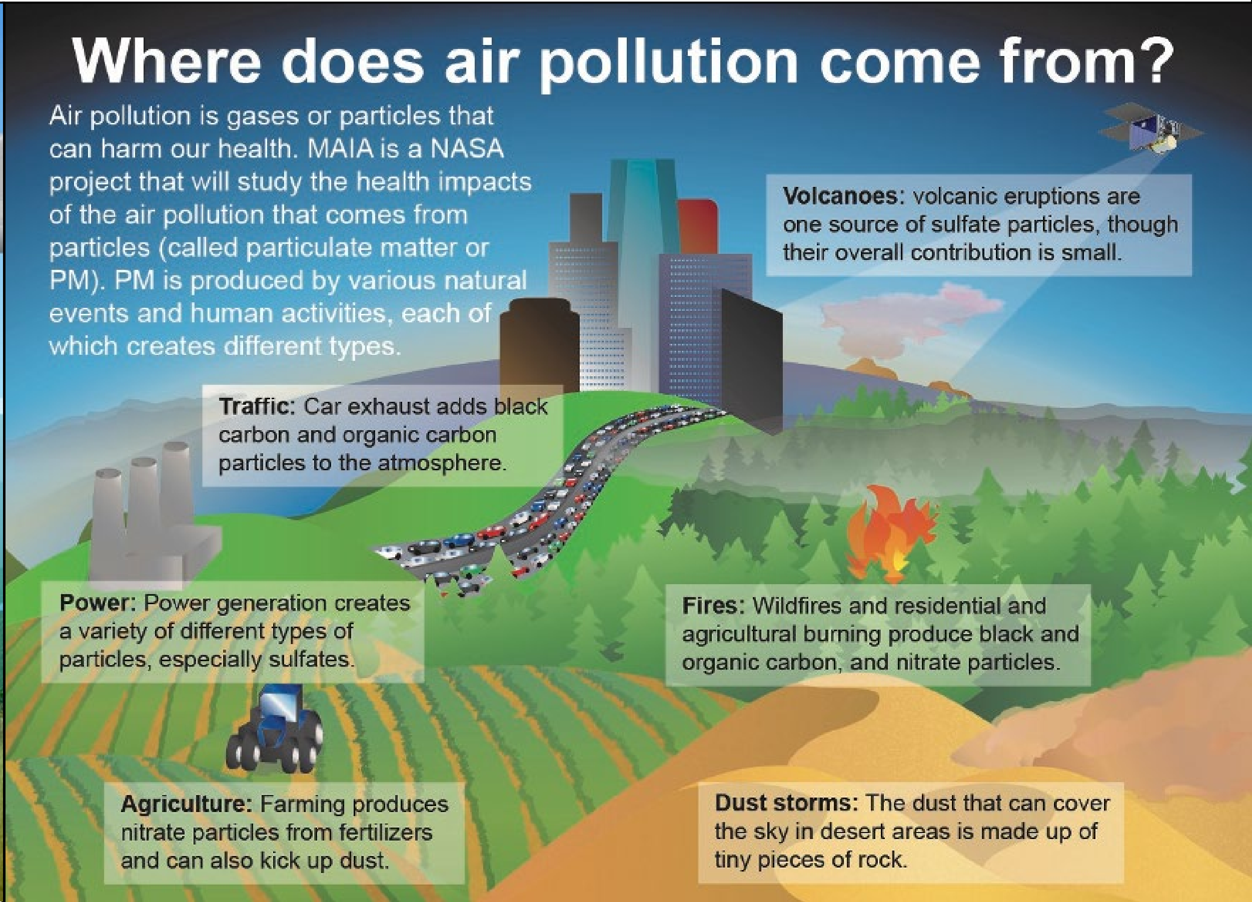
Air pollution is caused by solid and liquid particles and certain gases that are suspended in the air. These particles and gases can come from car and truck exhaust, factories, dust, pollen, mold spores, volcanoes and wildfires. The solid and liquid particles suspended in our air are called **aerosols**. (NASA)

- Any particle that gets picked up into the air or is formed from chemical reactions in the air can be an aerosol. Many aerosols enter the atmosphere when we burn fossil fuels, such as coal and petroleum, and wood. These particles can come from many sources, including car exhaust, factories and even wildfires.
- Some of the particles and gases come directly from these sources, but others form through chemical reactions in the air. Aerosols can come from other places, too, such as ash from an erupting volcano. Dust, pollen from plants and mold spores are also examples of aerosols.
- A gas called **ozone** is a major cause of air pollution. Ozone is also a greenhouse gas that can be both good and bad for our environment.

Ground-level ozone is formed when **volatile organic compounds (VOCs), also known as hydrocarbons, and nitrogen oxides (NOx)** interact in the presence of sunlight.

Sources of VOC and NOx emissions include large industry such as chemical manufacturers, and combustion sources such as power plants burning fossil fuels; small industry such as gasoline-dispensing facilities, autobody paint shops, and print shops; automobiles, trucks and buses; and off-road engines such as aircraft, locomotives, construction equipment and gasoline-powered lawn and garden equipment.





How many people die from air pollution each year?

Estimates of the global death toll from air pollution published in major recent studies

'All sources' includes both anthropogenic and natural sources:

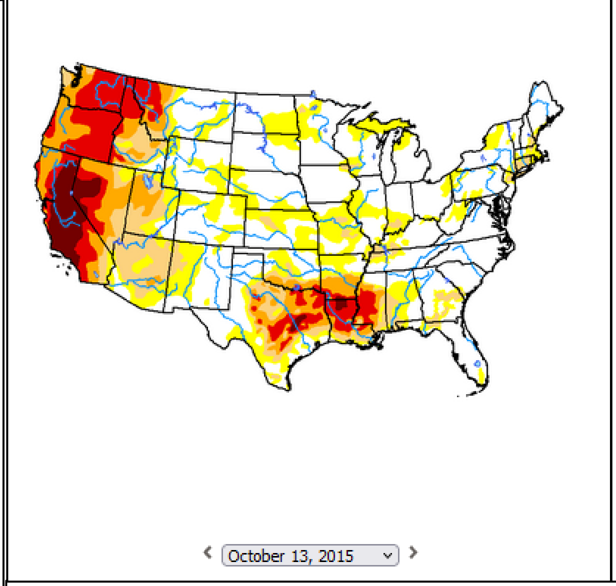
- The largest source of natural air pollution is airborne dust in the world's deserts. Other natural sources are fires, sea spray, pollen, and volcanoes.
- Anthropogenic sources include electricity production; the burning of solid fuels for cooking and heating in poor households; agriculture; industry; and road transport.

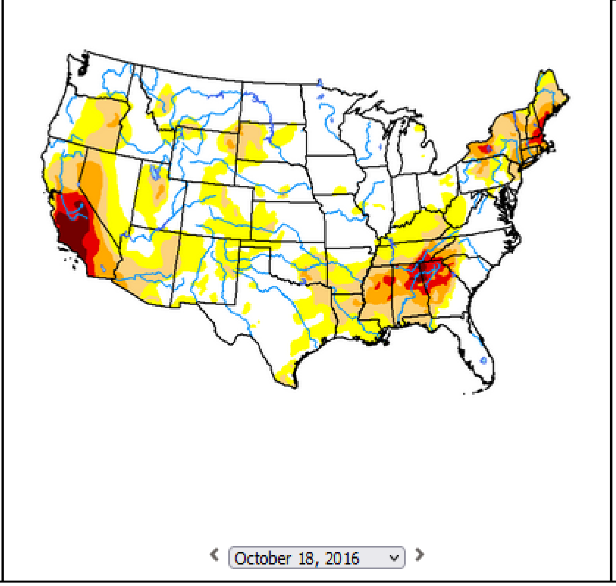
https://ourworldindata.org/data-review-air-pollution-deaths

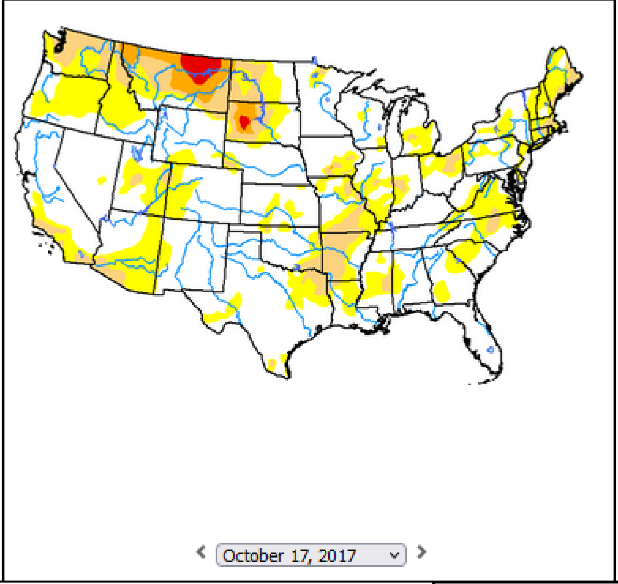
Data on annual death tolls from other causes is the latest data from the World Health Organization, UCDP, and Global Terrorism Database as of November 2021.

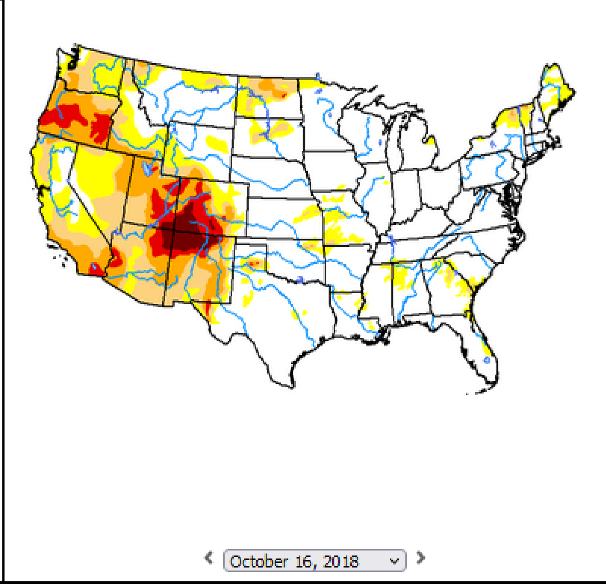
OurWorldinData.org – Research and data to make progress against the world's largest problems.

US Drought 2015-2022

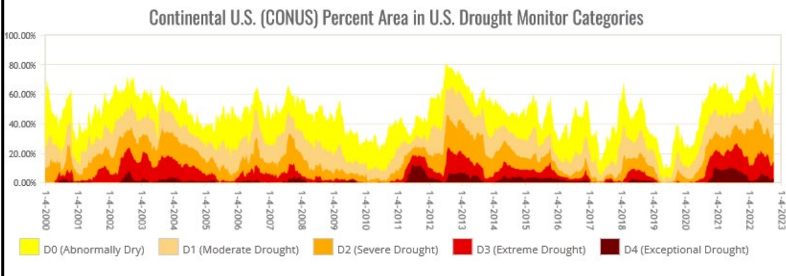


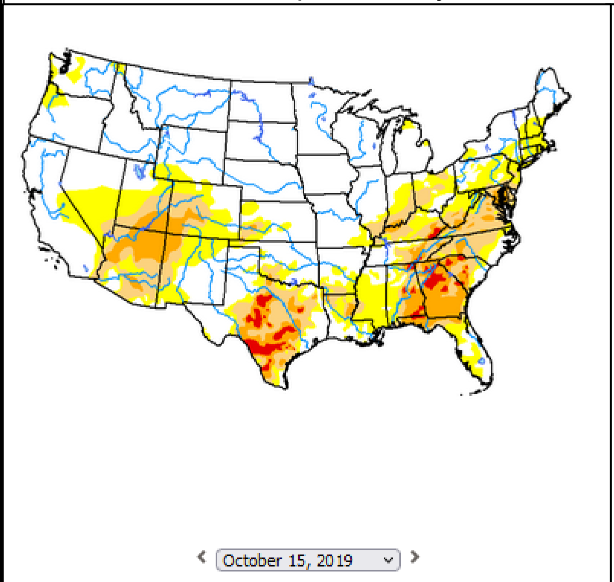


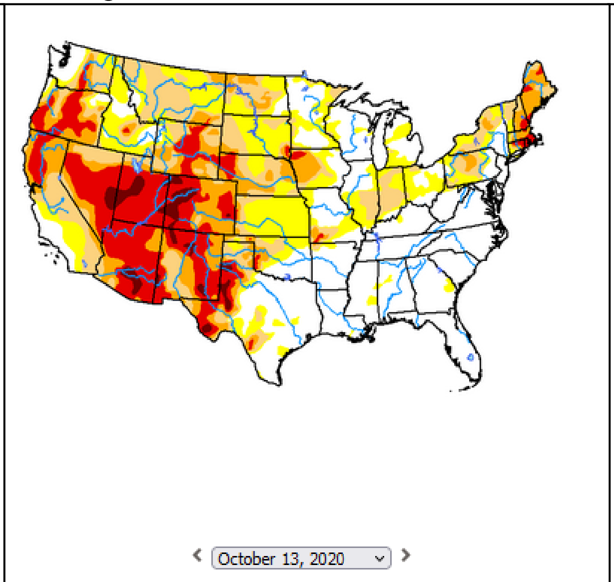


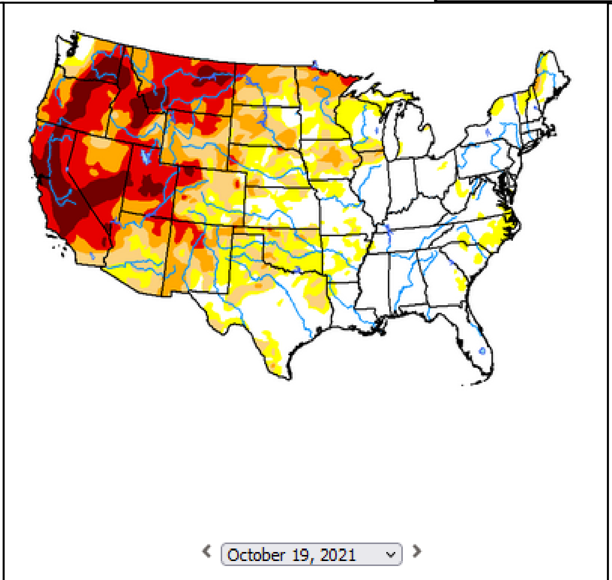


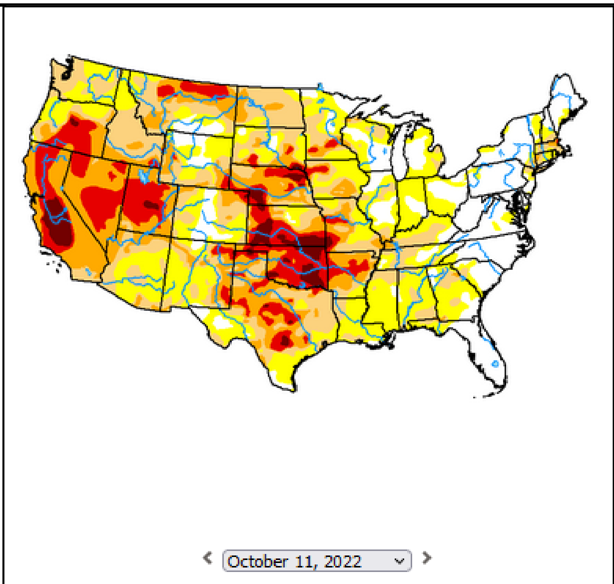
Societal Impacts from Drought: Anxiety or depression about economic losses caused by drought. Health problems related to low water flows and poor water quality. Health problems related to dust. Loss of human life. During 2022, drought impacted about a third of the entire US population. In regions that rely on rainfall for agricultural production, drought can diminish crop and livestock outputs and may severely affect farm profitability. Drought also reduces the quantity of snowpack and streamflow available for diversions to irrigated agricultural land. Locally, droughts can reduce farm income and negatively impact food processing and agricultural service sectors, while food prices may increase at the regional and the national levels.











DROUGHT

There have been at least three major U.S. droughts in the last 100 years. Two of these, the 1930s Dust Bowl drought and the 1950s drought, each lasted 5-7 seven years and covered large areas of the country with significant impacts. The current drought has persisted in many areas for the past 22 years, with conditions rapidly deteriorating over the last two years across the west.

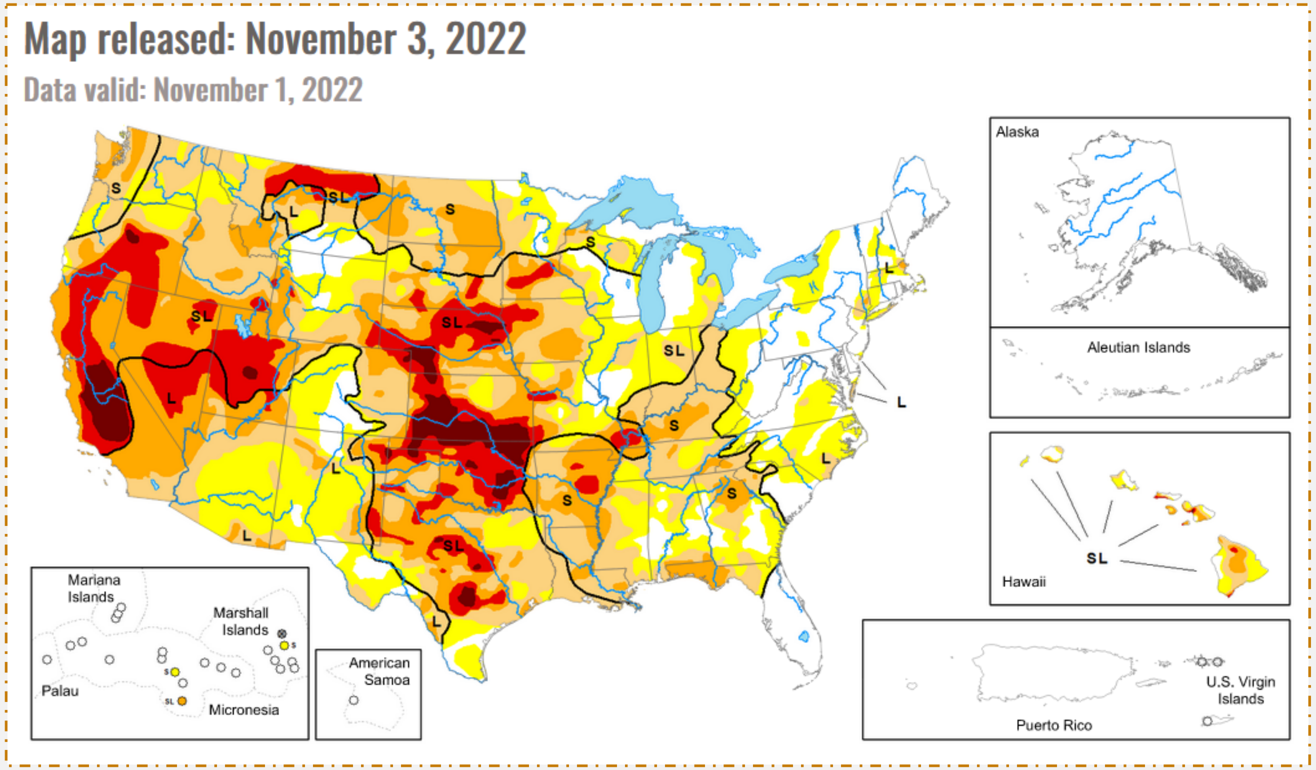
Research from Columbia University's Earth Observatory suggests the current drought is the driest period in 1,200 years and has increased the overall atmospheric 'thirst'.

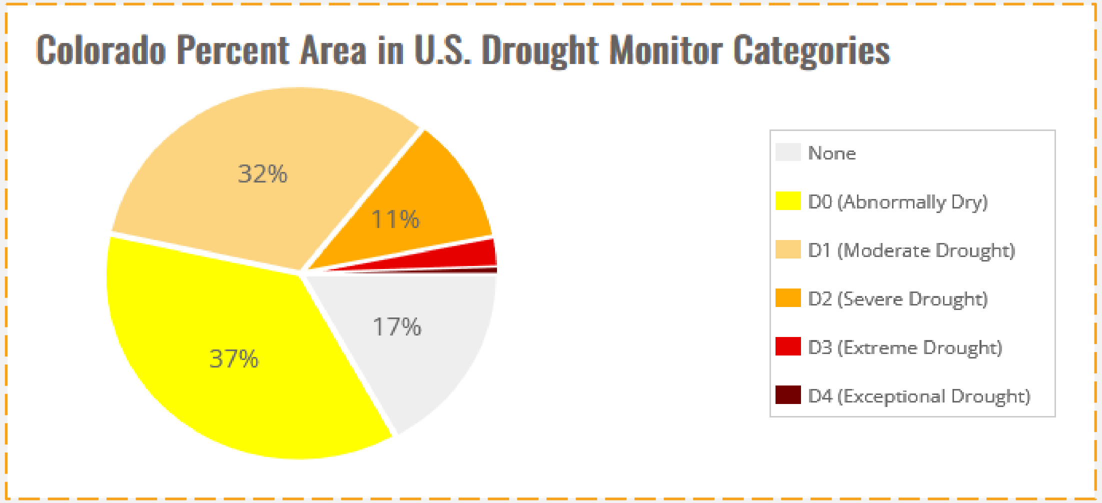
Meteorological drought is based on the degree of dryness (rainfall deficit) and the length of the dry period.

Hydrologic drought is based on the impact of rainfall deficits on the water supply such as stream flow, reservoir and lake levels, and ground water table decline.

Agricultural drought is based on the impacts to agriculture by factors such as rainfall deficits, soil water deficits, reduced groundwater, or reservoir levels needed for irrigation.

Socioeconomic drought is based on the impact of drought conditions (meteorological, agricultural, or hydrological drought) on supply and demand of some economic goods. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related deficit in water supply.





HEAT AND ATMOSPHERIC MOISTURE CONTRIBUTING TO FIRE SPREAD

The Evaporative Demand Drought Index (EDDI) - an experimental tool that examines how anomalous the atmospheric evaporative demand (E0; "the thirst of the atmosphere") is for a given location over a given period.

- EDDI can serve as an indicator of both rapidly evolving "flash" droughts (developing over weeks) and sustained droughts (developing over months but lasting years).

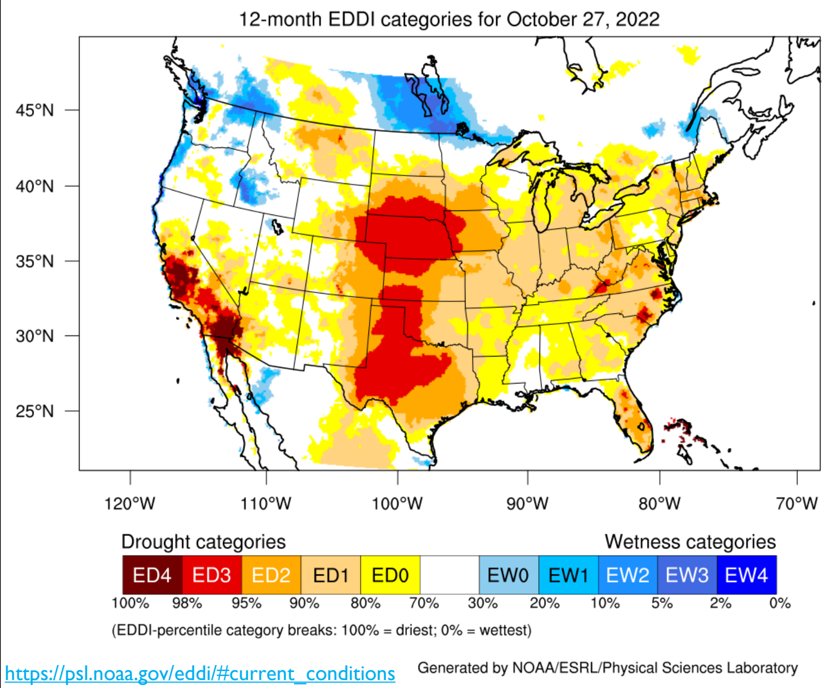
Flash drought - the rapid onset or intensification of drought. This occurs when lower-than-normal rates of precipitation are accompanied by abnormally high temperatures, winds, and radiation.

Evapotranspiration - the process by which water is transferred from the land to the atmosphere by evaporation from the soil, other surfaces, and by transpiration from plants.

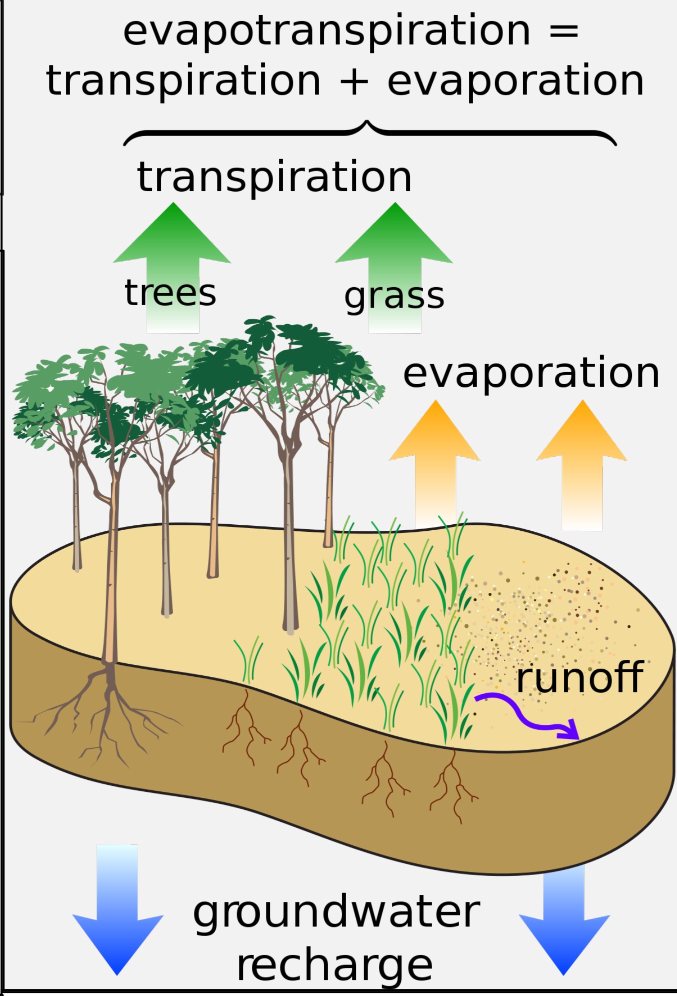
Excessive Heat Warning - a heat index of 105 °F or greater that will last for 2 hours or more.

- This increase is driven primarily by rising air temperatures and will significantly boost the risk of extreme wildfires.

EDDI Category Map



https://psl.noaa.gov/eddi/#current_conditions

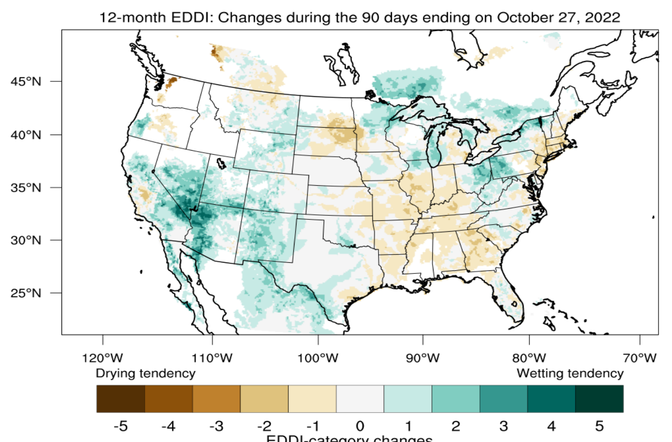


Research shows the likelihood of extreme multiyear droughts will increase, threatening regional water supplies.

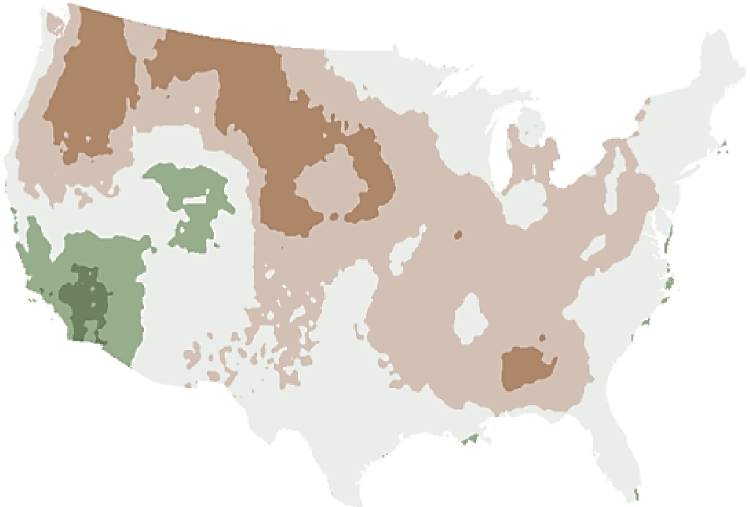
Currently, EDDI is generated daily—though with a 5-day lag-time—by analyzing a near-real-time atmospheric dataset. This lag-time results from the procedures to quality control the meteorological data used to estimate evaporative demand.

- EDDI can offer early warning of agricultural drought, hydrologic drought, and fire-weather risk by providing near-real-time information on the emergence or persistence of anomalous evaporative demand in a region. A particular strength of EDDI is in capturing the precursor signals of water stress at weekly to monthly timescales, which makes EDDI a strong tool for preparedness for both flash droughts and ongoing droughts.

Wildfire damage can amplify the drought impacts at the surface by removing trees and exposing soils to direct sunlight due to a lack of shade, stronger winds due to a lack of blocking which could cause additional drying and move loose, dried soil causing an increase in larger dust storms throughout the West increasing threats of fungal spread for threats like Valley Fever.



RISK FACTOR



Changing humidity

An increase in temperature also leads to an increase in the rate of water evaporation, causing changes to atmospheric humidity that affect the way heat impacts communities.

Change in relative humidity in 30 years

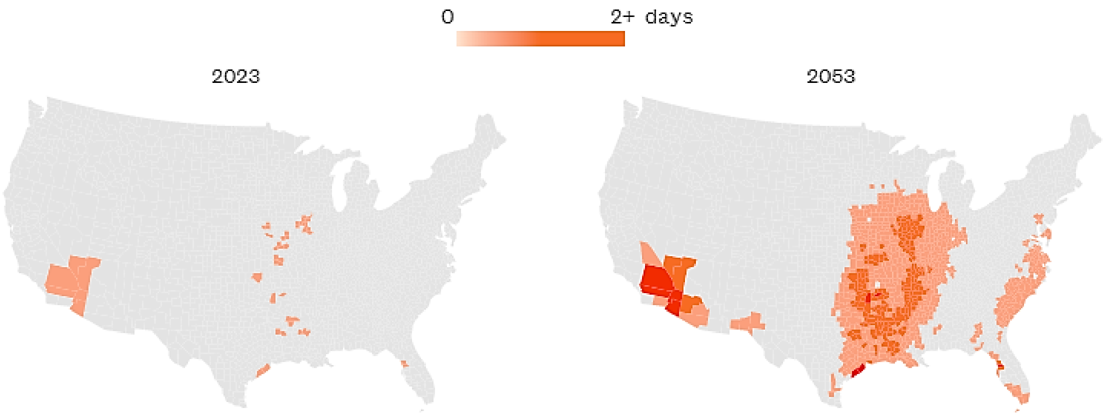
-4% -2% 0% 2% 4%

Climatology Lab MACAv2 downscaled GCM, based on historical period 1950-2005 and adjusted to future conditions using the RCP4.5 emissions scenario.

https://riskfactor.com/

Dangerous heat days

The middle of the U.S. is projected to see a rise in days with heat index temperatures above 125 degrees



Notes: Heat index temperature is the "feels like" temperature – what the temperature feels like to the human body when air temperature is combined with humidity.

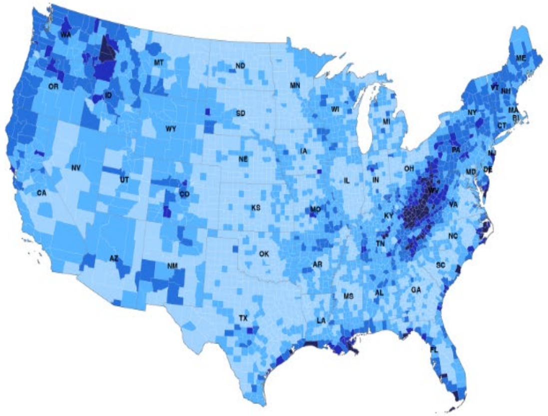
Source: First Street Foundation

Graphic: Nigel Chiwaya / NBC News

FLOOD Risk across the United States

FLOOD FACTOR | FIRE FACTOR | HEAT FACTOR

24.7 M	26 M	5.3 %
Properties at risk today	Properties at risk in 30 years	Change in risk



Property County

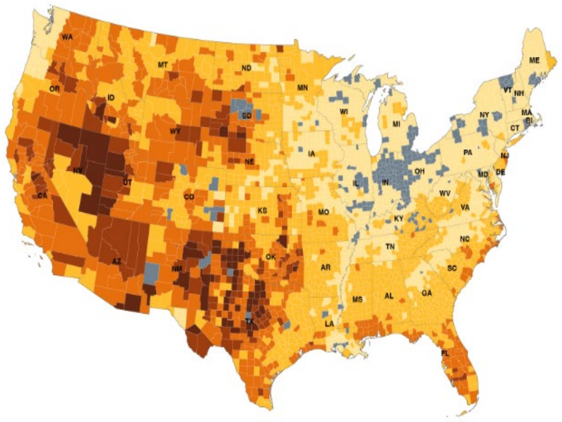
Distribution of properties at risk (145M analyzed)

- Minor - 1.3M
- Moderate - 5.4M
- Major - 7.4M
- Severe - 6.2M
- Extreme - 5.7M

FIRE Risk across the United States

FLOOD FACTOR | FIRE FACTOR | HEAT FACTOR

71.8 M	79.8 M	11.1 %
Properties at risk today	Properties at risk in 30 years	Change in risk



Property County

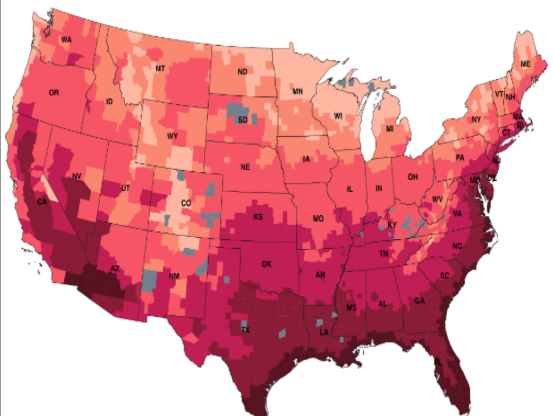
Distribution in properties at risk (145M analyzed)

- Minor - 49.4M
- Moderate - 20.2M
- Major - 6.0M
- Severe - 2.7M
- Extreme - 1.5M

HEAT Risk across the United States

FLOOD FACTOR | FIRE FACTOR | HEAT FACTOR

15.8 M	107 M	157 %
Properties with Extreme Risk	Population with yearly days above 125°F in 30 years	Avg. increase in local hot days



Property County

Distribution in properties at risk (145M analyzed)

- Minimal - 6.7M
- Minor - 15.7M
- Moderate - 39.6M
- Major - 36.4M
- Severe - 27.4M
- Extreme - 15.8M

Major Datacenters

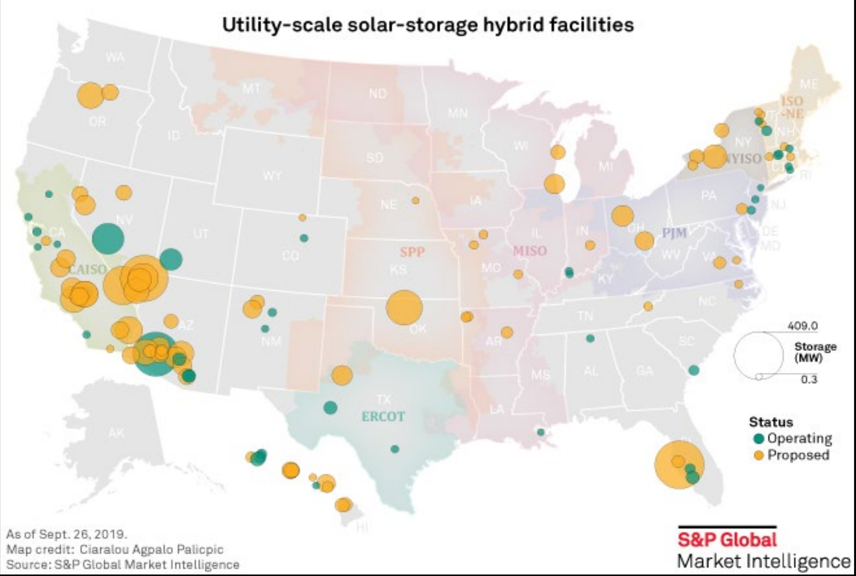
Drought and datacenters: About 20% of data centers in the United States rely on watersheds that are under moderate to high stress from drought and other factors.

In the US, there are about 2,600 data centers, many of which are clustered around Dallas, the San Francisco Bay area, and Los Angeles, according to a 2021 report by the US International Trade Commission.

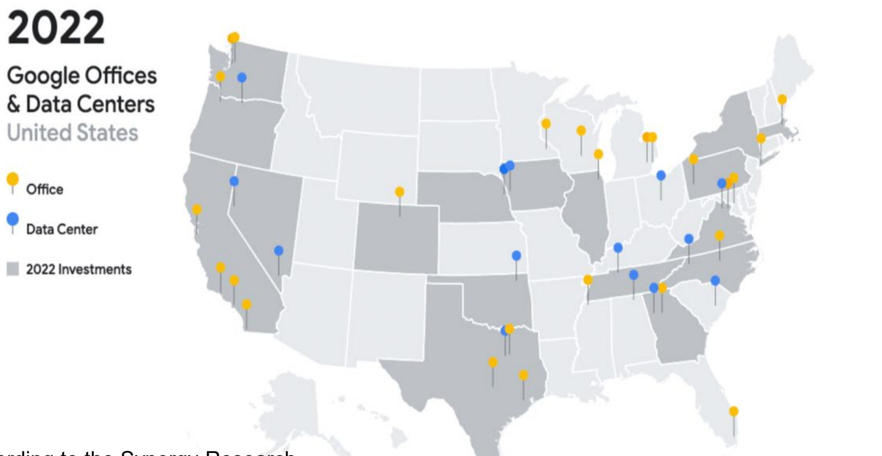
A mid-sized data center consumes around 300,000 gallons of water a day, or about as much as 1,000 US households.

Data centers are ranked among the top 10 water users in America's industrial and commercial sectors.

Researchers at Virginia Tech estimate that one-fifth of data centers draw water from moderately to highly stressed watersheds, mostly in the Western United States



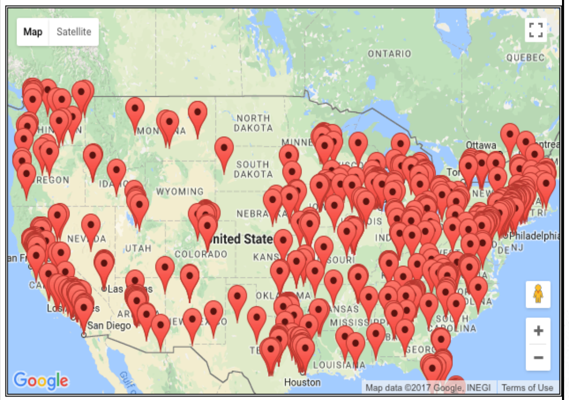
Data centers need water for cooling although many are in areas with significant drought growth and water restrictions.

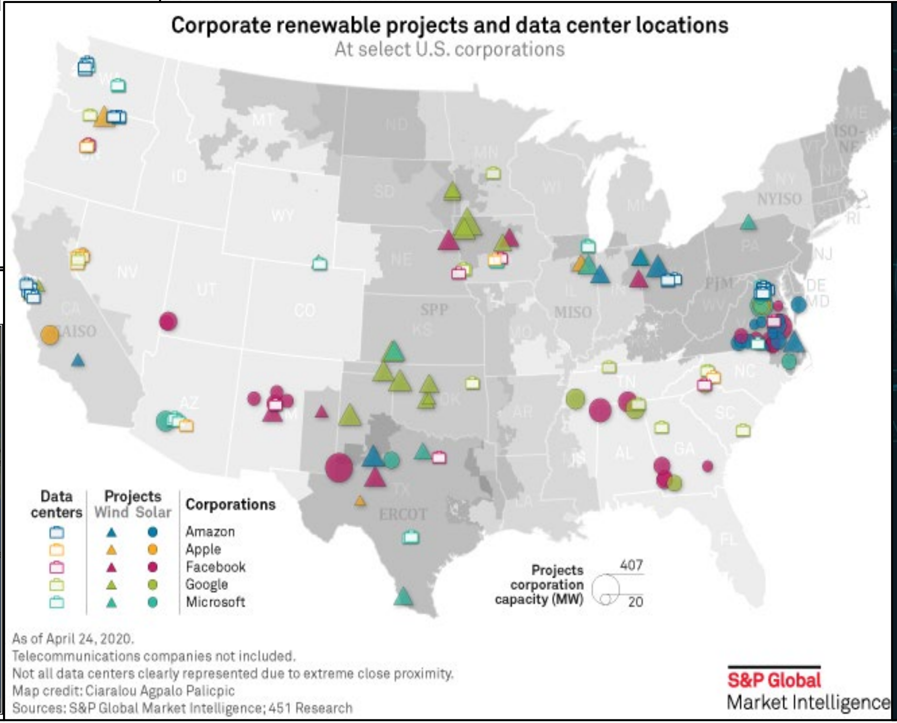


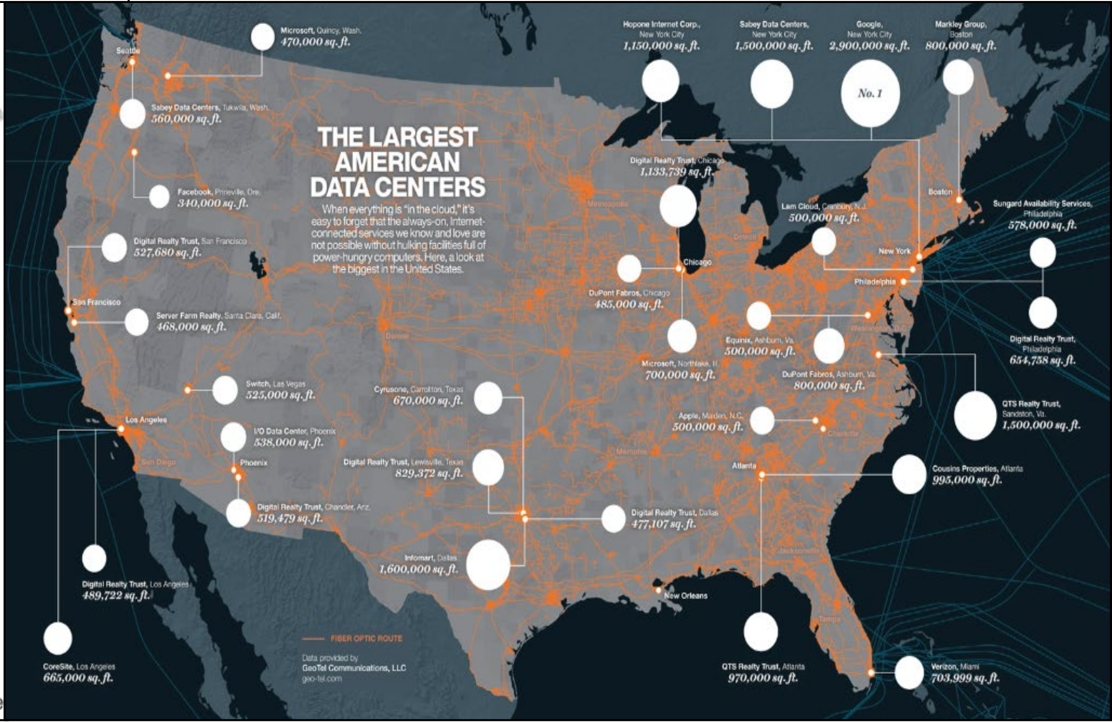
According to the Synergy Research Group, there were about 600 "hyperscale" data centers, large operations designed and operated by a single company that then rents access to cloud services, globally by the end of 2020 which is double the amount in 2015.

Almost 40% of them are in the US, and Amazon, Google and Microsoft account for more than half of the total.

US Data Center List







Heat, Drought, and Datacenters

The heat wave in the UK in mid-July 2022 caused 34 locations to exceed record temperatures. Oracle was forced to power down 'non-critical' hardware due to breakdowns in the cooling systems from the high heat.

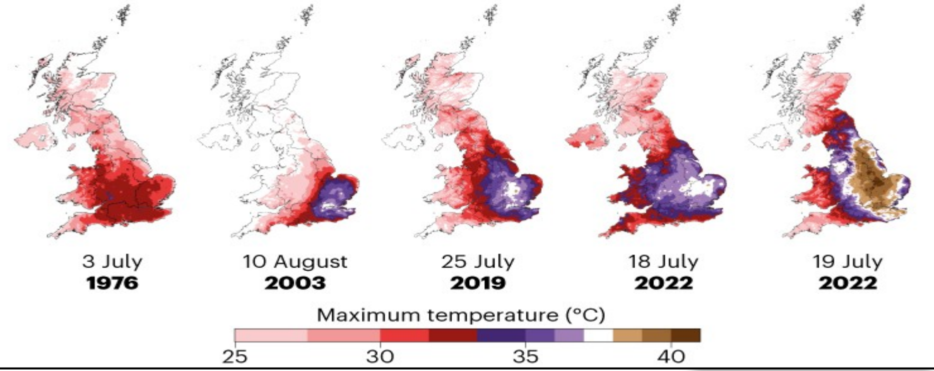
- Google also reported a cooling failure earlier the same day, impacting its europe-west2 region.
    - The immediate impact was that Google was inaccessible to numerous customers, error rates and latency issues were widespread across Europe, and service unavailability was reported for over two hours.
- Both industry leaders reported the issues were prompted by the extreme heat and resulting necessary shutdowns to prevent additional damages once cooling systems were impacted.

During that heat wave, following the datacenter threat announcement from two large industry leaders, some data centers in the UK took a more basic approach to cooling by spraying their roof-mounted AC units with water, which lowers the ambient temperature around the coils and enables the units to function efficiently.

- Utilizing water for cooling capabilities during a mass drought will not be a solution in the coming years as water resources become more strained and the overall atmospheric humidity levels could shift to decrease cooling effects from water combining with heat.
- As high heat expands further into regions unprepared for temperatures to reach certain thresholds for prolonged periods of time, more information technology related equipment is likely to see failures across multiple countries.
    - Areas with increasing humidity rates will no longer be able to rely on their cooling towers to sufficiently operate their datacenters or powerplants.
    - Power lines also sag and carry less electrical load during high heat events, making them less efficient and more hazardous.
- High heat causes more evapotranspiration which also reduces the amount of stored surface water in reservoirs and rivers, reducing the hydroelectric output and threatening systems which require flowing river water for their cooling systems.
    - Nuclear power plants in France encountered hot river water issues for ecology standards, resulting in reduced operations at a time when excess energy was necessary for winter storage. The result was the nuclear regulator granting temporary waivers to five nuclear plants to discharge hot water to rivers, breaching environmental standards but allowing for some increase in operational capacity.

HOTTER EXTREMES

The UK heatwave this year far surpassed previous record heat events, in terms of both peak temperatures and the area covered by the torrid conditions.



Using nature to cool data centers

Here are some ways data centers can use nature to cool their facilities:

- **Geothermal cooling** uses the near-constant temperature of the Earth below surface level to provide cooling. It's an old idea used to keep food cold centuries ago and adapted to our modern era. In data centers, geothermal cooling uses a closed-loop pipe system with water or another coolant that runs through vertical wells underground, filled with a heat-transferring liquid. Iron Mountain's western Pennsylvania data center, Verne Global in Iceland and Green Mountain in Norway use geothermal cooling for their data centers.
- **Evaporative cooling**, or swamp cooling, takes advantage of the drop in temperature that occurs when water is exposed to moving air and begins to vaporize and change to a gas. A fan draws warm data center air through a water- or coolant-moistened pad, and as the liquid evaporates, the air is chilled and pushed back into the data center. It can cost a fraction of an air-cooled HVAC system and works best in low-humidity climates.
- **Solar cooling** converts heat from the sun into cooling that can be used in data center air cooling systems. The system collects solar power and uses a thermally driven cooling process to decrease the air temperature in a building. This is useful in areas with a lot of sunlight or data centers looking to supplement their current cooling with a more environmentally friendly method.
- **KyotoCooling** is an enhancement of the free cooling method that uses a thermal wheel to control hot and cold airflows across the data center. Internal hot air is vented to the outside as the wheel rotates; the outside air then cools the wheel and the air that is drawn back into the facility. It uses between 75% to 92% less power to run than other CRAH systems, reduces carbon dioxide emissions and eliminates the need for water in the cooling system. The technology is used by United Airlines' data center outside of Chicago and by HP in its data center outside of Toronto.

Drought-Low Flows at the Rivers

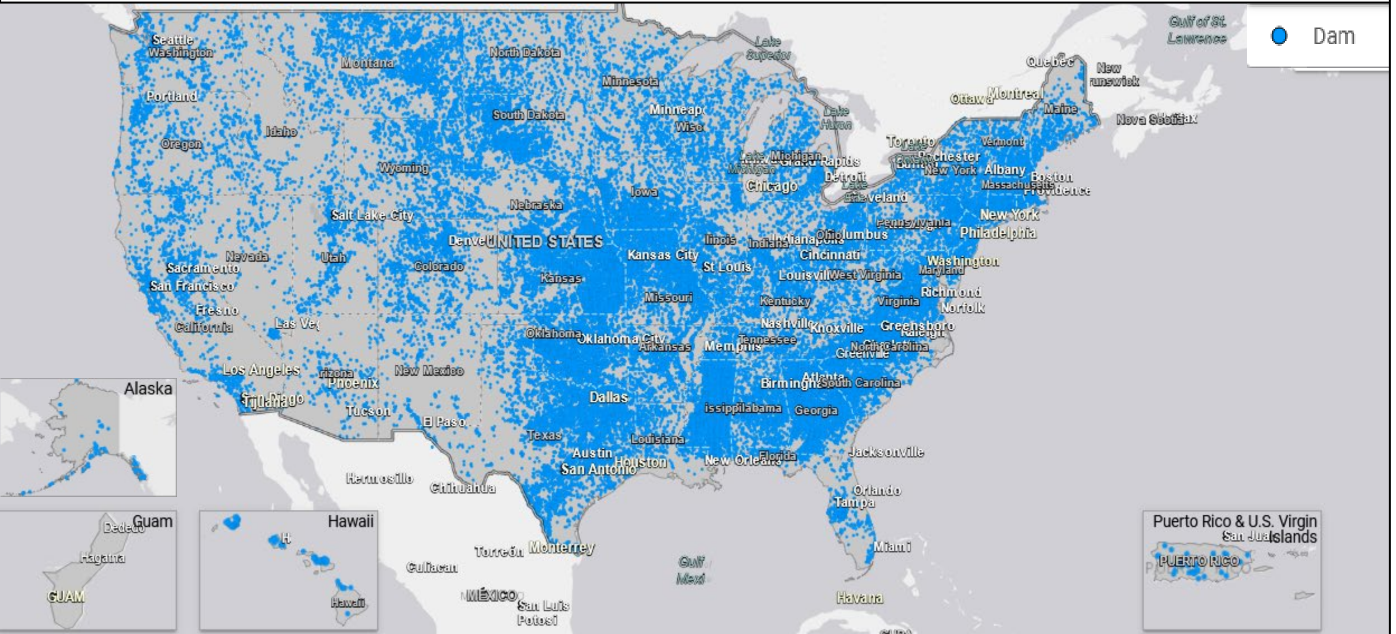
Low flowing river systems can have cascading impacts in river systems like the Mississippi and Missouri River Systems which both have reported incidents at the end of summer where water levels were so low that barge traffic came to a halt. Low flowing rivers and a loss of the surface water due to evaporation and dried soils can also impact hydroelectric provision. Last year the upper Missouri River System reported more than 28 hydroelectric facilities were closed due to low river water levels and this year hydropower production on the Upper Colorado River system for water year 2022, which ended on Sept. 30, was down about 20% compared with the previous year and about 30% compared with the yearly average since 2000, according to a Bureau of Reclamation.

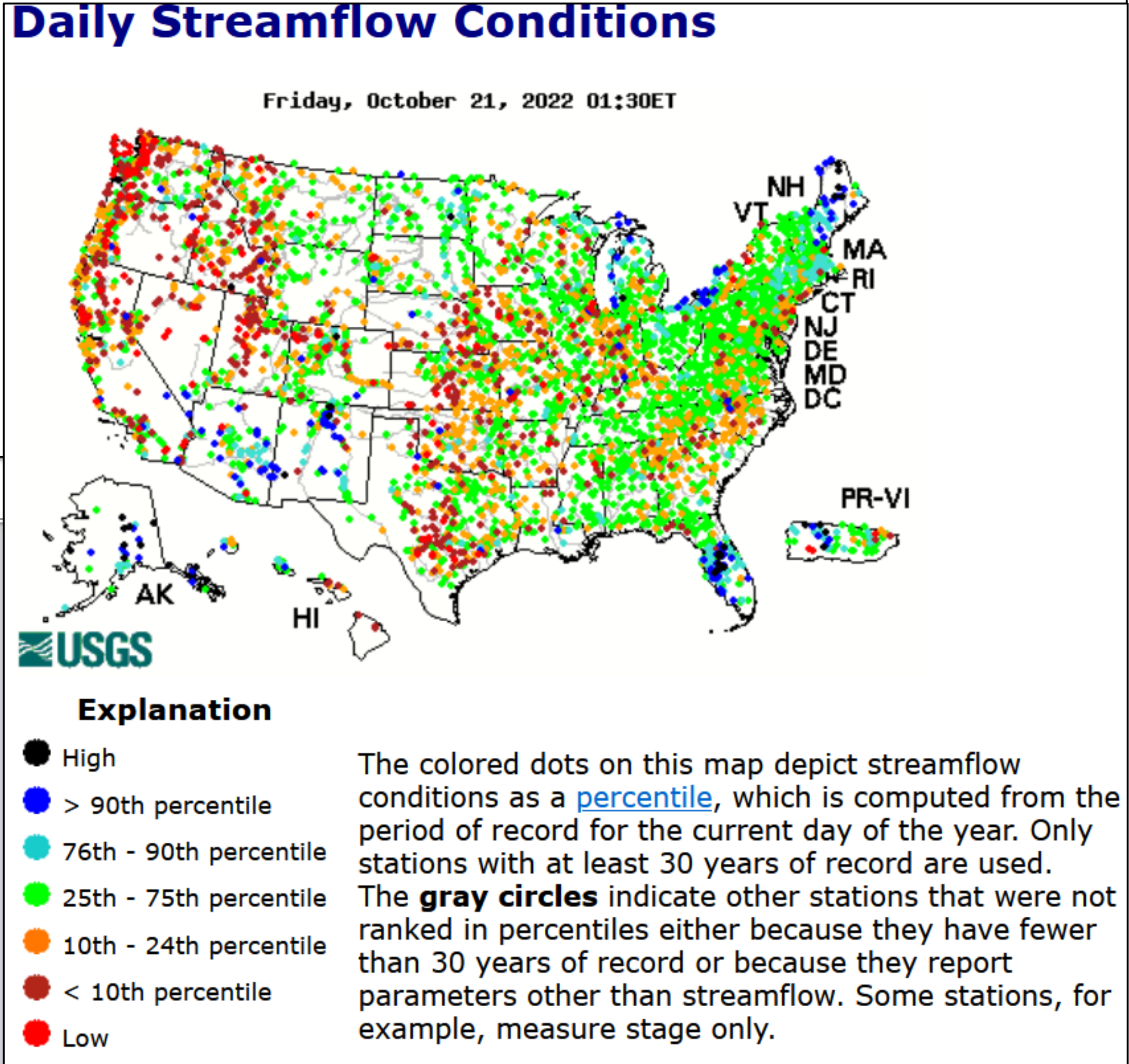
The last time hydropower generation from the Colorado River Storage Project was this low was in 1967 in which not every dam was producing energy at that point.

- When compared to a pre-drought average from 1988 to 1999, the most recent water year hydroelectric generation is down about 43%
- Lake Powell's Glen Canyon Dam produces 78% of the Colorado River Storage Project hydropower while Blue Mesa Reservoir accounts for about 5% of the production.

Infrastructure was put in place accounting for maintaining water levels, not for the evaporation and sudden downpours which control the surface water balance now.

- Costs will begin to reflect the needs for new infrastructure and increasing maintenance fees.



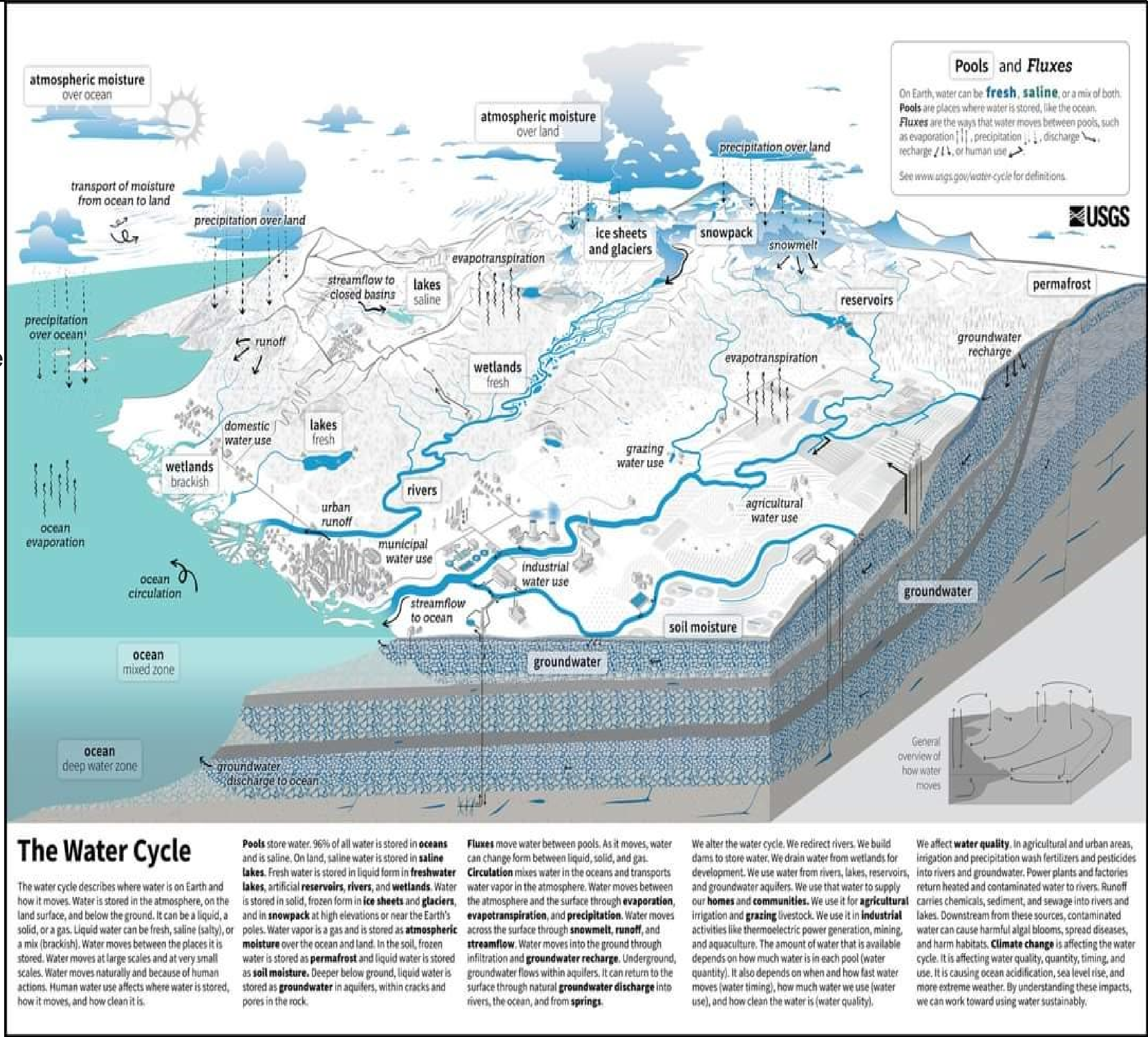


Impacts to Dams from Heat

Increasing direct solar radiation from the lack of storm system movement allowing heatwave conditions to persist can impact the hydromechanical elements (gates, motors) for dams and lock systems which may shorten the lifespan of the equipment which is rated around 30-50 years.

Heat also causes evaporation from bodies of water left under direct heating. The evaporation reduces the overall amount of water remaining in a reservoir, river, or canal and dries the soils and plants across the region.

- The soils and plants will take more absorption from the water as it passes through the areas during releases which will deplete the amount of water which was intended to move downstream in its entirety. The reservoirs still release a set amount of water, regardless of the drying conditions between the point of release and the point of need which will cause more areas requesting multiple releases from upstream stations to stave off immediate impacts.
  - An example: The Oklahoma City Water Utilities Trust is drawing water from Canton Lake in October to increase water levels in Lake Hefner. Before this summer, the city has not resorted to taking water from Canton since 2013. Now, the U.S. Army Corps of Engineers is sending water down the North Canadian River for the second time in three months.
- In July 2022 Fort Worth Water had 476 main breaks with 221 of those from June to July. The 182 breaks in 30 days is more than 38% of the yearly total.
  - The extreme heat and lack of rain dries out the ground to the point it shifts, causing main breaks.
  - Water main breaks during high heat events have been reported in multiple states across the US from Hawaii to Michigan to Massachusetts.
    - "When a pipe under the city of Odessa broke in mid June 2022, an estimated 165,000 people in the region immediately lost running water for basic household functions such as drinking, cooking, cleaning and toilet use."



Drought and Seismic Activity

A fault is formed in the Earth's crust as a brittle response to stress. Generally, the movement of the tectonic plates provides the stress, and rocks at the surface break in response to this. Faults form when rock above an inclined fracture plane moves downward, sliding along the rock on the other side of the fracture. Normal faults are often found along divergent plate boundaries, such as under the ocean where new crust is forming. Long, deep valleys can also be the result of normal faulting.

- Collisions zones are where tectonic plates push up, resulting in mountain ranges such as the Himalayas and the Rocky Mountains. The San Andreas Fault in California is the largest in the world at more than 800 miles from the Salton Sea to Cape Mendocino. A devastating earthquake is reportedly due by 2030 along this fault.

The number of earthquakes in the central U.S. has increased dramatically over the past decade. Between the years 1973–2008, there was an average of 25 earthquakes of magnitude three and larger in the central and eastern United States. Since 2009, at least 58 earthquakes of this size have occurred each year, and at least 100 earthquakes of this size every year since 2013. The rate peaked in 2015 with 1010 M3+ earthquakes. In 2019, 130 M3+ earthquakes occurred in the same region.

"The gravity recovery and Climate experiment (GRACE measurements) reveals that major earthquakes (Mw 5 and above) always occur in the dry stage, indicating drought and associated groundwater extraction is an important trigger for major earthquakes." Earthquakes result from strain build-up from without and weakening from within faults.

- The loss of an estimated 63 trillion gallons of water in West, most of it groundwater, was reported in a study done by researchers at the Scripps Institution of Oceanography. The loss of the water has caused the ground to rise more than a half-inch in California's mountains.

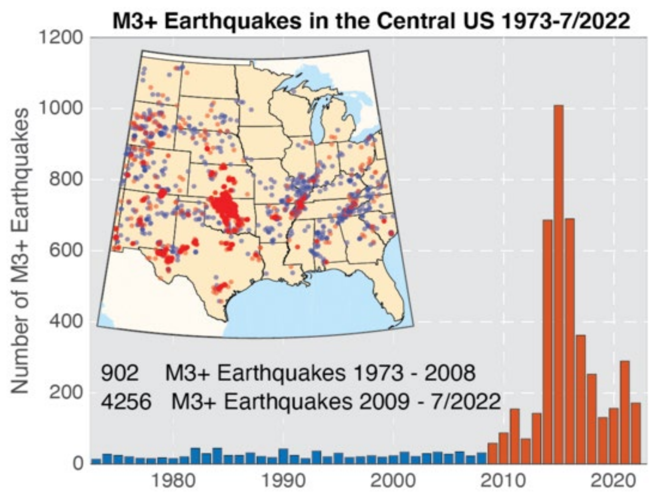
The areas around fault lines have valleys where the plates meet and are at their weakest point. Due to the lower elevations around these topography features, water tends to pool at the lowest elevation and thereby river systems were naturally located in the weaker spots of the fault line.

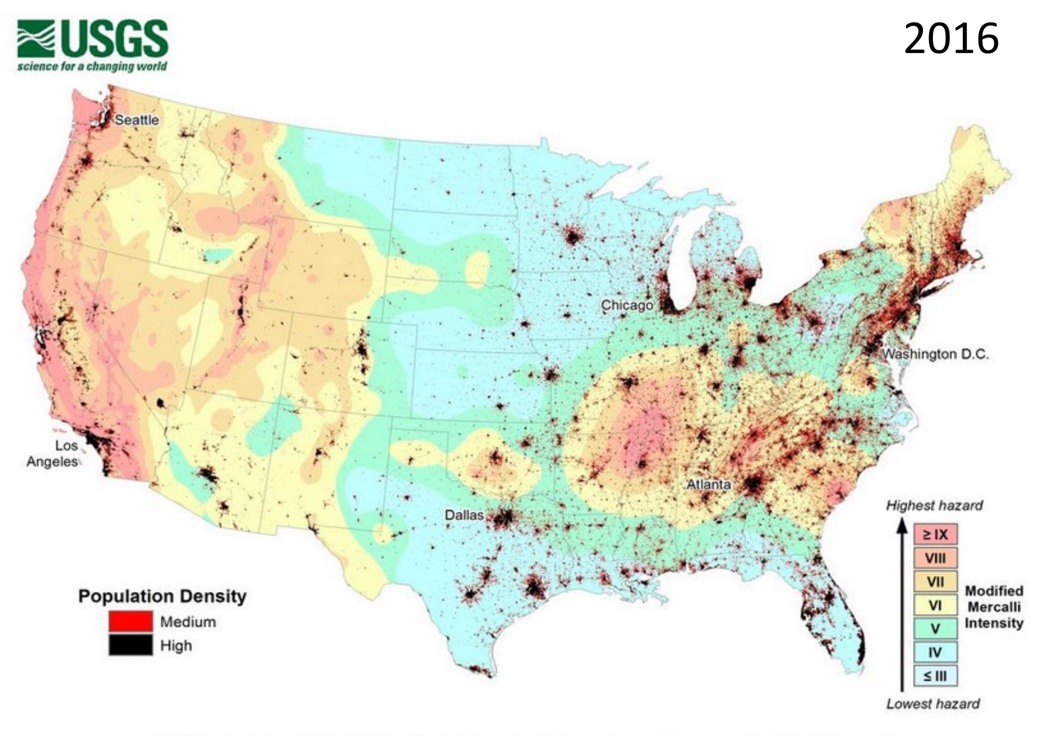
- Damming up the river system resulted in compounding water in different areas than were natural along some faults. As dams were installed, an increase in seismic activity was reported and subsequently as drought has developed, activity has increased again near the river/dam systems.

Water weighs about 8lbs per gallon of water, with more water falling in single events, rapid onsets of pressure on weak pooling points will have downward impacts as will sudden drying from increased evaporation and the drying of soils lifting the pressure on the plate upward.

Recent research has confirmed this correlation of water weight on the crust as a form of water-stress triggering earthquakes.

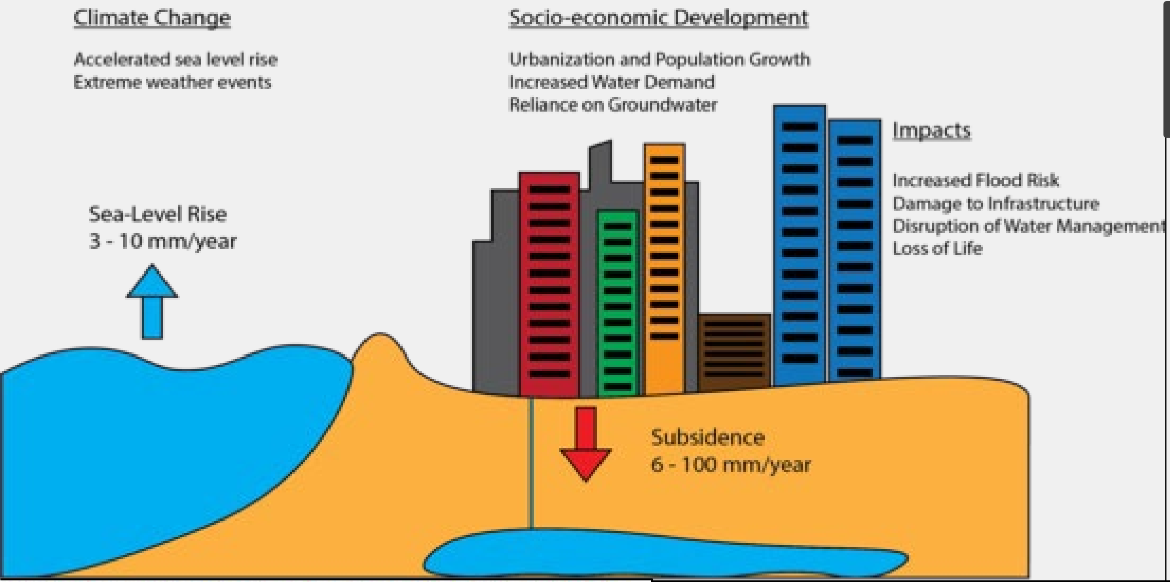
There are a notable amount of nuclear power plants built along river systems in the US and in areas experiencing increasing drought conditions presenting additional seismic concerns for public safety.





USGS map showing (1) the locations of major populations and (2) the intensity of potential earthquake ground shaking that has a 2% chance of occurring in 50 years

STUDYING SUBSIDENCE



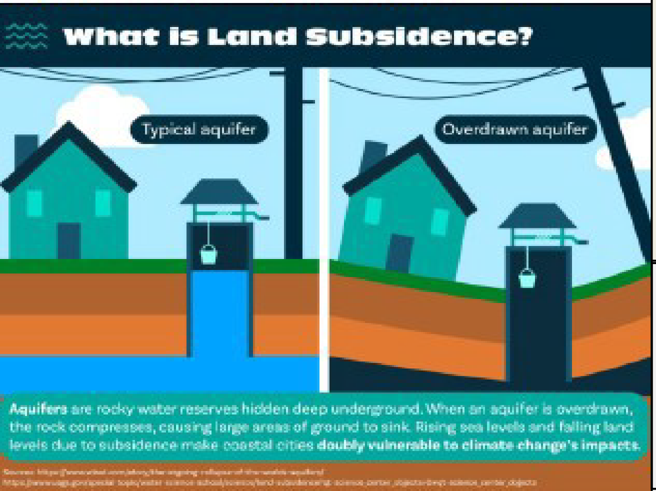
Subsidence has been recorded in the US at a rate of nearly 2-feet over three years for some aqueducts.

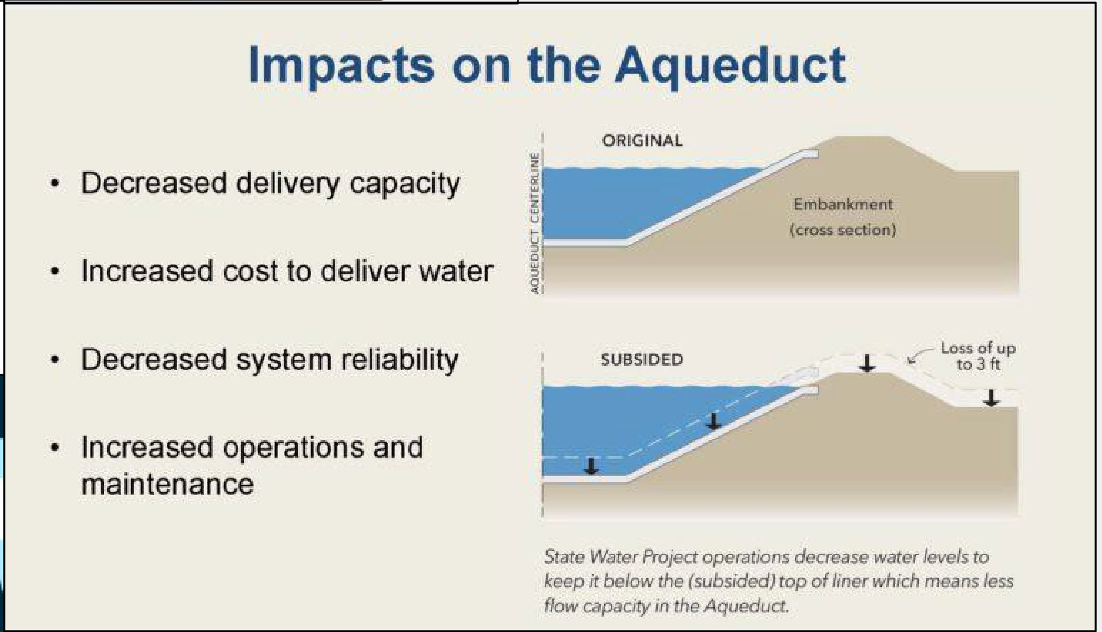
- Utilizing aqueducts to channel water from one area to another, pulling from wells at a faster rate, digging new wells to pull from the underground aquifers, pumping water from lakes/rivers, and creating supplementary channels along canals to siphon water from set provisions has compounded the upstream water provision in major riverways and tributaries out west and in other countries.

Subsidence from well water overpulling the groundwater aquifers and subsidence from degrading coal mines have similar impacts across developing regions. Residents of the areas may not be aware of the decreasing stability of their infrastructure until there is a partial or full collapse of a road, home, or canal resulting in permanent damage to the topography of the region.

- Wells dropping 4-8 feet throughout the Northern Rockies and up to 20 feet along the Pacific Northwest coastline indicates aquifer losses of 100-120 feet are possibly spreading across the west.

"The removal of water from aquifers without incoming rainfall or replenishment at the same or greater rate is causing the water table to lower beyond reach of wells and aqueducts which is resulting in deeper wells and more digging, further compounding the loss of water within the aquifer. The soil at that point loses the underneath saturation and begins to condense, known as compacting, and as the weight of the surface infrastructure in the area compounds the soil further, the region along the dried aquifer experiences subsidence (sinking) and the potential collapse the cavernous aquifer left without water to fill the volume. Mexico City, Tehran, rural Iraq, China, Turkey, Texas, and various parts of California have radar-confirmed studies linking subsidence to this issue with lasting damage to the structural integrity of various types of infrastructure considered to be imminent and potentially deadly if not mitigated." – Sunny Wescott, Meteorologist





It takes more than 3-years for shallow aquifers to recover stored groundwater from droughts, not accounting for the severe drought periods or the water being pulled from the aquifers via wells or aqueducts for the use of residents' daily needs.

https://www.sciencedirect.com/science/article/abs/pii/S0022169421009677

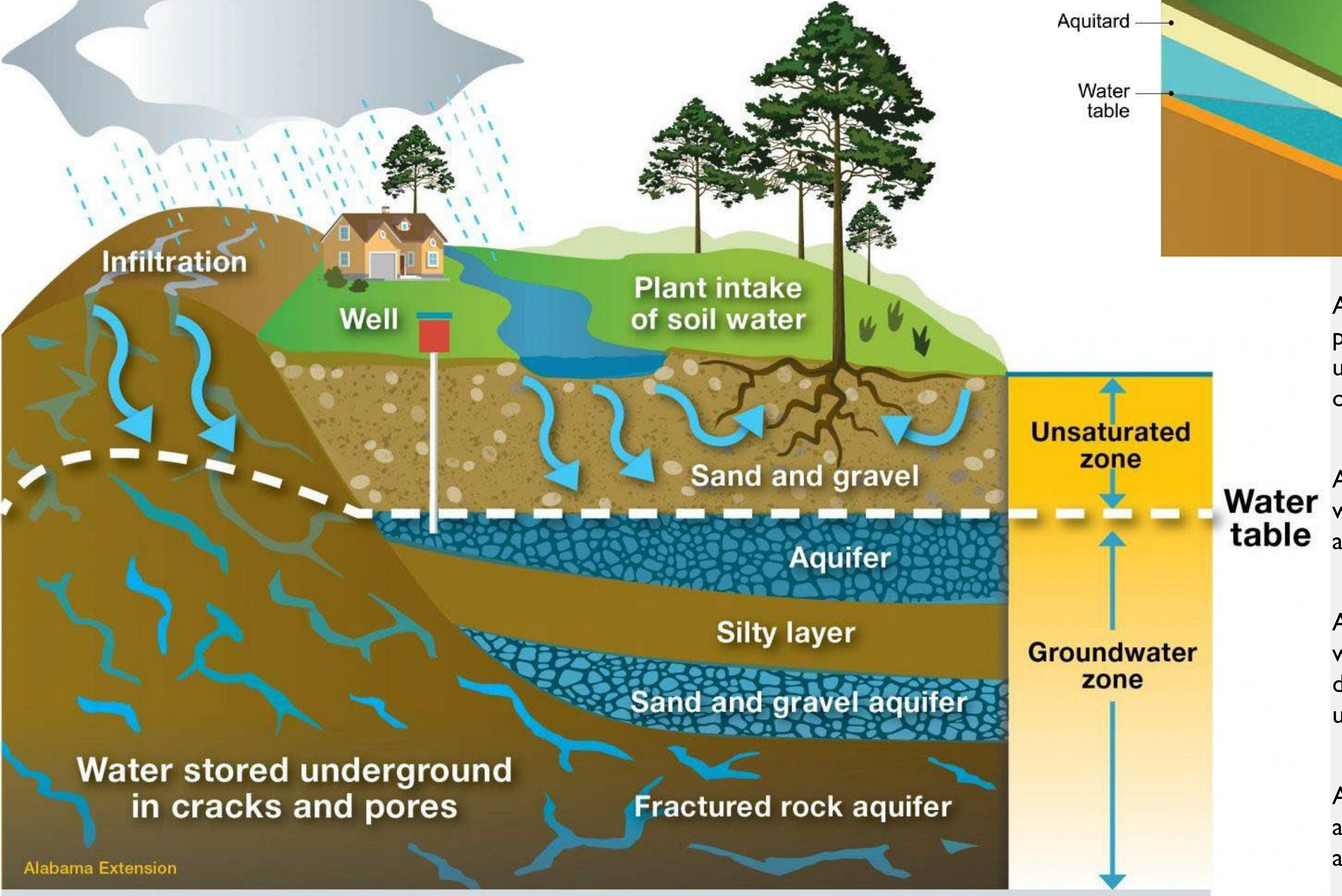
It takes about two years for rainwater drought to become groundwater drought, though in some cases it takes up to 15 years if rainfall persists below average throughout a region.

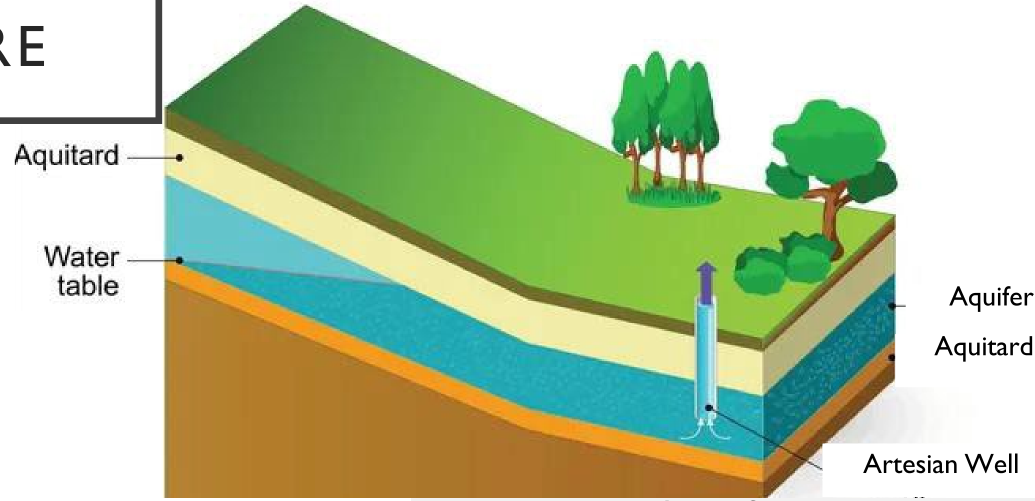
- Subsidence in the United States has directly affected more than 17,000 square miles in 45 states, and associated annual costs are estimated to be over $125 million.
- The principal causes of subsidence are aquifer-system compaction, drainage of organic soils, underground mining, hydro compaction, natural compaction, sinkholes, and thawing permafrost (National Research Council, 1991).
- As the ground drops across the state due to the compacting soils, the varying rates of sinking will increase flash flood total accumulation as water pools in the lowest lying points.
    - Subsidence may cause areas which were not previously the lowest-lying area to take on more water than previous flood plans accounted for.

Once subsidence causes ground collapse at the surface, the soils and materials which fall into the drying aquifer cause permanent damage to the groundwater system.

- Soil collapse along roadways and sewar system pipelines can cause hazardous materials to enter the aquifer system and degrade water quality for all wells pulling downstream of the impact site.

WATER TABLE STRUCTURE





Aquifer

An underground layer of water-bearing permeable rock, rock fractures, or unconsolidated materials (gravel, sand, or silt).

Aqueduct

An artificial channel for conveying water, typically in the form of a bridge across a valley or other gap.

Surface Well

A hole drilled into the ground to access water contained in an aquifer by digging, driving, or drilling. A pipe and pump are used to pull water out.

Aquitard

A geologic formation/stratum that lies adjacent to an aquifer which allows only a small amount of liquid to pass.

More than 80% of known land subsidence in the US is a consequence of groundwater use.

Subsidence resulting in ground collapse is permanent damage underneath the surface to the aquifer, meaning retention of groundwater in that area is now diminished for future needs.

An additional threat from subsidence is that areas which may have been elevated before, could be the lowest-lying area now, resulting in flowing flood waters runoff rates exceeding any historical norms and overwhelming local water infrastructure abilities.

Whaley Bridge Dam – Heavy Rainfall Damage 2019

Buckled canals from groundwater over pumping – California Aqueduct, Drought 2017

SUBSIDENCE IMPACTS IN COLORADO

https://coloradogeologicalsurvey.org/hazards/ground-subsidence/

A large sinkhole opened in January 2005 at the Ironbridge Development and Golf Course, in the Roaring Fork River Valley, approx. 6 mi. (9.7 km) southeast of Glenwood Springs. Two golf carts inside the structure were lost down the throat of the sinkhole. View is to the northeast. The red cliffs in the background are the Maroon Formation. For scale, note person in white hardhat standing in the snow. Photo credit: Jon White for the CGS.

Looking down into the sinkhole depicted to the side, which is approximately 40 ft deep, photographs show severed utility pipes and a storm-sewer pipe. Colorado's mountains are headwaters to 4 major rivers supplying water to downstream states.

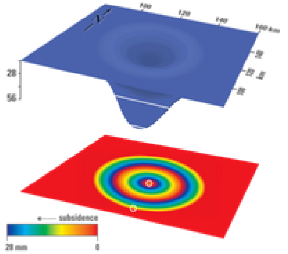
Future impacts of various types of subsidence: Proposed houses in Rockrimmon could join nearly 4,000 existing homes in Colorado Springs at risk of structural damage because of underlying coal mines that may collapse over time.

- Homes in threat areas will have to find private subsidence insurance as the state does not find the above area to qualify. Private insurance companies can suspend or change the terms at the company's discretion.
- Subsidence happens as coal mines collapse or erode, causing land above them to sink and that can cause sinkholes or, more commonly, cosmetic damage, such as walls cracking.
    - In the above area only 19% of threatened homes in the community are covered by Colorado's subsidence insurance program.

Groundwater pumping aside, development exacerbates subsidence in several ways. Extracting oil and natural gas can cause the strata they're found in to collapse.

Groundwater pumping can also expose the soil's organic matter to oxygen, which in turn enables its decomposition. Once the soil is aerated, as much as 95% of it decays, which enables significant compressions from the top down due to gravity.

Subsidence in the United States has directly affected more than 17,000 square miles in 45 states, and associated annual costs are estimated to be over $125 million. The principal causes of subsidence are aquifer-system compaction, drainage of organic soils, underground mining, hydro compaction, natural compaction, sinkholes, and thawing permafrost (National Research Council, 1991).



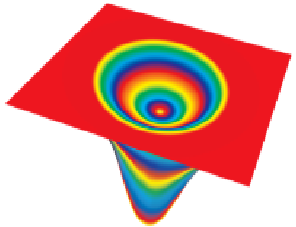
Sources/Usage: Public Domain.

Step 1: Mapping InSAR displacement. In this illustration, two InSAR fringes are equal to 56 mm of deformation. (Public domain.)

Step 1

Count the number of InSAR fringes between two points on the interferogram, where one fringe is one complete color cycle (i.e. red, orange, yellow, green, blue, purple).

The figure illustrates how land-surface displacement, in this example it's subsidence, is represented on an interferogram. In this example, each fringe, or color cycle, represents 28 mm of range change



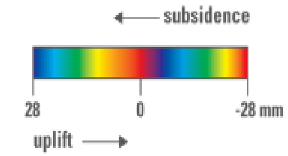
Sources/Usage: Public Domain.

Step 2: Processing interferograms. In this example, two InSAR fringes are equal to 56 mm of subsidence. (Public domain.)

Step 2

Multiply the number of fringes by 28 mm (1.1 in.).

Because there are 2 fringes, the maximum displacement (at the bottom of the bowl), is 56 mm. Depending on processing, one fringe could represent a different magnitude of displacement. Generally, about 1/3 of a fringe (two colors) is discernible displacement; in this example, 10 mm of displacement. If we process the data such that 14 mm of displacement is represented by 1 fringe, then about 5 mm of displacement is discernable.



Sources/Usage: Public Domain.

The third and final step in interrpeting interferograms is determining deformation. An increase in range means subsidence is depicted. A decrease in range denotes uplift. (Public domain.)

Step 3

Determine if the ground moved closer (uplift) or farther away (subsidence) from the satellite by matching how the colors change between the two points with the InSAR scale bar. An increase in range (i.e. red, orange, yellow, green, blue, purple) signifies subsidence, and a decrease in range indicates uplift.

COLORADO

Colorado has additional threats of post-fire mudslides, flooding, and charred mountainsides after historic wildfires in 2020 and the most destructive wildfire in state history in terms of insured losses in 2021.

- The Colorado State Forest Service published its annual forest health report recently, highlighting the current conditions of forests across Colorado and how the agency is improving the health of the state's forests in the face of persistent drought and historic wildfires.
    - https://csfs.colostate.edu/forest-management/forest-health-report/

Recent model projections indicate that Colorado could face a 30% decrease in snowpack by 2050 which would have cascading impacts to the state's water plan as more precipitation falls as rain in the future.

- Scientists predict Colorado will see a 50-60% reduction in snow by 2080.
    - While large snowpack losses have been observed in mid-altitude areas, the relatively higher altitude regions have experienced little to no change in the snowpack.
    - The study also stated: "In some parts of Colorado, we will see a higher-elevation preservation of snowpack, because it is so high. But other areas like the San Juan Mountains were seen to be losing snowpack significantly". https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021EA002086

With recent pricing increases for crops due to widespread drought and heat degradation to the agricultural sector, a warehouse near Denver is being converted to into vertical farms. With water recycling, vertical farms could reduce agricultural water drawing by 97%.

- This water recycling program, using Grey Water recycling, reduces home water use by 25%.
- Castle Rock, Denver, and Pitkin County are the only communities that allow in-home water recycling.

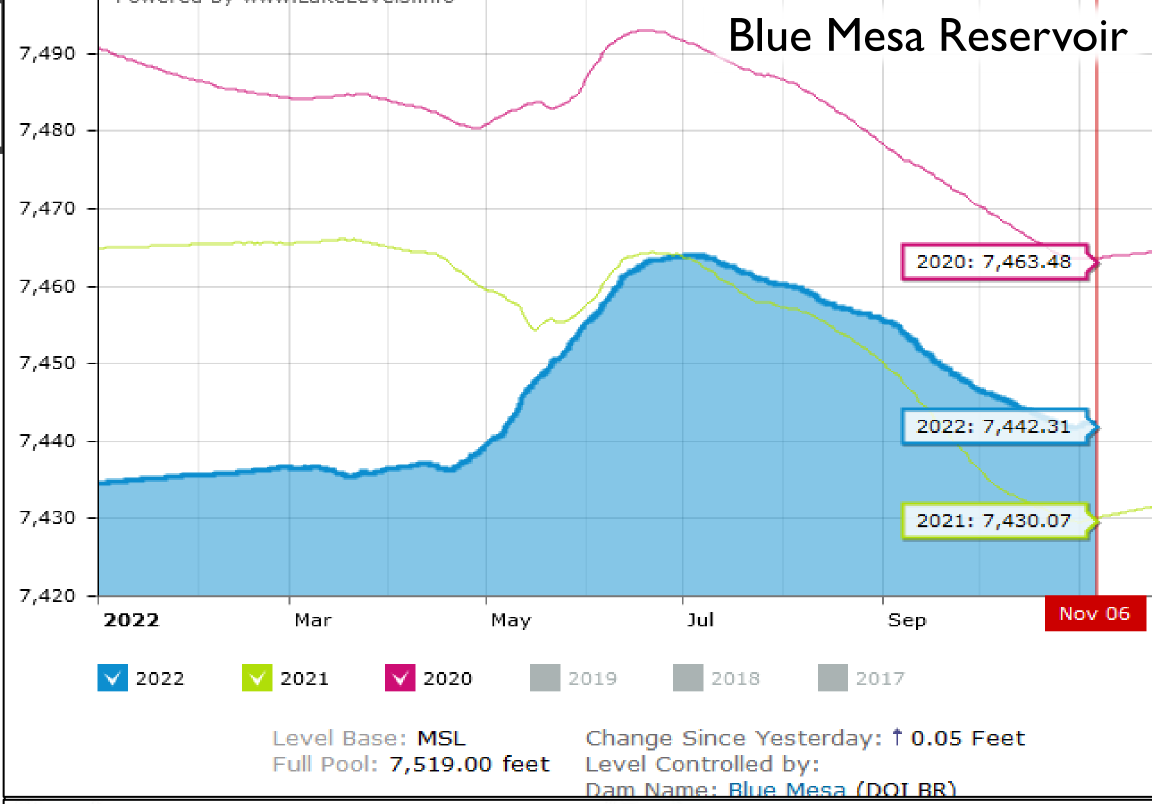
After the 2020-2021 fire season, contaminates entering the water system have caused some river water to be avoided for use due to the ash and debris present from wildfires in the surrounding forest landscape.

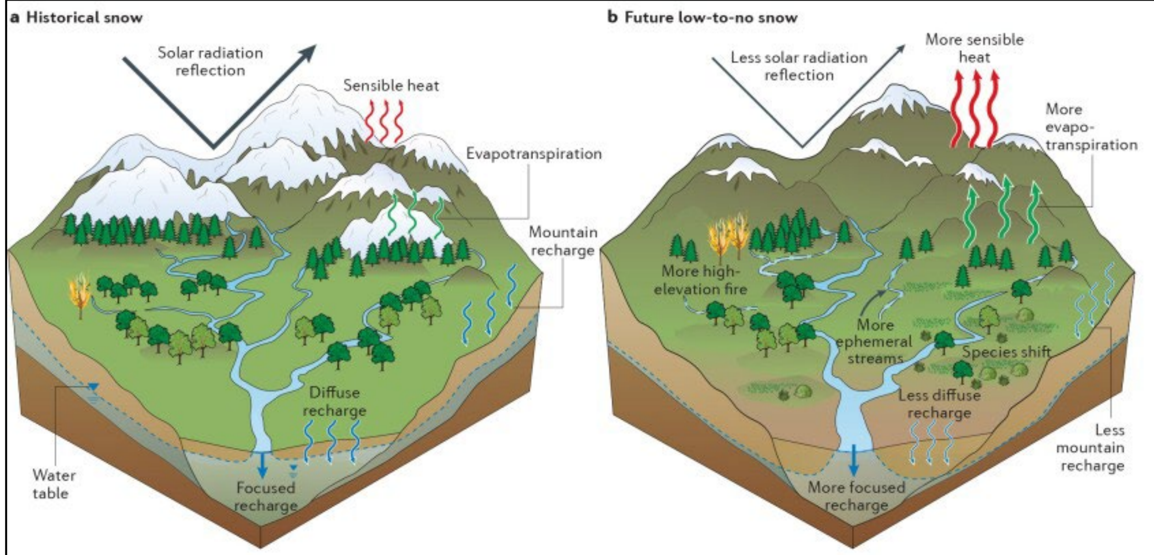
- Permanent structures are being built out to block fire debris from entering the water treatment plants – Fort Collins Water Resources & Treatment.
- For 2022, wastewater treatment plants have faced filtration overuse due to debris flow runoff increases.

Wells across the western US reported pulling groundwater at 2-3x previous rates due to increased drought conditions.

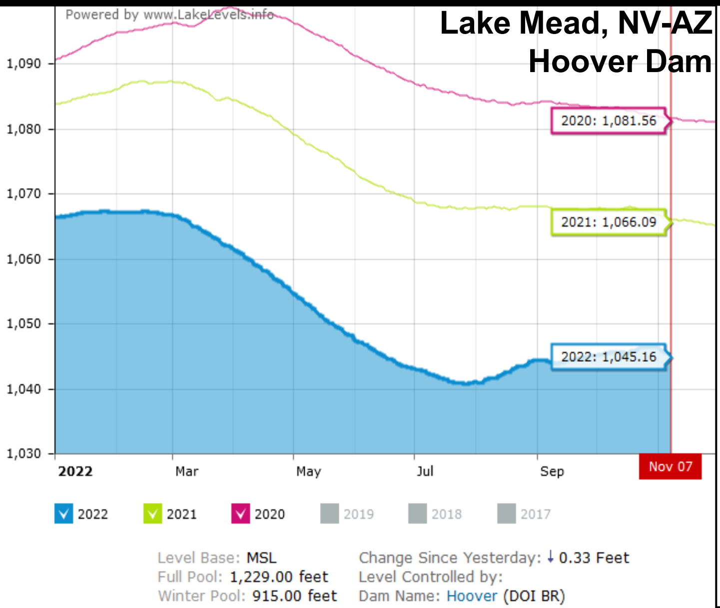
- Wells typically do not have water purification systems installed, meaning water quality is not tested.

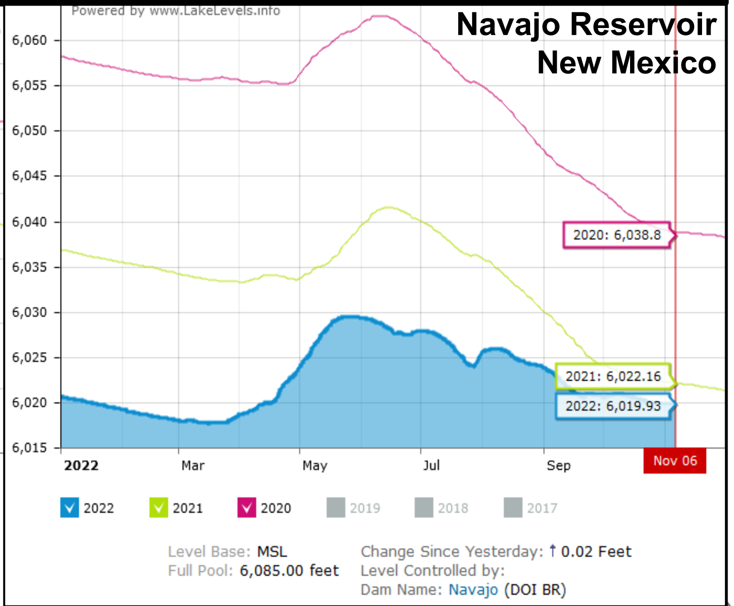
The Environmental Protection Agency estimates the average potable water loss through delivery system leaks nationwide is about 16%.

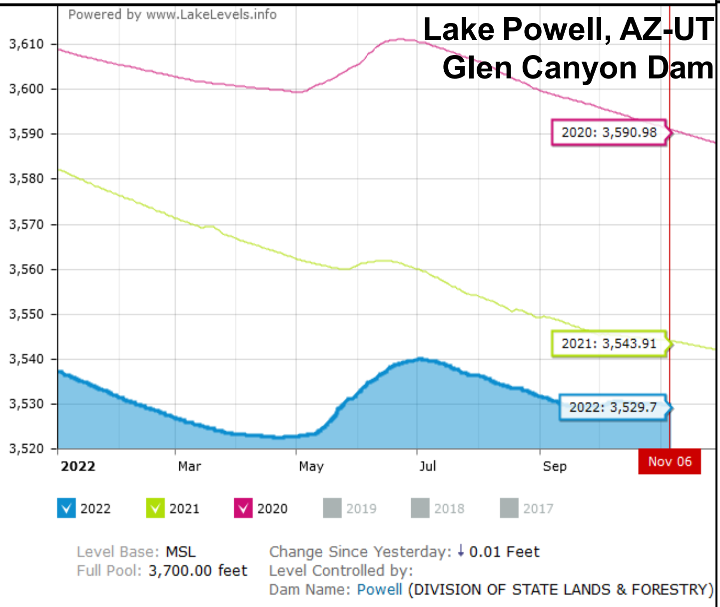


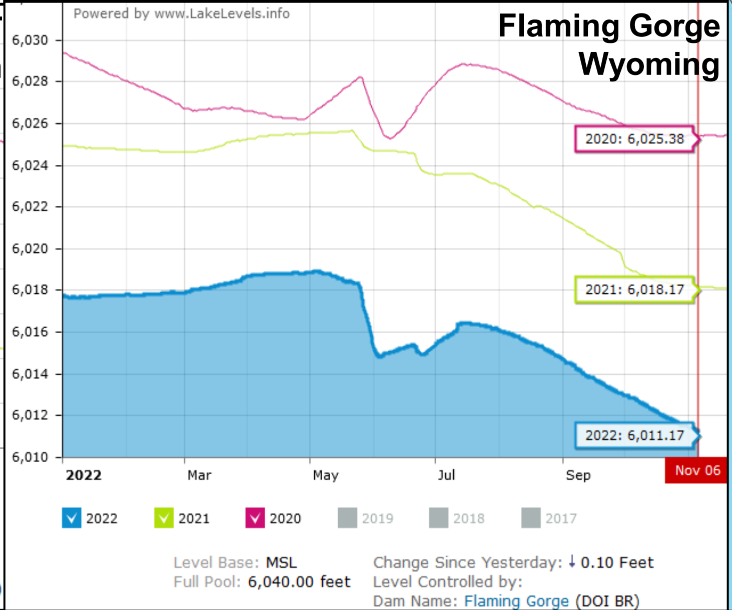


COLORADO RIVER SYSTEM RESERVOIRS









https://discover.lanl.gov/news/0518-colorado-river-basin

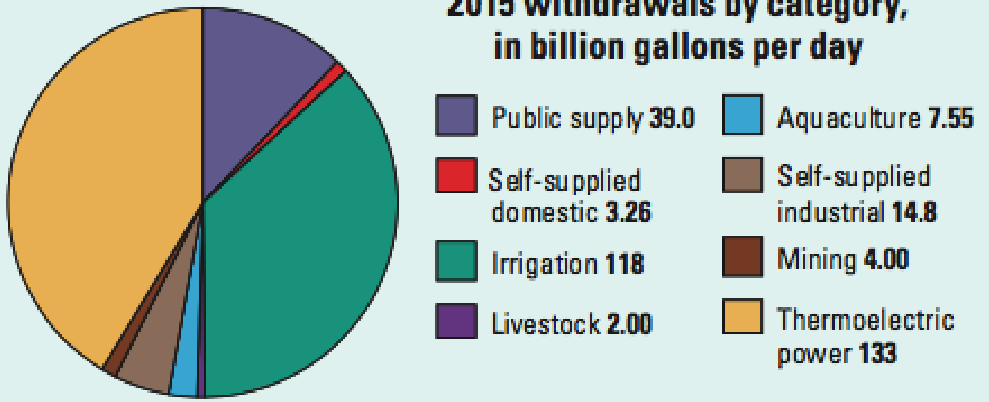
Water Use
Groundwater and Surface Water

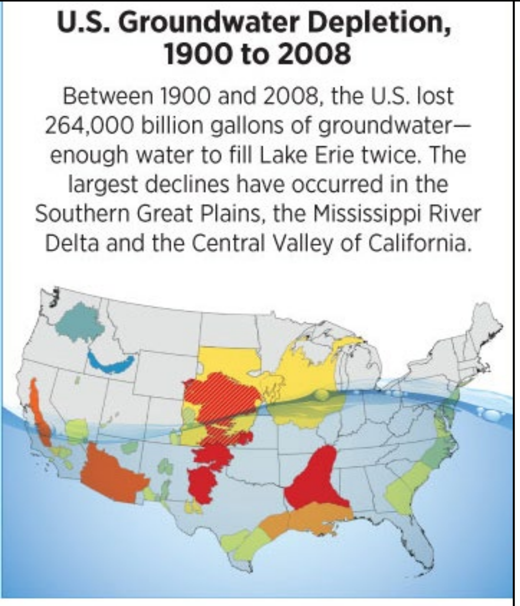
The estimated price tag of fully funding U.S. water infrastructure is more than $3 trillion over the next 20 years. "As a result of water stress, states are fighting over the resource, and the number of legal fights is expected to grow. Recent examples include Mississippi's failed lawsuit against Tennessee over Memphis' heavy use of the Sparta-Memphis Sand Aquifer and Florida's failed lawsuit to limit Georgia's use of the Chattahoochee River."

- Water theft is also expected to increase from all sites with dedicated provisions once additional water shortages are announced both out West and in the Central Plains.
  - Previous water theft incidents caused rapid water pressure drops resulting in water main bursts or city water shutdowns due to automation systems perceiving a leak.

The BlackRock Investment Institute found that about 60% of the global real estate investment trust (REIT) properties will experience high water stress by 2030, more than double the current amount. As groundwater depletes and subsidence threats expand, datacenters will be increasingly strained.

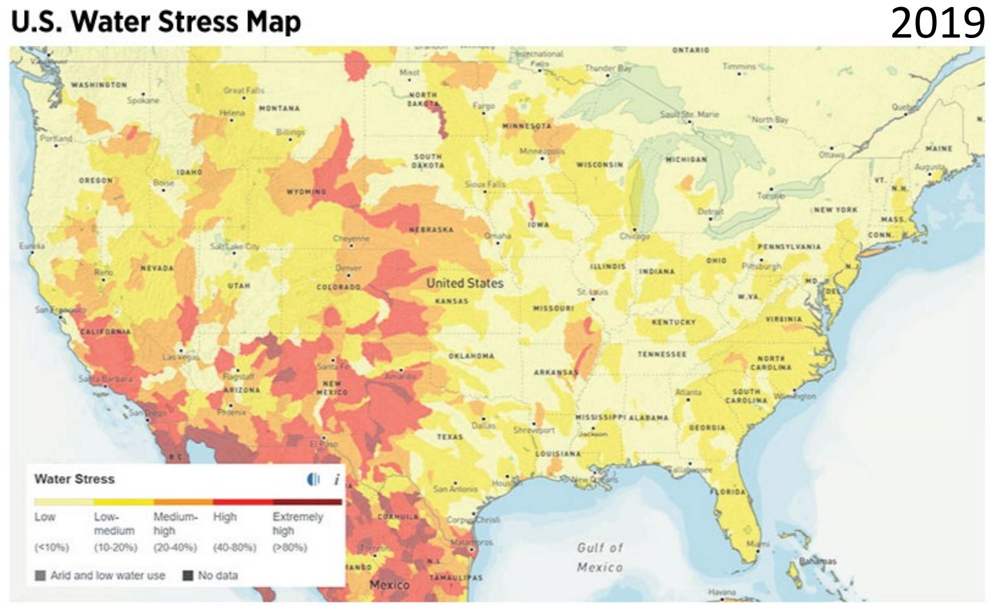
Groundwater



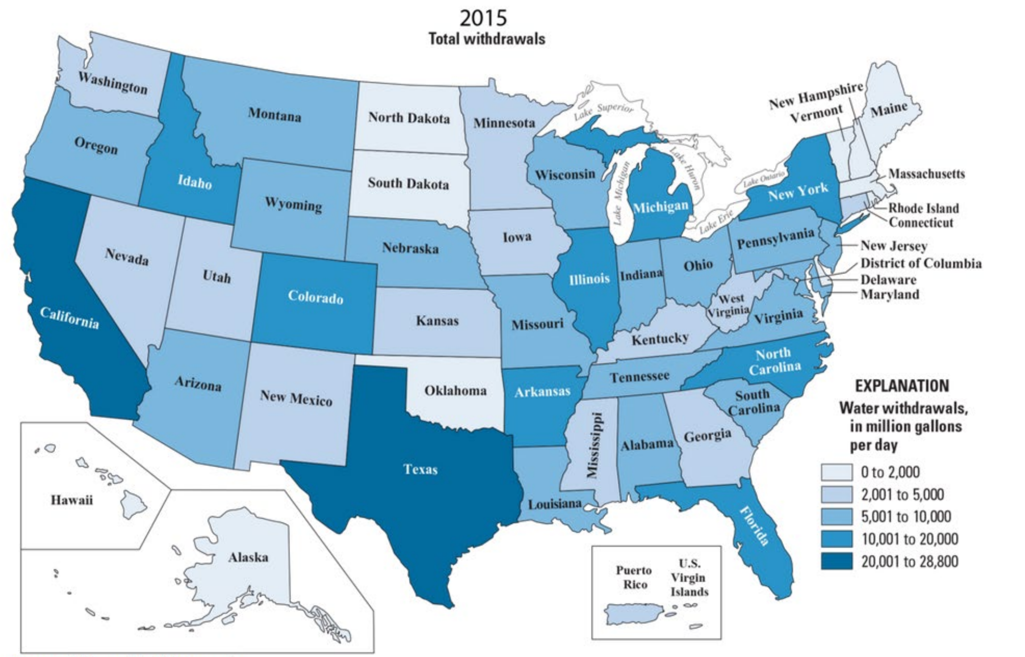


SOURCES: Circle of Blue and U.S. Geological Survey.

2019

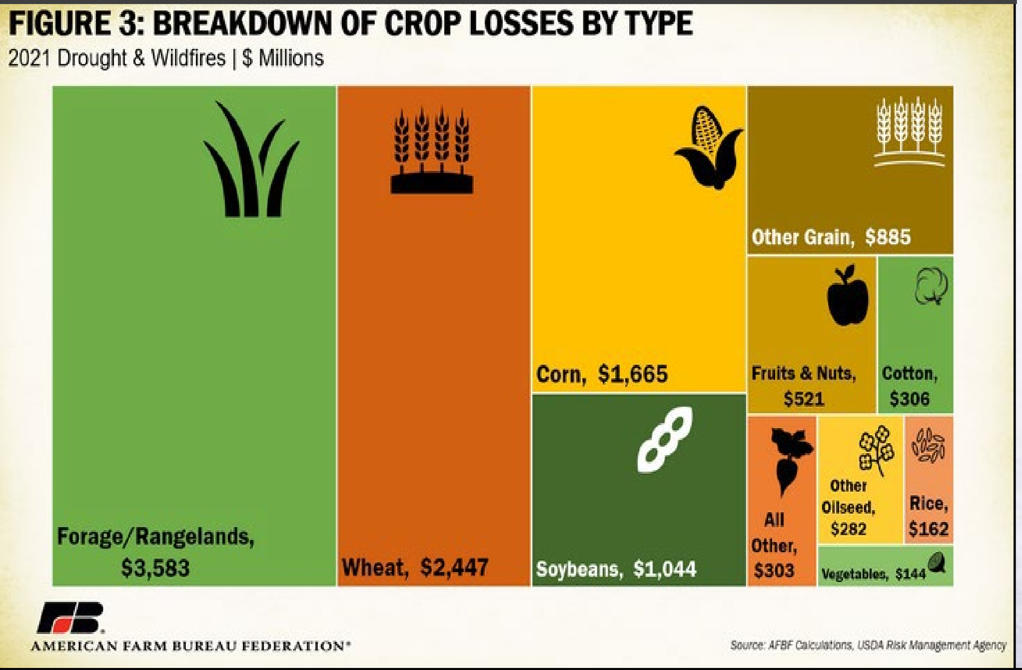


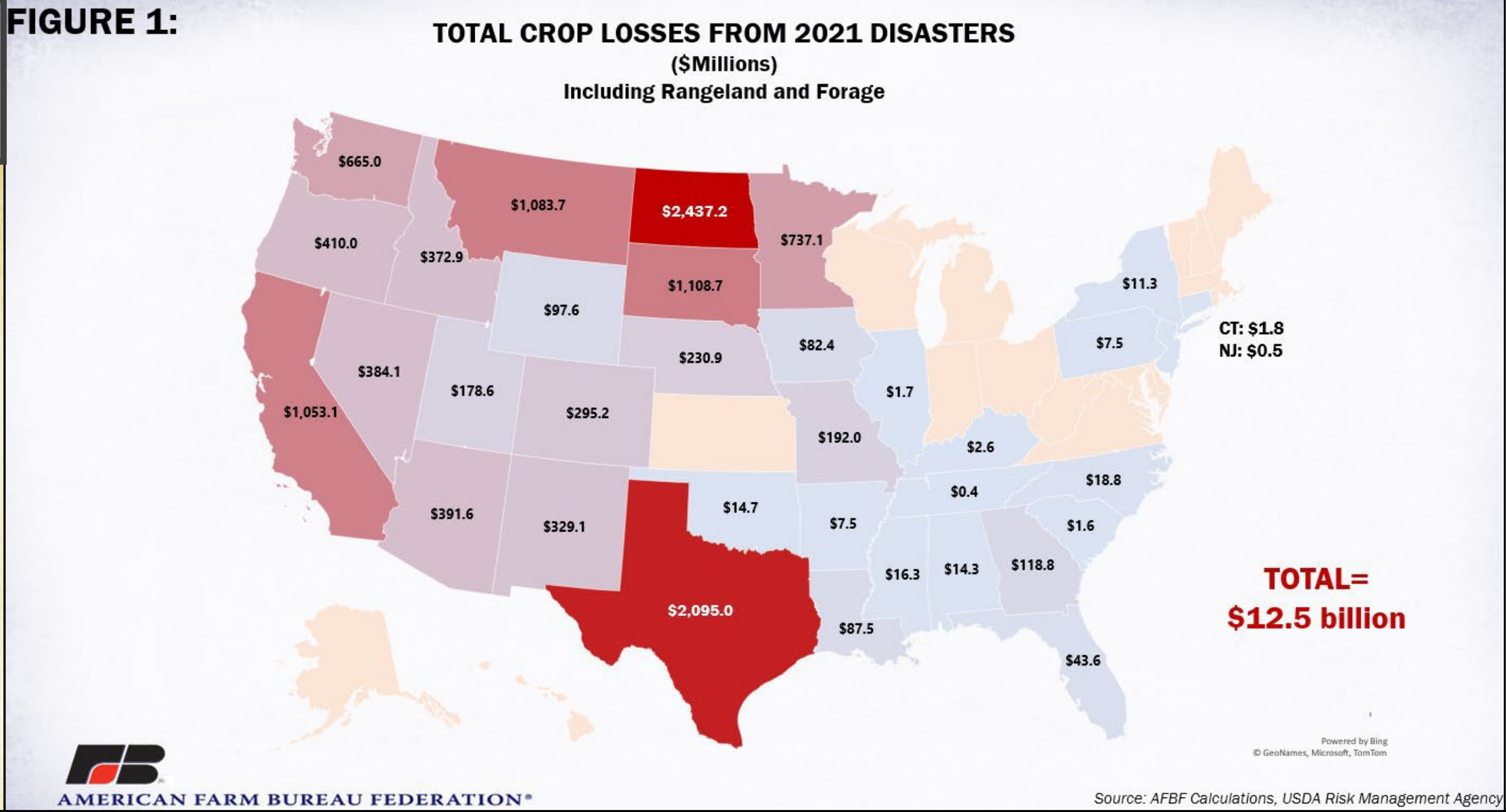
SOURCE: World Resource Institute's Beta Aqueduct Water Risk Atlas.



Sources/Usage: Public Domain.

AGRICULTURAL IMPACTS





According to NCEI's Global Annual Temperature Rankings Outlook, it is virtually certain (> 99.0%) that 2022 will rank among the 10 warmest years on record.

- Freeze-Thaw-Freeze causes crop damage to fruit blossoms and with prolonged winter weather throughout the Northern US and damaging winds along the Front Range of the Rocky Mountains through the Central Plains, initial spring crops may see impacts to spring fruits: Apples, Apricots, Avocadoes, Bananas, Carrots, Cherries, Oranges, Grapefruit, and Pears.

In 2020, **Colorado** generated around $7.3 billion in agricultural cash receipts with the highest valued commodities being cattle and calves, dairy products, specifically milk, and corn and 2.1% of the state GDP. Studies in Colorado have concluded that cows exposed to wildfire smoke on the eastern plains produce less milk than those kept in their pens during the heavy smoke days.

The Colorado economy is divided roughly by the state's landscape. Farming activities are found in the flat eastern plains. Between the eastern plains and the western mountains, Colorado's urban areas are home to most services, and manufacturing activity. The Rocky Mountains, in the western part of the state provides numerous recreation areas and the state's numerous petroleum and coal deposits.

- Colorado's agricultural production is dominated (75%) by livestock and livestock products, driven by the cattle industry. Over 60% of the state's agricultural revenues are provided by the growth of cattle and calves.
- Colorado's agricultural sector remains one of the state's largest economic sectors and employs 7% of the workforce. About 86% of Colorado's water diversions go toward irrigated agriculture on only about 4.5% of the state's land.
- Nearly $2 billion of Colorado's agricultural sales are attributable to international sales. Colorado was ranked 24th in the nation in agricultural exports.

"Colorado farmers grow for the world and Colorado consumers buy from the world. There's no exclusivity."

AGRICULTURAL SECTOR

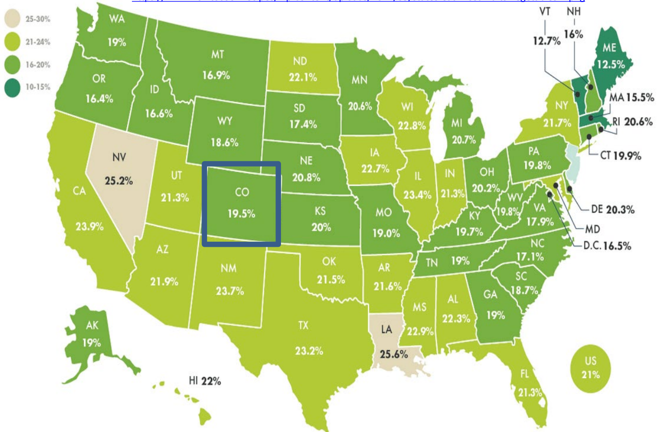
Recent studies have indicated as plants continuously are exposed to drought conditions; the quality of the plant perpetuates degradation.

- The plant's memory retains the exposure and associated stress from the abiotic abnormal event causing the overall yield and size of the plant to permanently reduce.
- Seedlings from stressed plants can prematurely sprout as overall global temperature increases continue, meaning harvests will be more susceptible to late season frosts or annual flooding periods when plants normally would hibernate.
- Recent studies at Pennsylvania State University tracked the ability to induce stress inheritance within plants.
    - "When plants are modified epigenetically, they can modify many genes in as simple a manner as possible," Mackenzie pointed out. That includes adjusting the circadian clock, detecting light and triggering growth and reproductive phases, and modifying hormone responses to give them maximum flexibility, making them more resilient."
    - By adjusting the epigenetic architecture of a plant, researchers were able to access its resiliency network, and see how genes are expressed quickly and broadly to adjust a plant's growth to adapt to the environment.

Potential Solutions: Hydroponic systems, moving plants into a covered atmosphere such as a greenhouse, shifting to vertical plant landscapes, greywater and blackwater recycling systems, drip irrigation systems, shade netting, hybrid breeding plants to be more heat and drought resistant regionally, or genetic isolation of traits for new generation of seedlings.

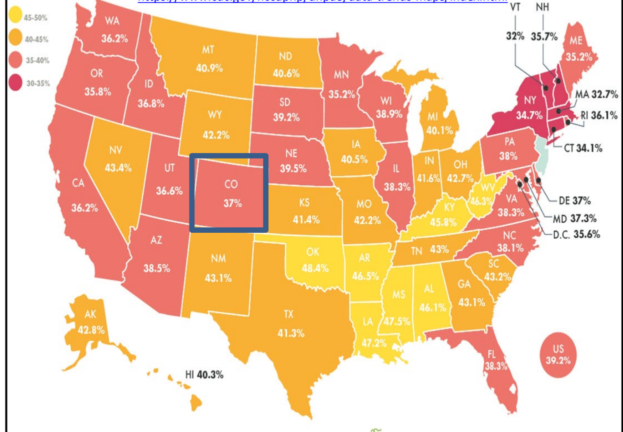
Vegetables Which States Consume the Most Vegetables Daily

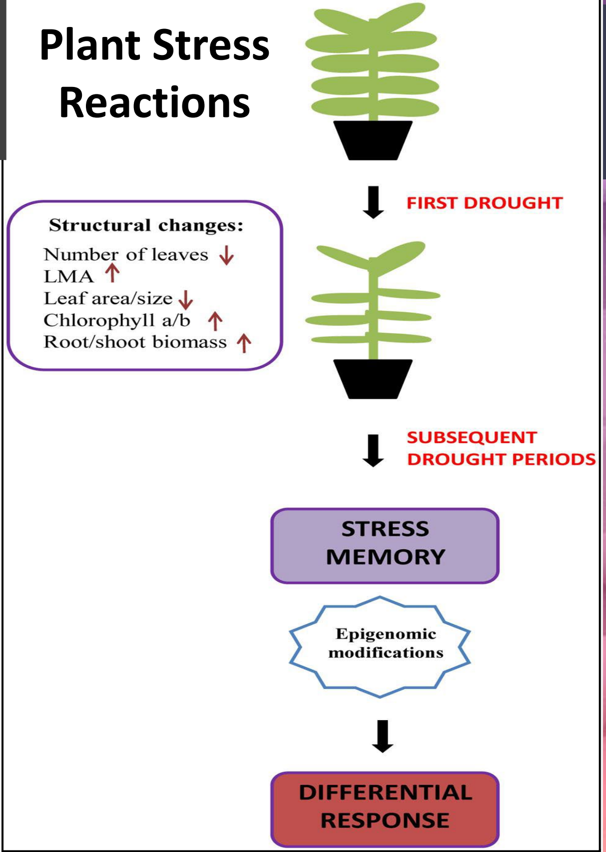
https://www.howtocook.recipes/wp-content/uploads/2021/05/states-eat-most-fruits-vegetables-4.png

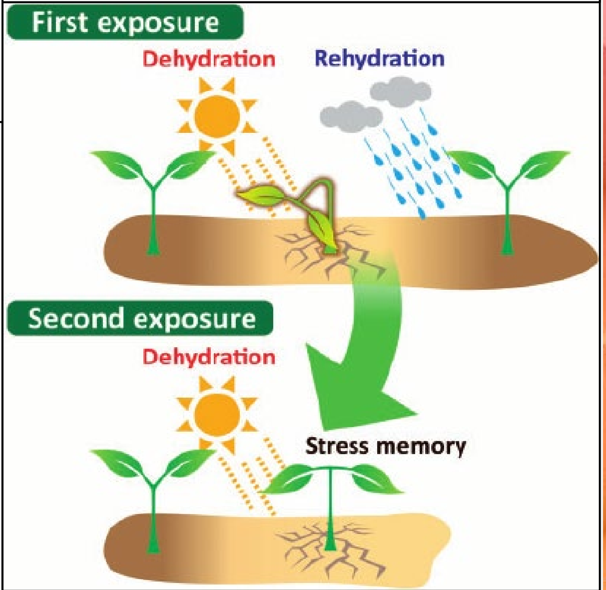


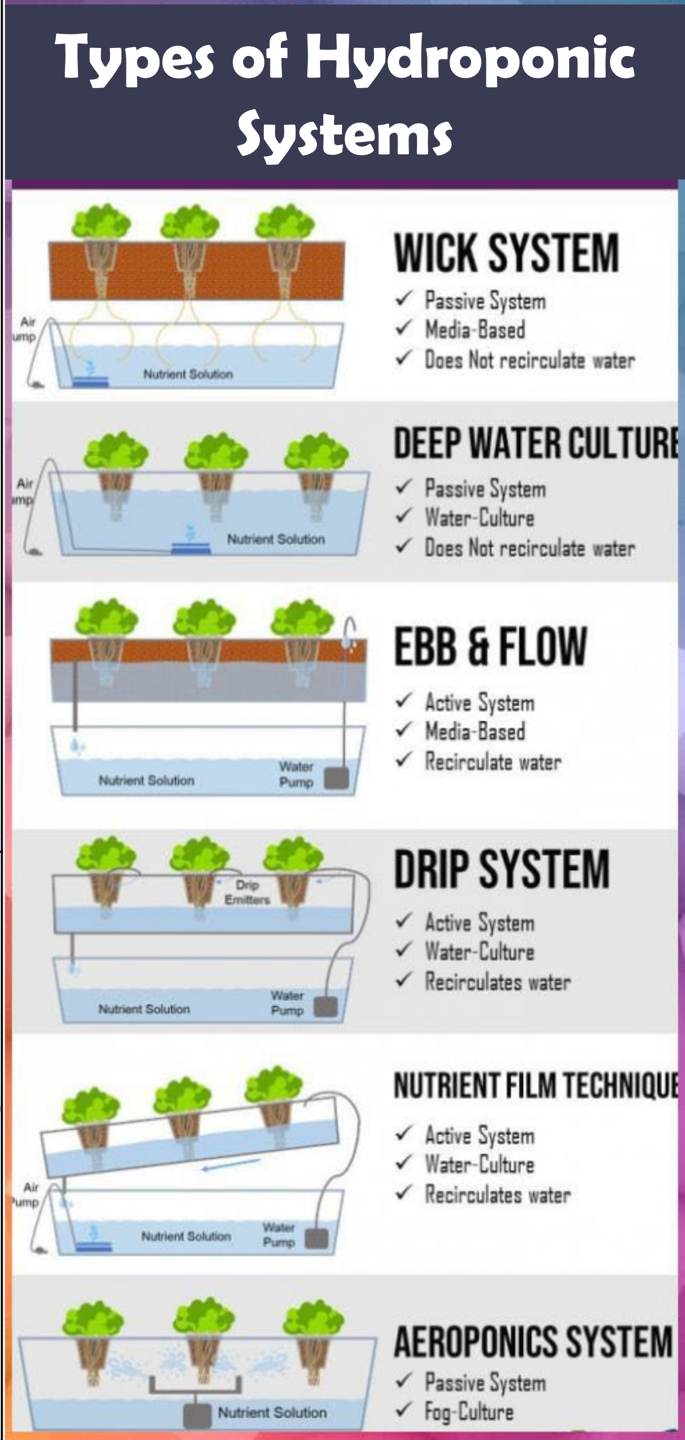
Fruits Which States Consume the Most Fruits Daily

https://www.cdc.gov/nccdphp/dnpao/data-trends-maps/index.html







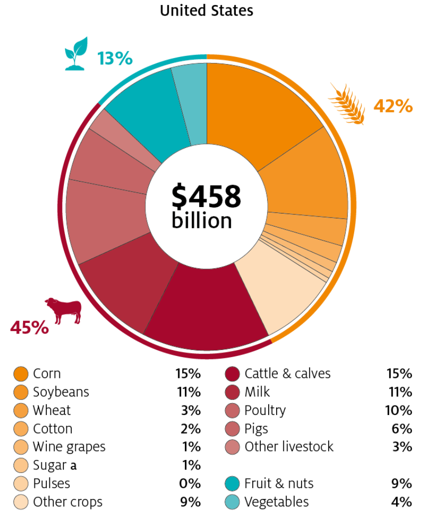


AGRICULTURAL SECTOR

2000–2021 was the driest 22-year period since at least 800 and matches the duration of the late 1500s megadrought.

Losses reported in 2021 from the drought and flash heat across various states in the West, the Northern Plains, and into the Upper Midwest include: Cotton, Honey, Almonds, Cotton Oil, Spring Wheat, Winter Wheat, Barley, Corn, Potatoes, Plums, Apples, Oats, Hay, Soybeans, Pal Oil, Dairy, Beef, Tomatoes, Canola Oil, Salmon, Grapes/Wine, and Flour. The US, Canada, and Russia are the top three global producers of wheat products.

- Widespread decrease in harvest yields from 2020: Wheat -35% (lowest in 14 years), Canola -24% (lowest in 9 years), Barley -27%, Oats -33%, Corn +0.8%, Soybeans -8%, Rye -9%, Flaxseed -28%, Lentils -31%, Chickpeas -71%, Dry Field Peas -43%, Mustard Seed -20%.
    - Canada produces 48% of the total world export for hard wheat (durum) used in making pastas and semolina. The Spring wheat crop was the smallest since 2007 and the all-wheat harvest to include durum and winter wheat was down 1-million tons from the estimated output, which already accounted for drought impacts. Canola Oil was down 34% from 2020. The US produces one-fifth of the world's supply of beef.
    - Canada is the largest pea-producing region in the world and due to the worst drought on record over the past century covering more than 90% of the agricultural land in western Canada, 45.9 million acres of cropland were affected.
        - This resulted in a 45% drop in pea production, according to plant-based ingredient producer Roquette. Subsequently, pea prices increased by 120% compared to 2020. Pea protein is utilized in a multitude of non-dairy protein products for lactose sensitive groups.
- Soils are drying out to the extent of compacting, resulting in a future inability for saturation and less favorable crop yields. Pesticides and herbicides do not break down in dried soils and pose a hazard. **The primary direct economic impact of drought in the agricultural sector is crop failure and pasture losses**
- 25-30% of cattle were culled in US, Canada, and Mexico from the 2021 drought/heat causing a +10% increase in cost.



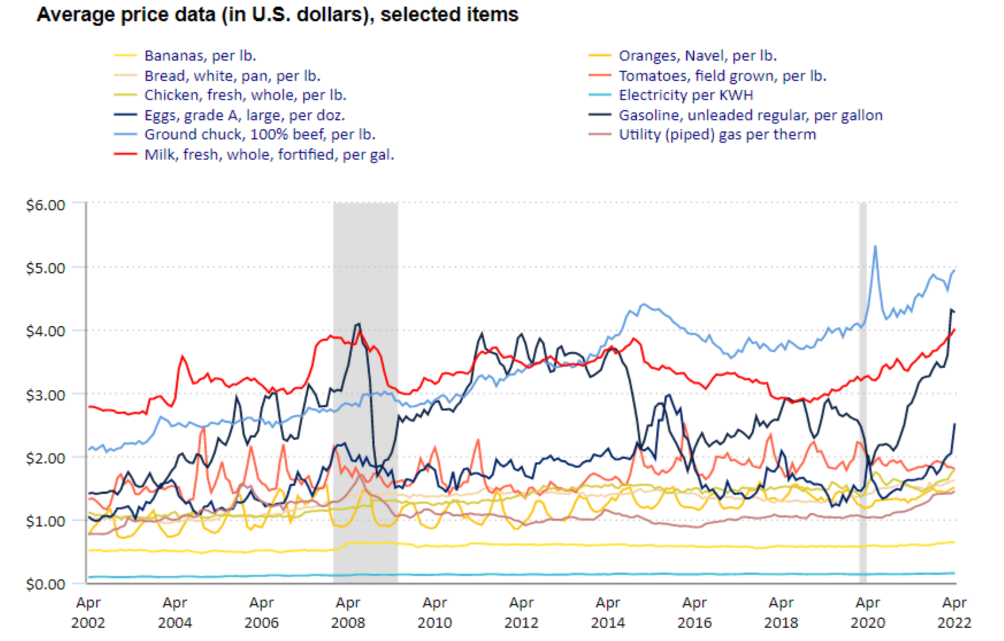
Colorado crops contribute **$7.5 billion** to the economy

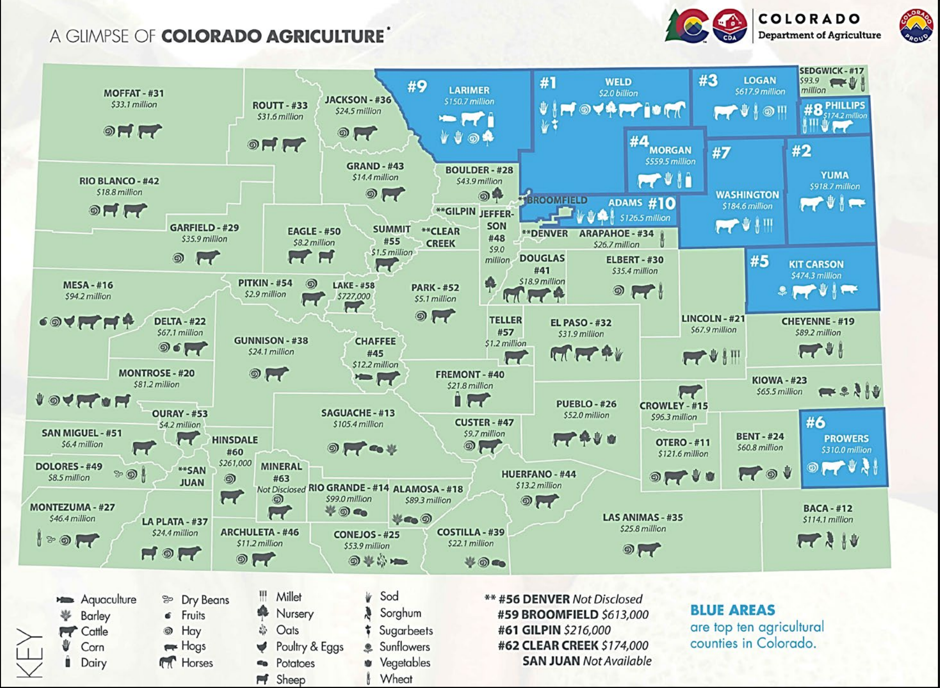
TOP CROPS: CORN, WHEAT, POTATOES

In terms of revenue generated, Colorado's top five agricultural products are **cattle and calves, dairy products, corn for grain, greenhouse/nursery products, and hogs**.

In Denver and Colorado Springs, the summer season has warmed by 2.6 degrees since 1970 which is higher than the national average.

A warming trend for the next 30 years means longer frost-free seasons, earlier spring runoff in the mountains, and earlier blooms for flowers and fruits.





SEVERE STORM INCREASES

In 2021 CO had $550,000 in tornado damage. May 2008 had the most damage at $147 million in private home damage and $1 million in electric transmission line damage from an EF3 tornado.

Tornadoes are formed by a combination of atmospheric instability and wind shear. Instability occurs when warm, moist air is wedged under drier, cooler air aloft. Most tornadoes form during supercell thunderstorms, but not all supercell thunderstorms produce tornadoes. https://www.meted.ucar.edu/education_training/course/2

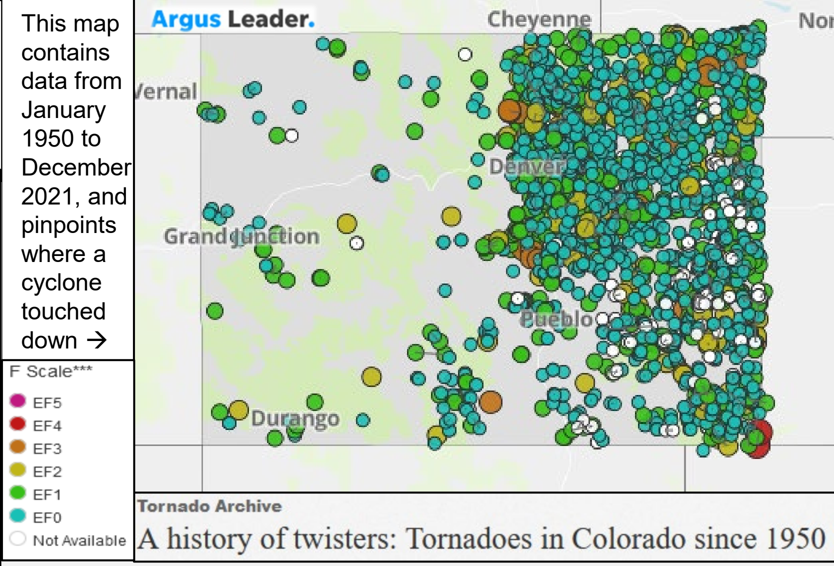
Tornado activity from 2008-2021 in comparison with 1991-2010 data indicates overall the seasonal frequency has remained the same but the location and intensity of tornadic supercells has shifted from “Tornado Alley” to “Dixie Alley” and is capable of larger, longer lasting damage tracks. Tornadoes in Colorado are most prevalent in the eastern grasslands.

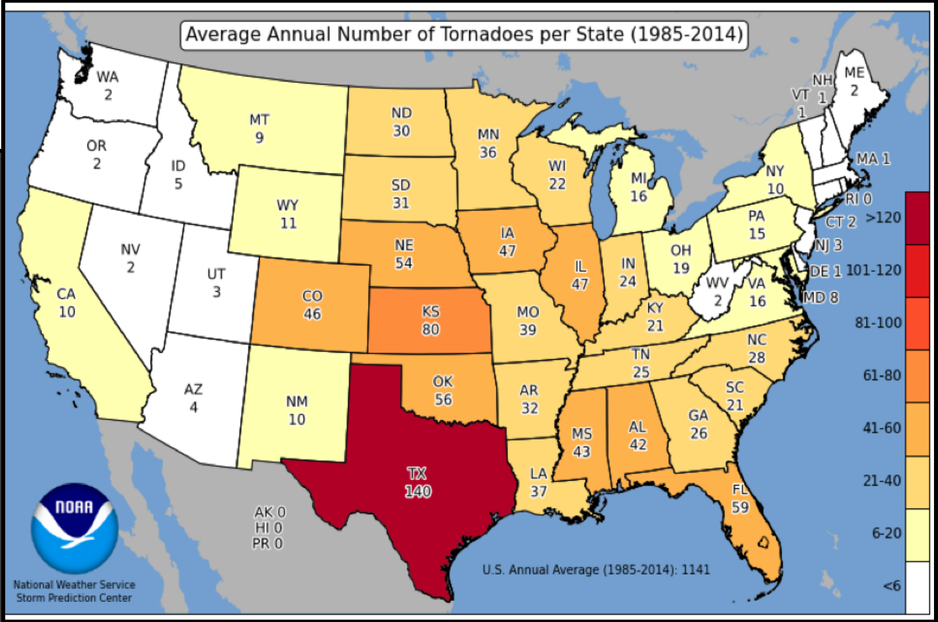
Colorado is ranked #9 out all US States in terms of how many tornadoes touch down at ~40 tornadoes annually (48 in 2021).

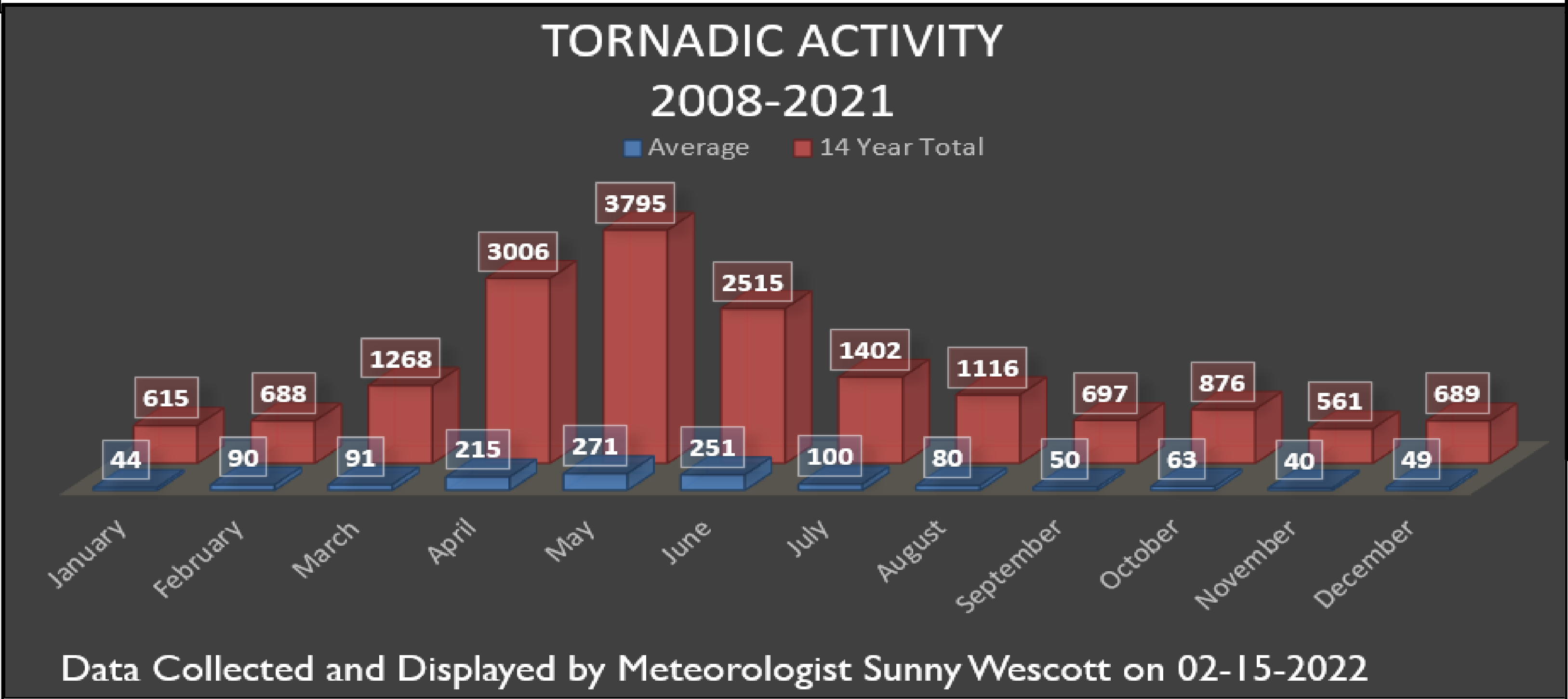
Tornado records date back to the 1950s and the assessment of tornado wind speeds damage changed in 2007 with the implementation of the Enhanced Fujita (EF) Scale for tornado damage intensity. https://data.argusleader.com/tornado-archive/

- Factors impacting increases: population increase for witness accounts, dual-pol radar, internet access to report, increase in spotter network, combining first responder data with storm reports, and overall heat increases.
- The US has already reached 300 tornadoes this year, or a quarter of the annual average of 1,200.
- March produced more tornadoes (236) than May, June, or July on average over the past 14 years.
- In 2021 the US confirmed 1,377 tornadoes, (+177 average).

This map contains data from January 1950 to December 2021, and pinpoints where a cyclone touched down →







The EF scale is a set of wind estimates based on damage. Its uses three-second gusts estimated at the point of damage based on a judgment of 8 levels of damage to the 28 indicators listed below

EF SCALE	
EF Rating	3 Second Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	Over 200

WHERE TO WATCH FOR STRONGER STORMS

Hail events throughout the US are forecasted to intensify regarding size of the hailstones this year as warmer climates enable stronger updrafts for supercell storms responsible for large hail.

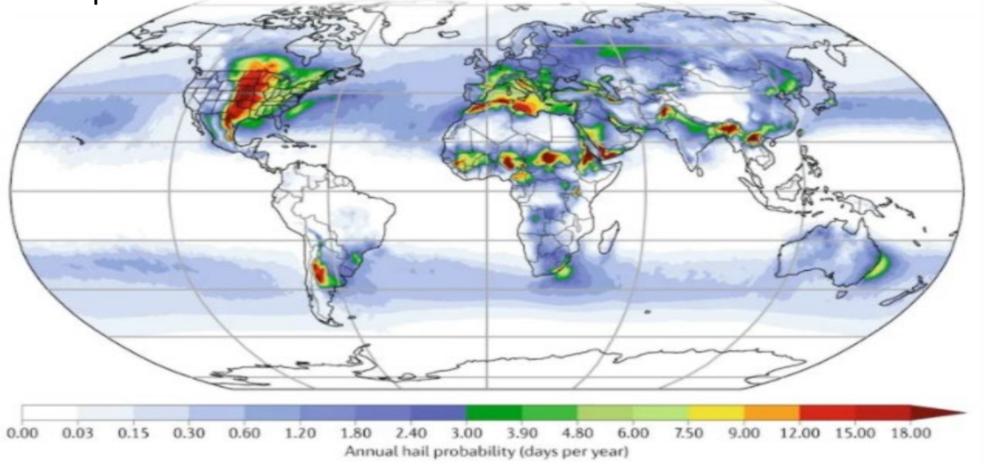
- The most damaging hail events are in downbursts, driven by powerful downdrafts. Downbursts are typically only a few miles across and last a few minutes but can have vertical windspeeds of 156-179 mph with large, destructive hail. https://www.tornadohq.com/ or http://preview.weather.gov/edd

Tornadoes from 2010-2020 caused about $14.1 billion in insured U.S. property loss. Insured U.S. hail losses average from $8 billion - $14 billion per year, or $80-140 billion per decade, as noted by the Insurance Information Institute.

The heaviest hailstone ever recorded fell in Gopalganj district of Bangladesh in 1986, weighing 2.25lbs. The hailstorm killed 92 people and injured 400 others.

In Texas, Colorado, and Alabama the records for largest hailstone have been broken in the last three years, reaching sizes of up to 16cm (6.2 inches) in diameter. **US Hail Damage averages > $10 Billion.**

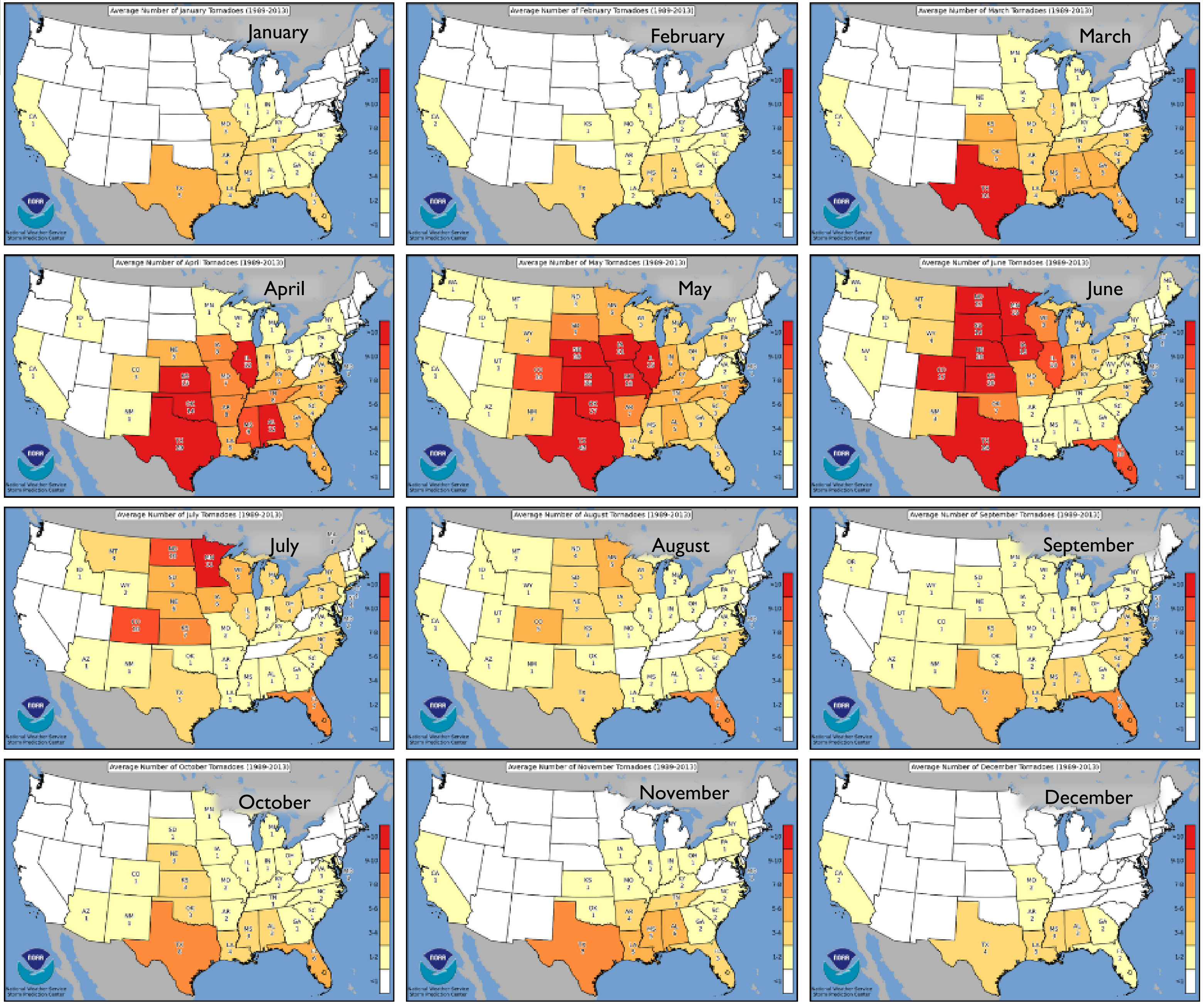
A map of annual hail with diameters above 1-inch for 1979-2015.



Global estimated average annual probability of hail with a diameter of more than 2.5 centimeters (roughly one inch), normalized to areas of 100 by 100 kilometers, for 1979–2015. For most locations in the world, hail is a rare event. (From Raupach, et al., 2021, adapted from Prein and Holland 2018, CC BY 4.0)

25-Year Average Number of Tornadoes per State by Month (All tornadoes, 1989-2013)

Mouse over image to see month. Click on image for full resolution map.



MORE SEVERE STORMS

Tornado events have become more clustered, with outbreaks of multiple tornadoes becoming more common even as the overall number of tornado days has remained unchanged meaning more unstable energy is available per developing storm system.

Despite a year-over-year decrease in number of hailstorms, nearly 10% more U.S. properties were affected by hail in 2021 than in 2020. This was due, in part, to a growing number of hailstorms in more populous, Eastern states outside of the traditional "hail alley" states of Nebraska, **Colorado**, and Wyoming. Pennsylvania and Maryland entered the top ten ranking in 2021 with properties affected by hail at 6th and 5th place, respectively.

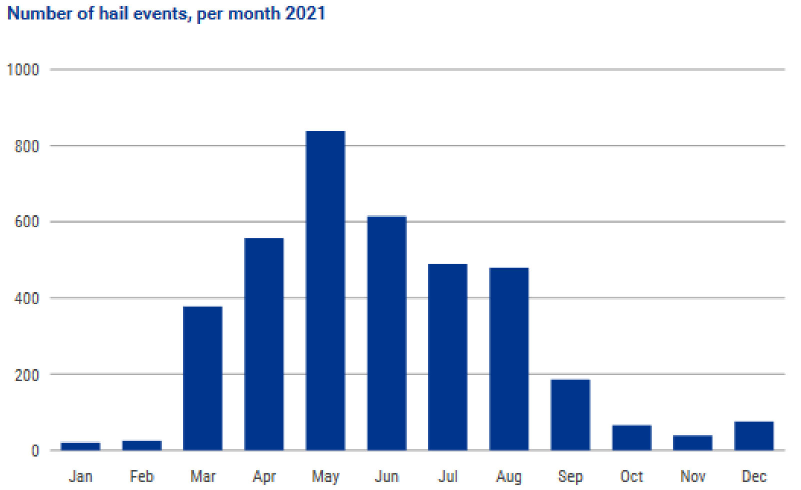
A report providing a breakdown of the counties reporting the most properties affected in each of the top 10 states impacted by hail in 2021 is available in a Verisk Report:

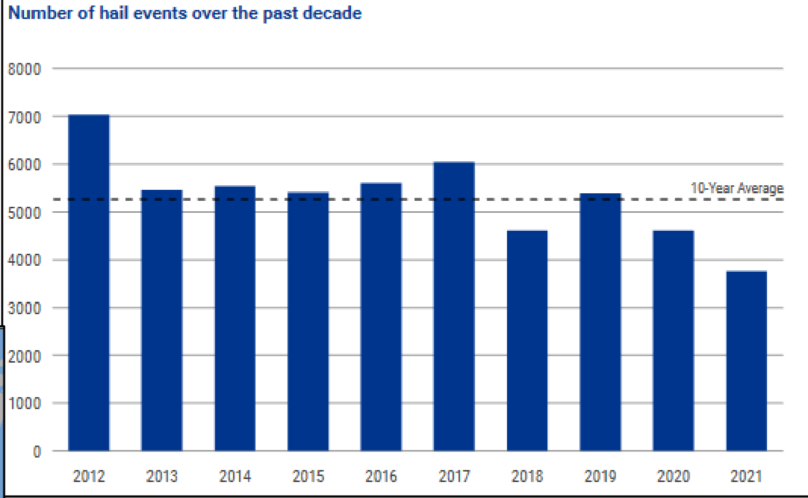
- https://www.verisk.com/siteassets/media/campaigns/gated/underwriting/understanding-evolving-hail-risk.pdf?__FormGuid=e57afcfe-228a-472c-818d-892ea5513336&__FormLanguage=en-US&__FormSubmissionId=2aed94b1-9021-4e44-9dbd-c076295dcda6

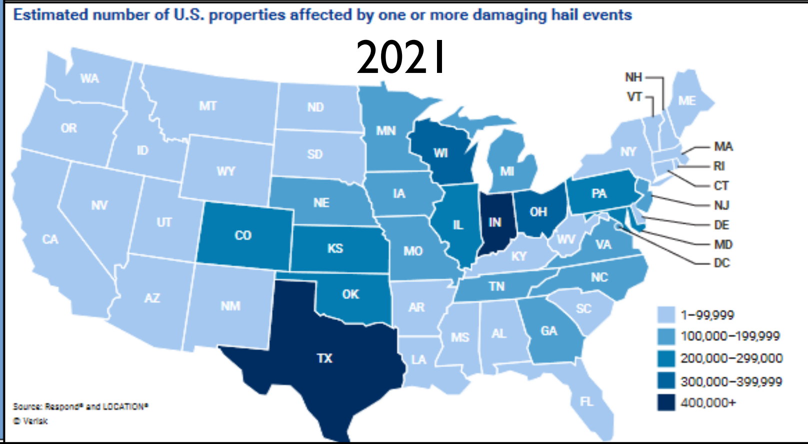
Texas recorded the single largest hailstone in the state's history in 2021: at 1.26-pounds, measuring 6.4-inch inches in diameter. In 2021, Texas had nearly 1 million more properties affected by hail than the next-highest state, Indiana.

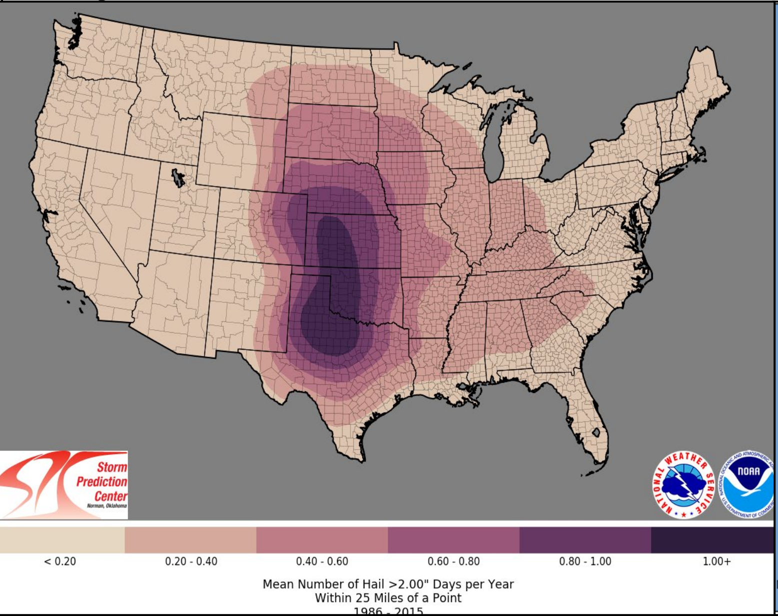
Extreme thunderstorm environments have increased in frequency over the last few decades and have been tied to an increase in economic losses. Stronger surface heating at higher elevations tied to aridification and earlier snowmelt could result in earlier severe storm events each year the overall atmospheric temperature increases, and drought conditions continue to worsen across the US.

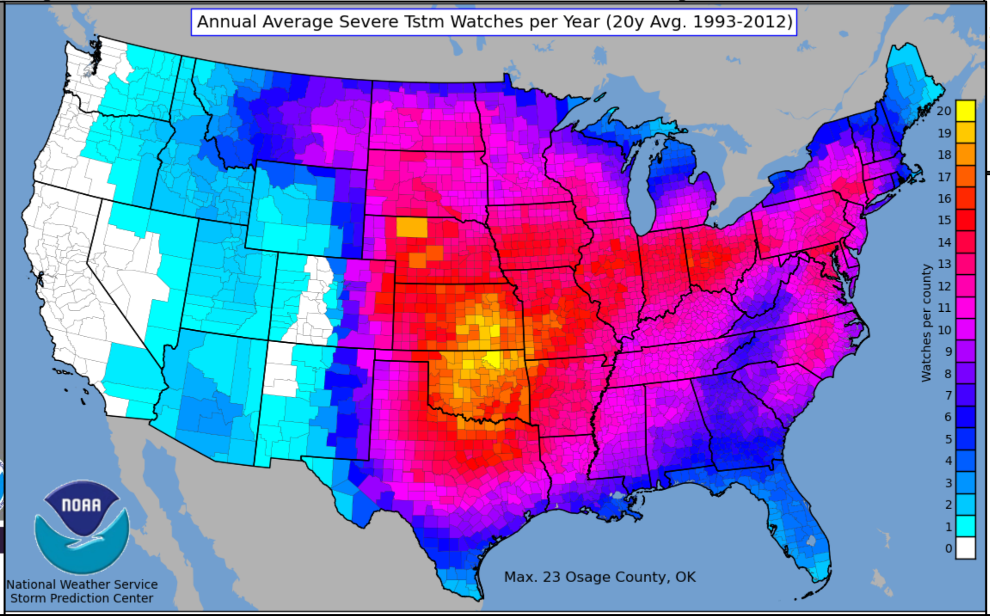
In Colorado, hail impacts Douglas county the most with 31% of properties affected, followed by Arapahoe, Jefferson, El Paso, and Denver. In the past decade 2 floods caused $4.5 billion in damages across the Southwest while rainstorms have caused $20 billion in damages, Snow and ice storms caused $13.7 billion in damages, and storms have caused $20 billion in damages.











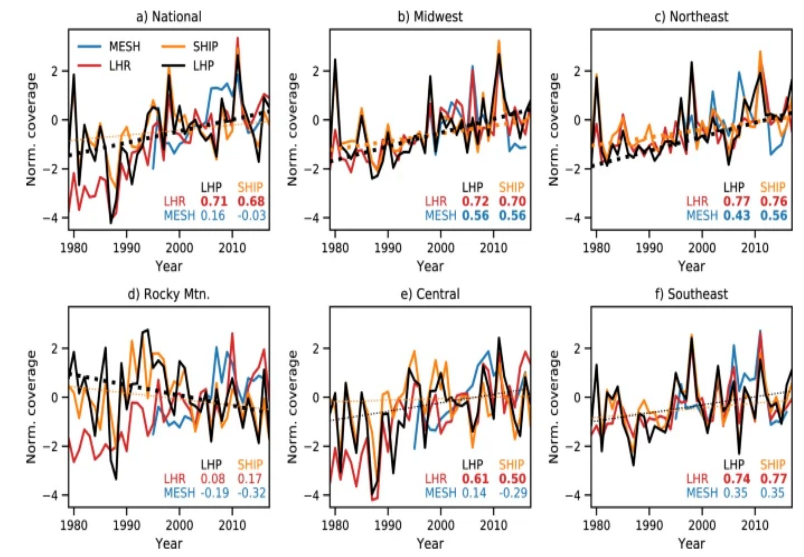
HAIL EVENTS

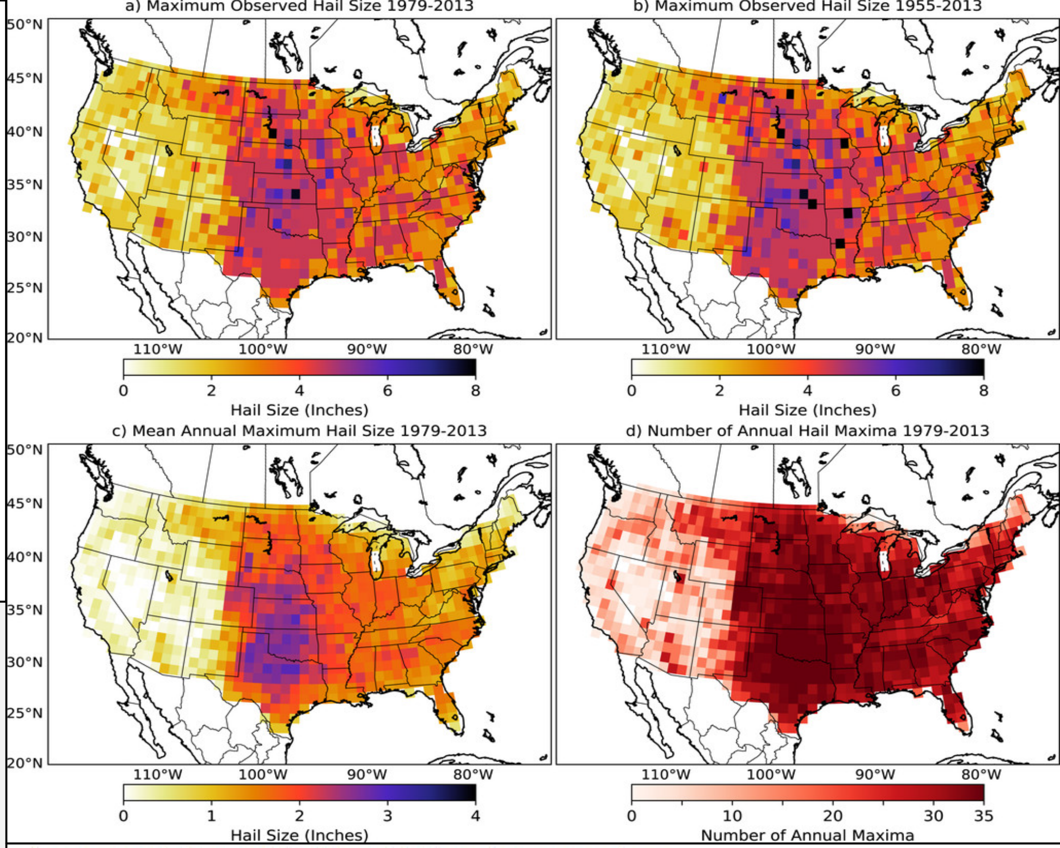
Hail related insured losses from 2000-2019 averaged $8-14 billion a year (Aon). There were 3,763 major hailstorms in 2021 (NOAA).

Over 6.8 million properties in the US were affected by damaging hailstorms in 2021, an increase from 6.2 million in 2020.

While 2021 had a wider hail geographic area impacted by hail, and more properties at risk by association, while there were fewer hailstorms than in 2020 and less than the 10-year average.

Fig. 3: Annual large hail environment, report, and radar-derived area.

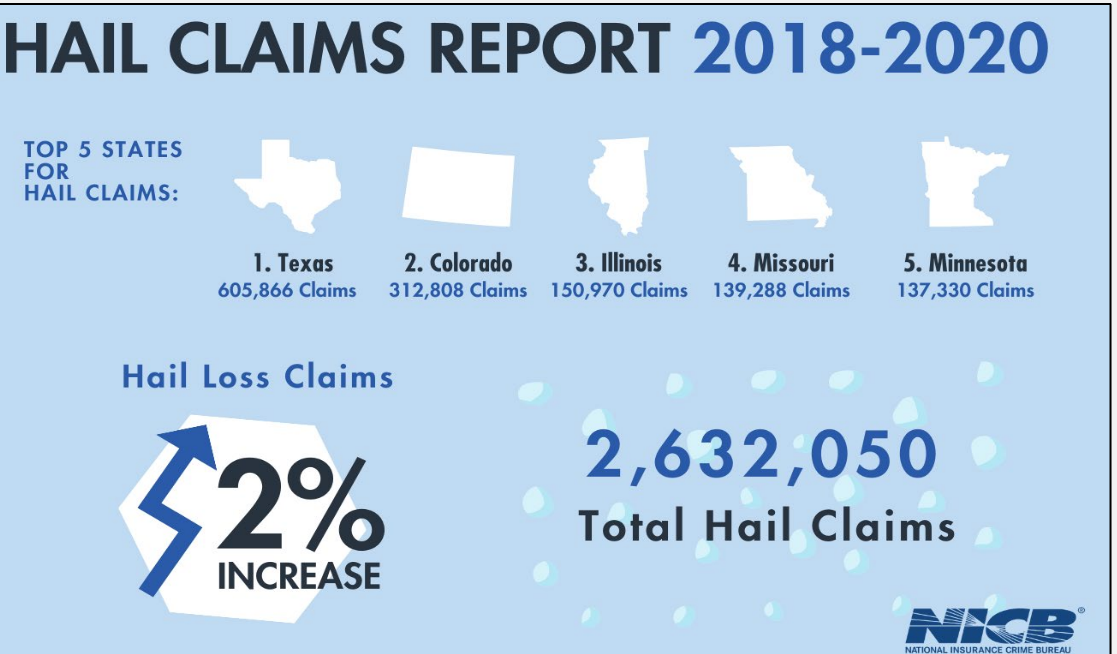




US Hail Damage averages over $10 Billion.

A total of 784,814 hail damage claims were filed in 2019. The NICB released a three-year study of hail damage claims for the years 2017-2019.

From 2000 to 2013, U.S. insurers paid ~9 million claims for hail losses, totaling more than $54 billion. The average claim severity during those six years was 65% higher than the period 2000-2007.



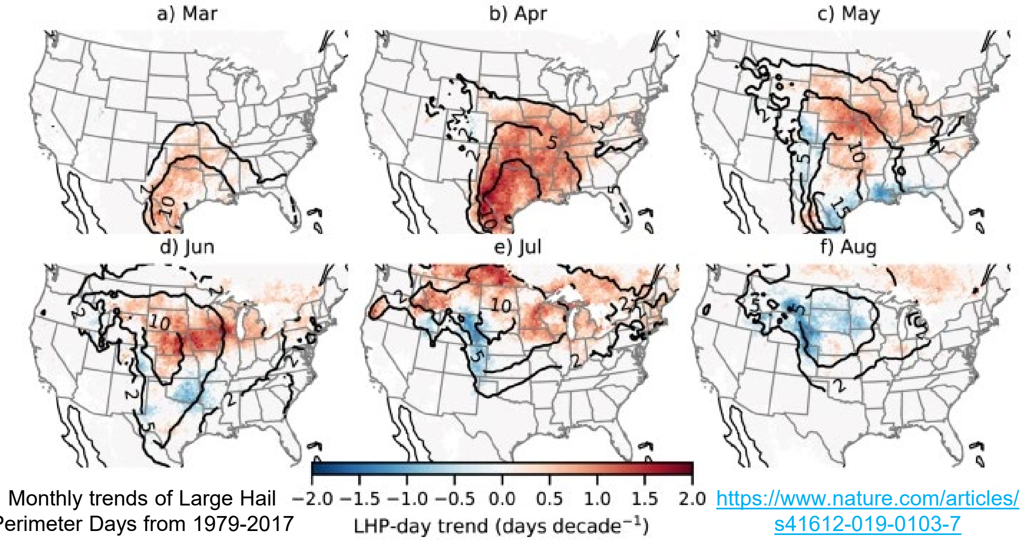
2019: 7.1 million properties impacted totaling more than $13 billion in damages.

2017: 10.7 million properties impacted totaling $2.3 billion dollars in damage.

2016: 12.6 million properties impacted with over $8 billion in damage.

The threat of hail damage has spread from "hail alley" (Colorado, Nebraska, and Wyoming) northward through the Midwest, south toward the Gulf Coast and desert Southwest, and east toward the Appalachian region.

Fig. 2: Trends in monthly large hail environment days.



Monthly trends of Large Hail Perimeter Days from 1979-2017

https://www.nature.com/articles/s41612-019-0103-7

WHAT IT ALL MEANS

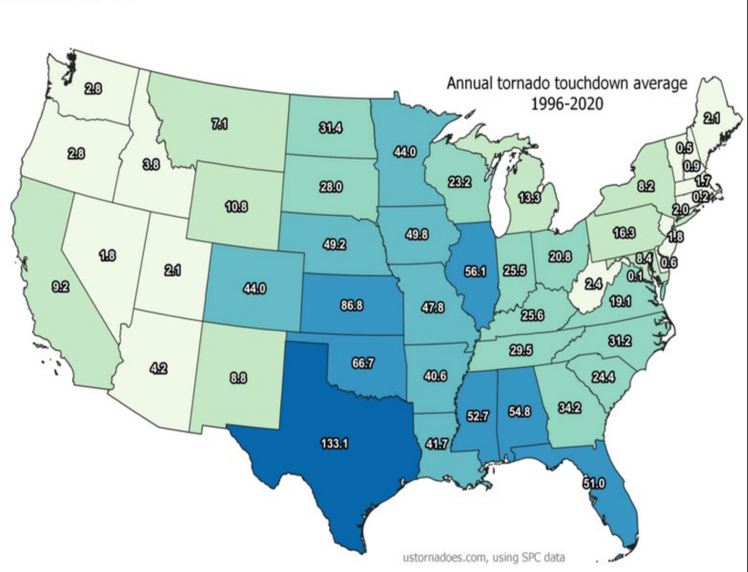
As the baseline temperatures increase through the US, coupled with the increase in water vapor, widespread atmospheric instability could result in more tornadic swarm events annually.

- Days which would typically produce only a few tornadoes have the potential to produce >15 tornadoes due to high heat/humidity.
- Increases in tornadic activity have been reported in various states from 2020-2021 with associated damage and cost reports rising as activity expands into densely populated areas.
- Severe thunderstorms can produce damaging winds in excess of 65 mph, large hail ranging between 2-3 inches in diameter, flash flooding events of 3-4 inches in <6 hours, and frequently lightning.

Tropical instability through the Summer-Autumn months can amplify tornadic activity and severe thunderstorm cells throughout the Southeast, Mid-Atlantic, and New England States.

- Deeper than normal tropical lows are moving further inland than typical bringing threats to the Tennessee-Ohio River Valleys, the Great Lakes, and the New England states with increased rainfall and damaging surface wind.
- Higher heat holding more moisture will enable tropical events to cause heavier initial rains.

Tornadoes by state



Top 10 States, By Number Of Tornadoes 2021

Rank	State	Number of tornadoes	Fatalities
1	Texas	118	1
2	Alabama	100	7
3	Mississippi	92	1
4	Illinois	80	6
5	Iowa	70	0
6	Tennessee	66	4
7	Georgia	57	0
7	Kentucky	57	73
8	Nebraska	53	0
9	Louisiana	50	1
9	Missouri	50	2
10	Colorado	48	0

(1) Tornadoes that cross state lines are counted in every state in which they touch down.

Source: U.S. Department of Commerce, Storm Prediction Center, National Weather Service.

Tornadoes And Related Deaths By State, 2021 (1)

State	Tornadoes	Fatalities	Rank (2)	State	Tornadoes	Fatalities	Rank (2)
Alabama	100	7	2	Montana	1	0	34
Alaska	0	0	(3)	Nebraska	53	0	8
Arizona	6	0	29	Nevada	3	0	32
Arkansas	41	2	13	New Hampshire	0	0	(3)
California	5	0	30	New Jersey	13	0	24
Colorado	48	0	10	New Mexico	18	0	21
Connecticut	8	0	27	New York	14	0	23
Delaware	2	0	33	North Carolina	19	3	20
D.C.	2	0	33	North Dakota	21	0	21
Florida	32	0	16	Ohio	37	0	15
Georgia	57	0	7	Oklahoma	39	0	14
Hawaii	0	0	(3)	Oregon	0	0	(3)
Idaho	0	0	(3)	Pennsylvania	44	1	12
Illinois	80	6	4	Rhode Island	2	0	33
Indiana	19	0	20	South Carolina	24	0	18
Iowa	70	0	5	South Dakota	19	0	20
Kansas	46	0	11	Tennessee	66	4	6
Kentucky	57	73	7	Texas	118	1	1
Louisiana	50	1	9	Utah	4	0	31
Maine	0	0	(3)	Vermont	2	0	33
Maryland	11	0	25	Virginia	9	0	26
Massachusetts	7	0	28	Washington	2	0	33
Michigan	17	0	22	West Virginia	2	0	33
Minnesota	37	0	15	Wisconsin	28	0	17
Mississippi	92	1	3	Wyoming	2	0	33
Missouri	50	2	9	**United States (4)**	**1,377**	**101**	

(1) Ranked by total number of tornadoes.
(2) States with the same number of tornadoes receive the same ranking.
(3) State had no tornadoes in 2021.
(4) The U.S. total will not match data used in other charts because it counts tornadoes that cross state lines.

Source: U.S. Department of Commerce, Storm Prediction Center, National Weather Service.

Flooding Changes: Flashier Flash Floods

Floods are the most common natural disaster in the US and about 41 million U.S. residents are at risk from flooding along rivers and streams.

- River flooding can result from heavy rainfall, rapid snow melt, or ice jams.
- Urban flooding refers to flooding that occurs when rainfall overwhelms the local stormwater drainage capacity of a densely populated area.

Extreme flooding will continue to be concentrated in regions where humans have built on floodplains or low-lying coastal regions. As extreme weather events increase, risks will extend into new areas.

- 1000-year flood events will occur more often due to increased land use and heavier precipitation. The term “1,000-year flood” means a flood of that magnitude (or greater) has a 1 in 1,000 chance of occurring in any given year.

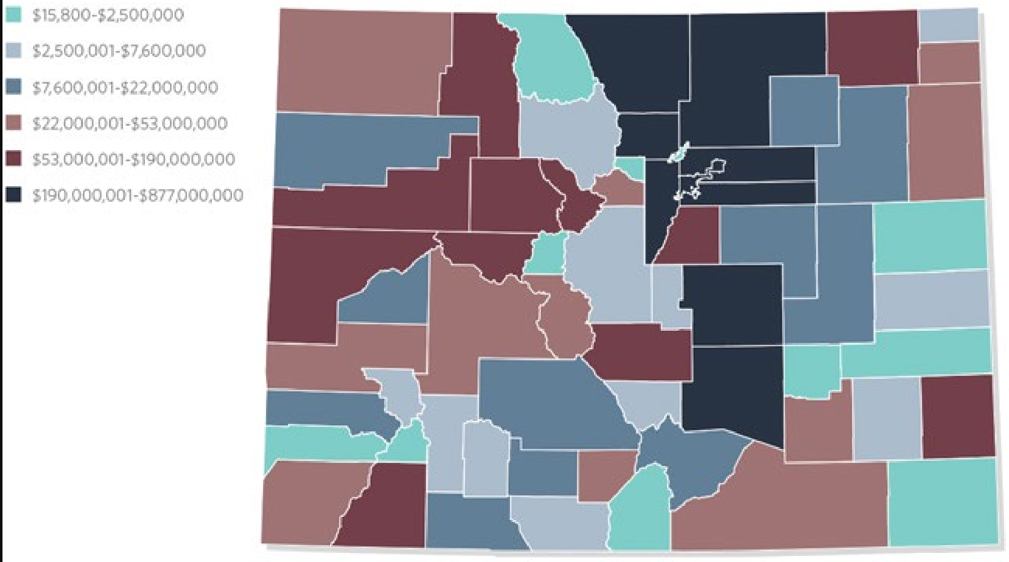
New research shows as the baseline temperature annually creeps upward due to moderate to high emission rates, flooding events would become 8% “flashier” by the end of the century. This means that heavy rainfall events are likely to occur quickly and in concentrated areas that could lead to flooding.

- A more than 10% increase in flash flooding in the Southwest U.S. which accounts for the greatest increase in “flashiness” among hot spots.
- “The 20-year return floods will more likely occur every two to five years, especially alarming for the emerging flashiness hotspots that will be facing unprecedented challenges with aging infrastructure and outdated flood risk measures” Yang Hong.. https://www.un.org/en/climatechange/reports?gclid=Cj0KCQjwjN-SBhCkARIsACsrBz6h_uH-xJnN2929g3CDEV9GZVLFEGh6KWfiNgneXUlf6d78n4Tlk24aAg3fEALw_wcB

Figure 1

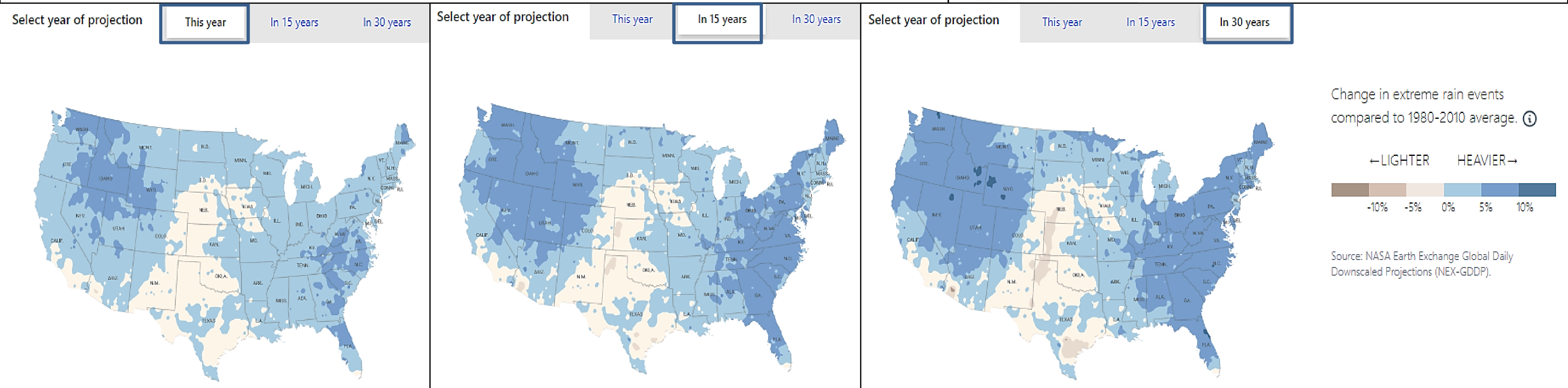
Colorado Floods Are Projected to Cost Millions in Damage

Total economic loss estimates in 1% annual chance flood hazard areas



Note: The 1% annual chance floodplain represents a flood that has a 1% chance of being equaled or exceeded in any single year.

Sources: Federal Emergency Management Agency, Hazus software; Colorado Division of Homeland Security and Emergency Management, “Flood Hazard Mitigation Plan for Colorado” (November 2013)

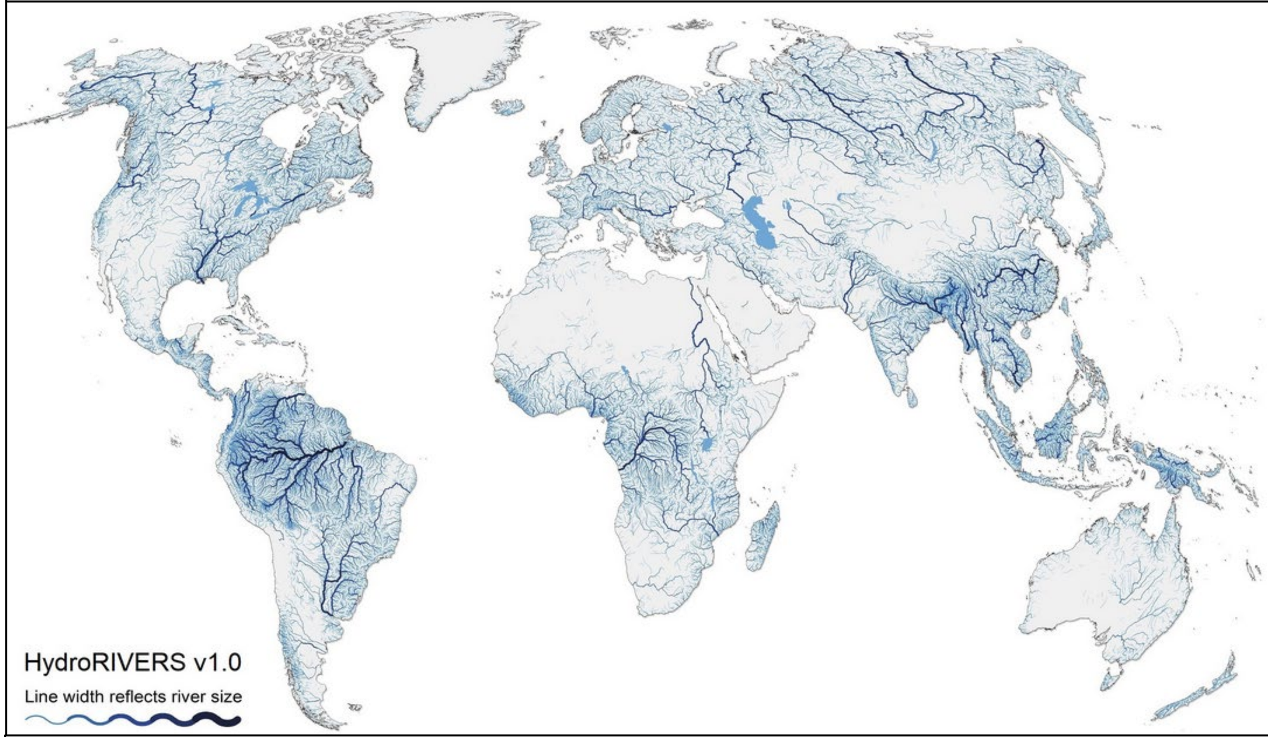


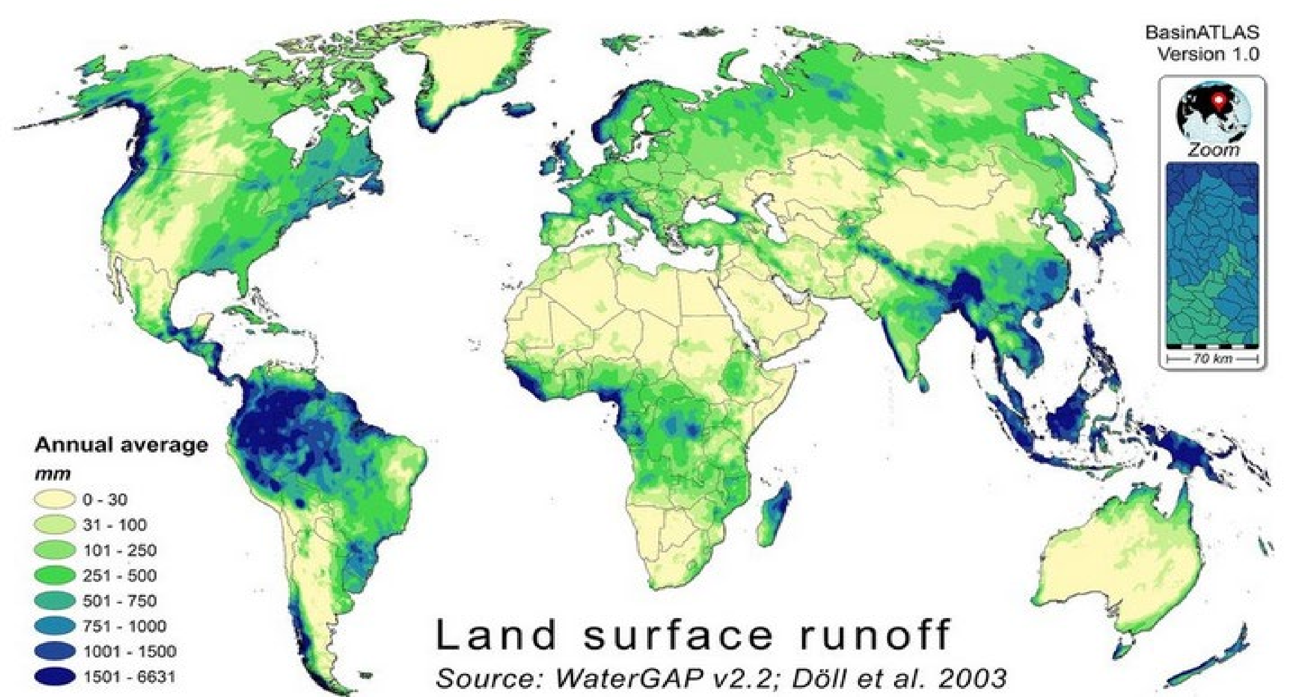
Flood Waters and the Impacts to the River Systems

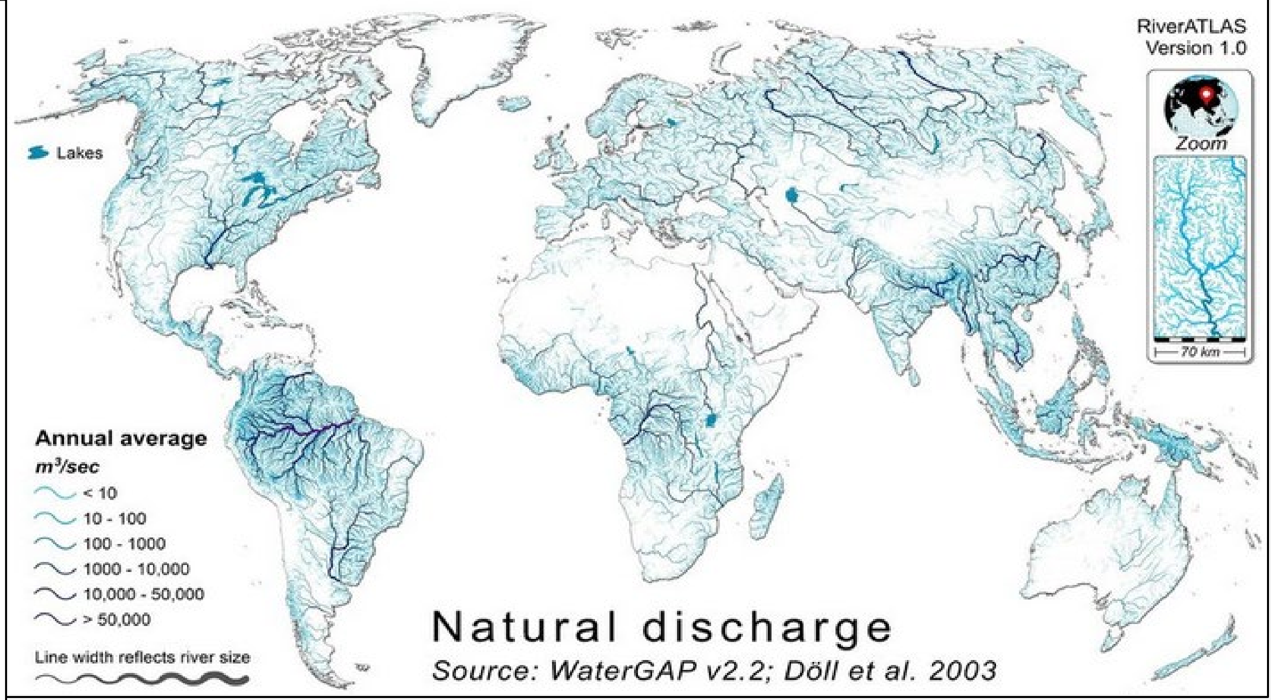
As the warming climate adds more water vapor into the air through evapotranspiration, it will have an immediate cascading impact downstream with higher rainfall rates in shorter periods. Areas of focus are along the Northwest, Midwest, Great Lakes, and Northeast.

- Rain has been reported this year at a torrential rate which will scoop surface materials from farms, damaged infrastructure, burn scars, and general surface debris and move it into river systems in sudden waves of rapid runoff. Some impacts of note:
    - Damage to wastewater treatment facilities and infrastructure in the floodplain
    - Polluted waterways and damage to river infrastructure like locks and dams
    - Toxic levels of metals, minerals, and materials into surface water basins
    - Some access points to aquifers could be jeopardized
    - Heavy rainfall post-drought conditions could reveal new areas of lowest elevation due to subsidence from overpulling of regional aquifers via the wells

Dry soils in heat waves between storms can see soil compact which reduces absorption rates. When rain does fall, less is absorbed initially which could overwhelm rivers.







Climate Migration Patterns

Climate migrants are **people who leave their homes because of climate stressors**. Climate stressors, such as changing rainfall, heavy flooding, and sea level rise, put pressure on people to leave their homes and livelihoods behind. It makes their homes uninhabitable.

- Since 2008 over 318 million people around the world have been forcibly displaced by floods, windstorms, earthquakes or droughts, 30.7 million in 2020alone.This is equal to one person being displaced every second. The number of people affected by climate change could double by 2050

13 million U.S. coastal residents are expected to be displaced by 2100 due to sea level rise. In the worst-case scenario, in which sea levels rise by six feet by 2100, the resulting map shows portions of almost all counties on the East and West Coasts, and along the Gulf of Mexico, under water.

the 2018 wildfire that displaced some 50,000 residents in and around the city of Paradise, California. “It’s increased the property values of neighboring towns,” he says. One such town is Chico, which became the top refuge destination and turned into a boomtown almost overnight. By the end of that year, home sales doubled, and housing prices jumped 21%, compared to December 2017.

People may also flock to major urban centers like Dallas and Houston, which the model predicts will absorb the most migrants, and drive up the pace of urbanization.

Heat waves will drive people north—and could make cities like Duluth and Buffalo “climate havens.” Urban flooding will reshuffle populations within a city.

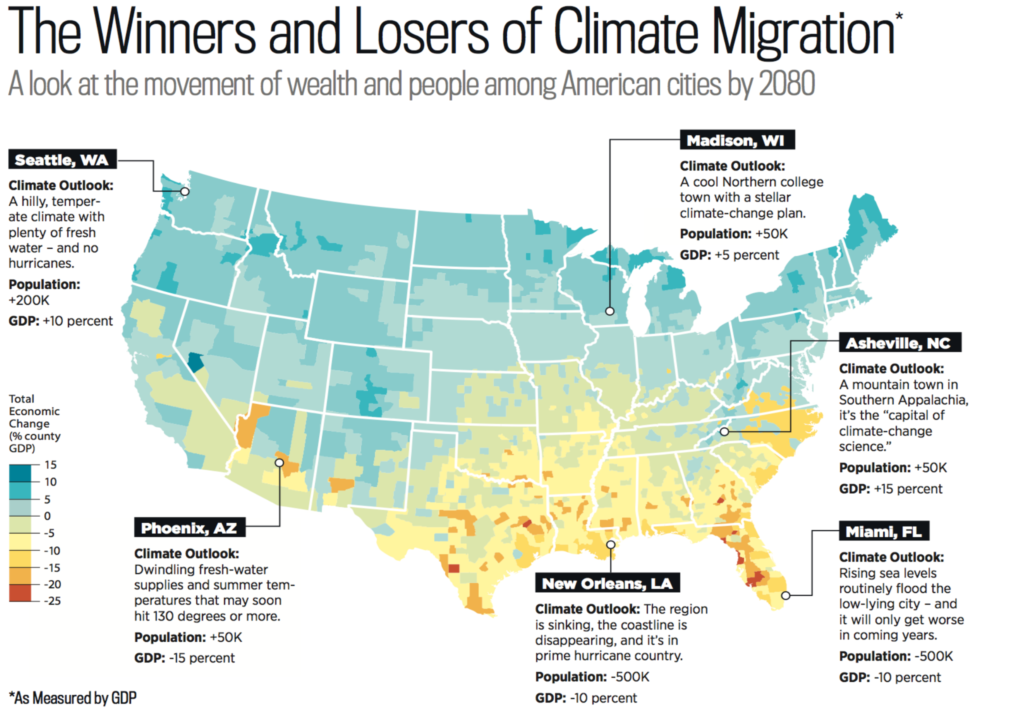
Climate change related-migration, as used in this report, is an umbrella term describing the spectrum of climate change’s relationship with human mobility—including the circumstances of “trapped populations” for whom migration is not an option despite exposure to climate-related threats. Even in the United States, one extreme event can result in a relatively high degree of permanent relocation of low-income populations exposed to chronic and worsening conditions over time.

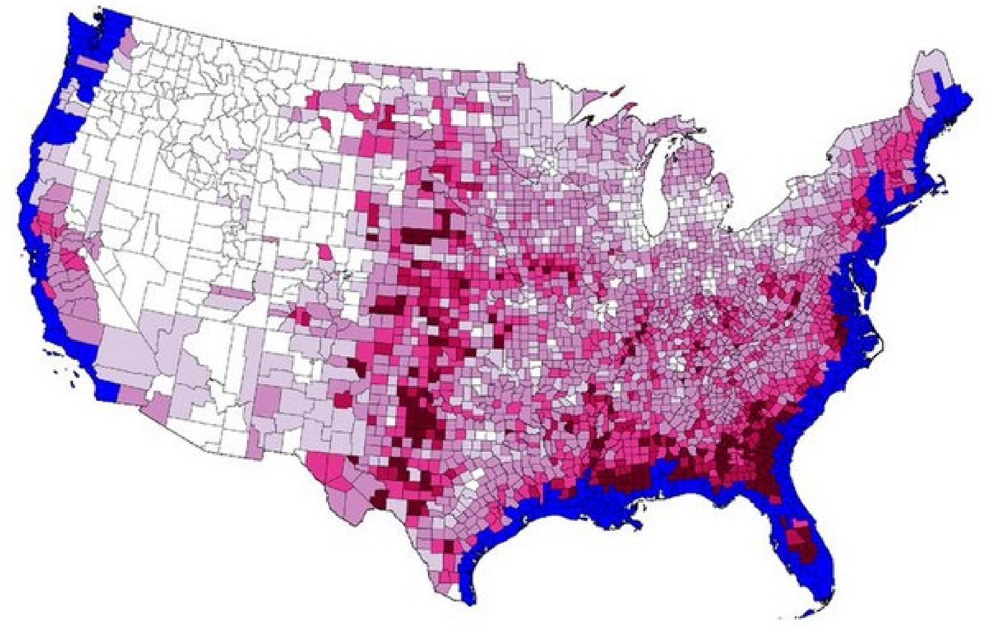
https://www.whitehouse.gov/wp-content/uploads/2021/10/Report-on-the-Impact-of-Climate-Change-on-Migration.pdf

Extreme weather events and conflict are the top 2 drivers of forced displacement globally, together responsible for the annual movement of nearly 30 million people from their homes.

Climate change can cause or exacerbate resource scarcity, which may drive conflict directly as well as induce migration of populations in vulnerable situations attempting to secure safety or livelihoods.

The subsequent movement of large numbers of people, by force or by choice, brings new groups into contact with one another, potentially shifting power balances, causing further resource scarcity, or igniting tensions between previously separated groups





Sea level rise could displace some 13 million people. Here's where they might go. *PLOS One*

While most climate displacement in the past has typically happened internally, with people returning soon after the disaster, increasingly the impacts of climate change are making certain areas uninhabitable and returning difficult.

- Insurance providers have remarked that rates are expected increase as flooding, fires, and heat waves increase with the potential that some insurance companies may leave the business which would decrease the competition regionally. Individuals renting may not have the same protections and reimbursement as homeowners impacted by extreme weather events damaging residential areas.

Population displacement can create competition, for food and clean water access, but also on labor markets, while also exacerbating existing ethnic tensions, or gender violence. Furthermore, climate migration often combines with conflict-related displacement, and worsens the situation in already sensitive regions touched by war and violence

<u>Where people live influences their vulnerability to climate change:</u>

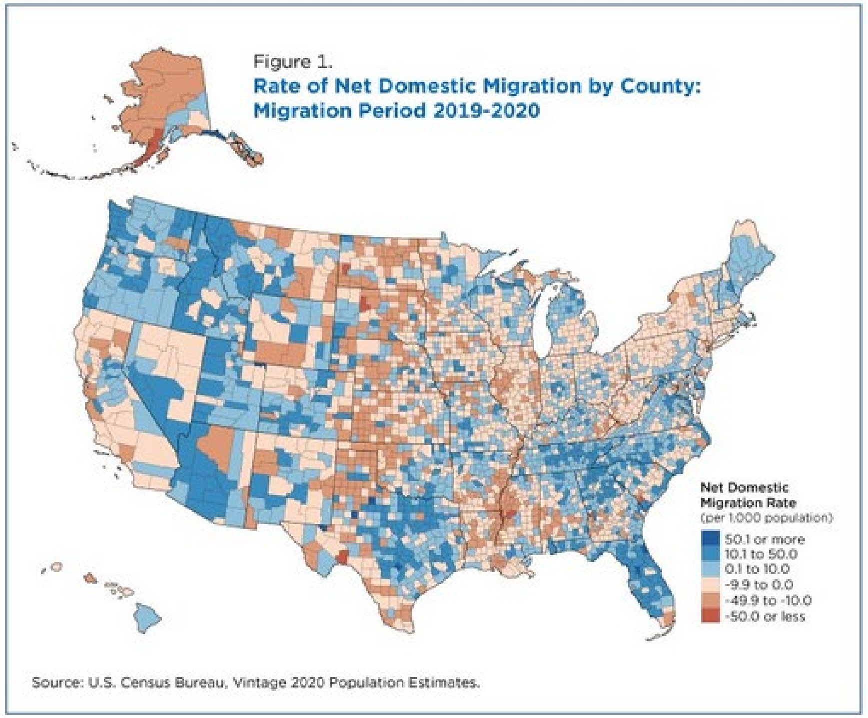
About 80% of the U.S. population lives in urban areas. As a result, increases in heat waves, drought, or violent storms in cities would affect a larger number of people than in suburban or rural areas

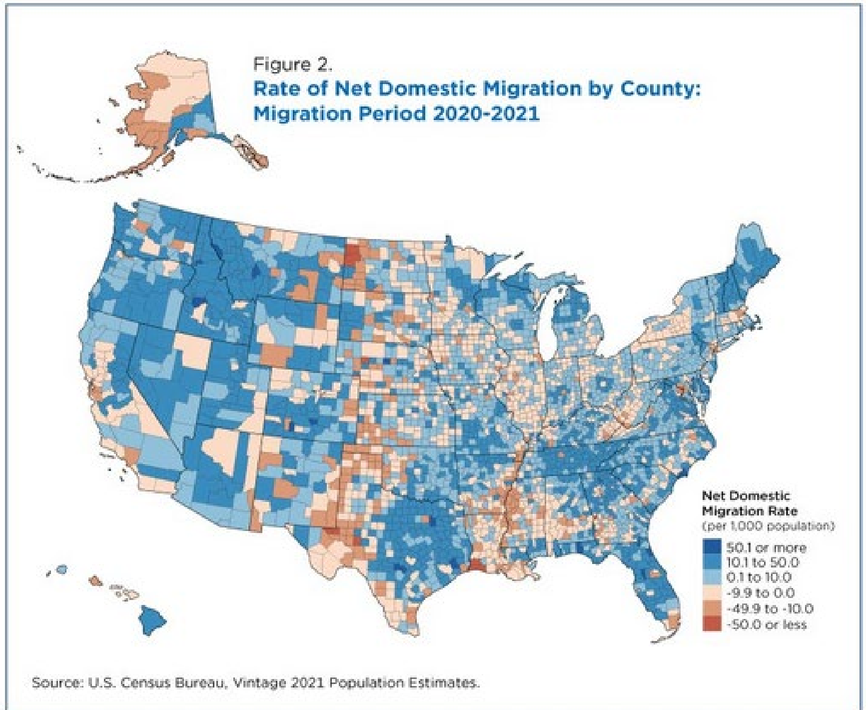
- Over the past 40 years, population has grown rapidly in coastal areas and in the southern and western regions of the United States. These areas are most sensitive to coastal storms, drought, air pollution, and heat waves.
- Populations in the Mountain West will likely face water shortages and increased wildfires in the future.
- Arctic residents will likely experience problems caused by thawing permafrost and reduced sea ice.
- Along the coasts and across the western United States, both increasing population and changes in climate place growing demands on transportation, water, and energy infrastructure.

The top 10 counties that lost the most population were concentrated in California, New York, Illinois and Florida. Los Angeles County lost the most residents, around 185,000, and New York County had the greatest percentage loss of residents with a negative 6.9% rate.

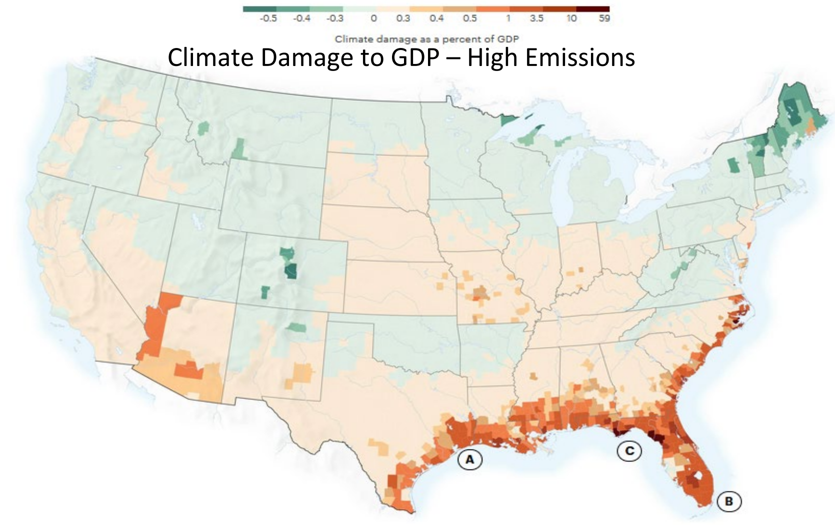
- The states that had the largest growth rates were Utah, Texas, California, Arizona and Florida. The county that added the most residents was Maricopa County in Arizona, which contains the state's biggest city, Phoenix, adding around 58,000 residents. Utah County came in at the 10th spot on the list by adding just under 22,000 residents to bring its population to around 685,000 people.
- St. George, Utah grew by nearly 10,000 new residents between July 1 of 2020 and July of 2021, a 5.1% increase. Two other Utah cities made the list of top-10 fastest-growing metro areas, with the Provo-Orem area ranked eighth at 3.3% and the Logan area ranked 10th at 2.9%.

Climate change can impact the health and well-being of indigenous tribes by making it harder for tribes to access safe and nutritious food including traditional foods important to many tribes' cultural practices. Many tribes lack access to safe drinking water and wastewater treatment in their communities. Climate change could increase health risks associated with water quality problems like contamination and may reduce availability of water during droughts.



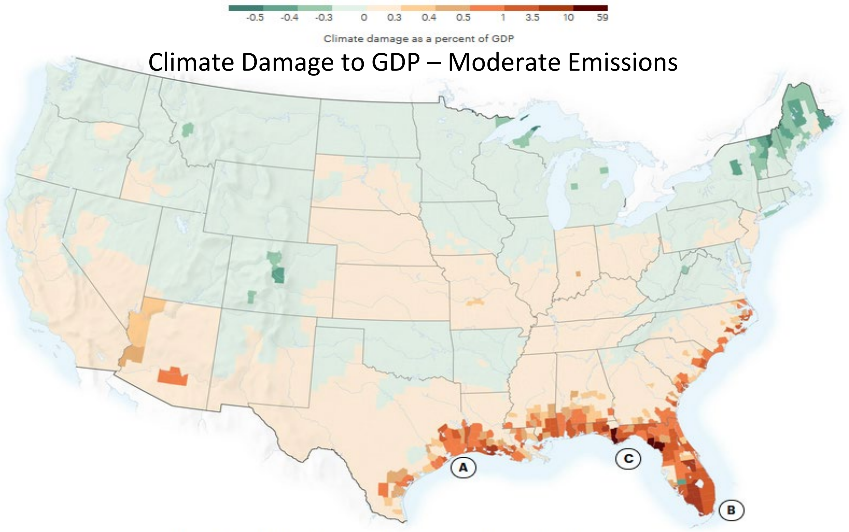


Climate Damage to GDP – High Emissions



Populous cities with expensive real estate, including Houston (A) and Miami (B), will see damage tallied in the billions — losses worth several percentage points of GDP — largely driven by storms, sea level rise and deaths from high heat, Hess said. Climate will have a larger proportional impact in rural places like Gulf County, Florida (C), which might lose half its economy.

Climate Damage to GDP – Moderate Emissions



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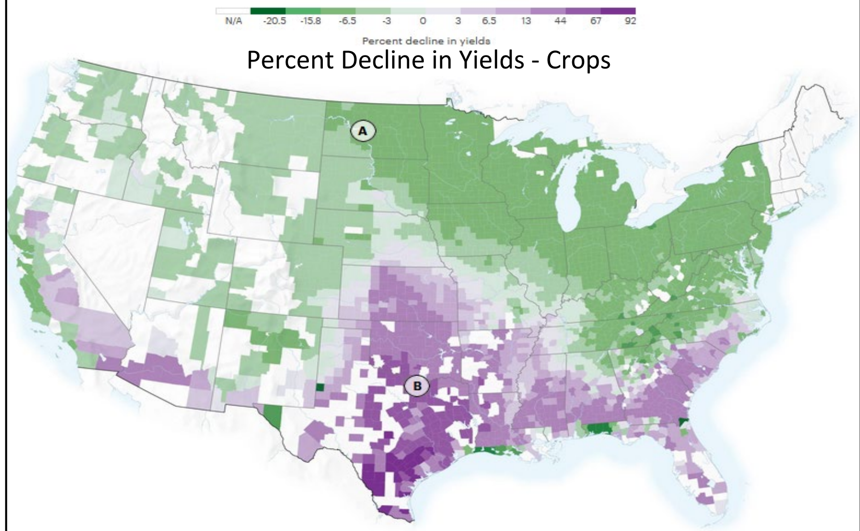
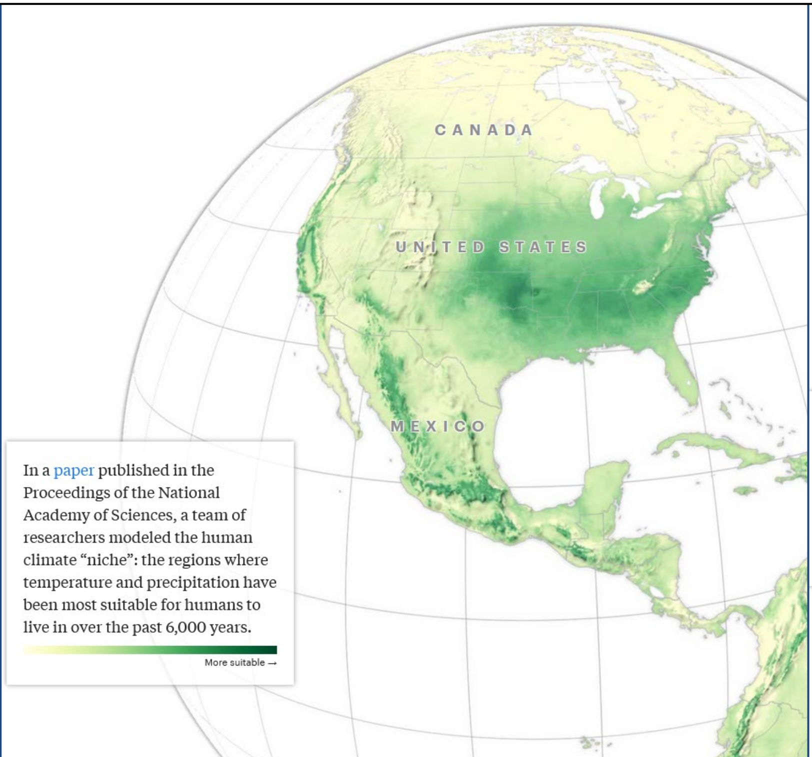
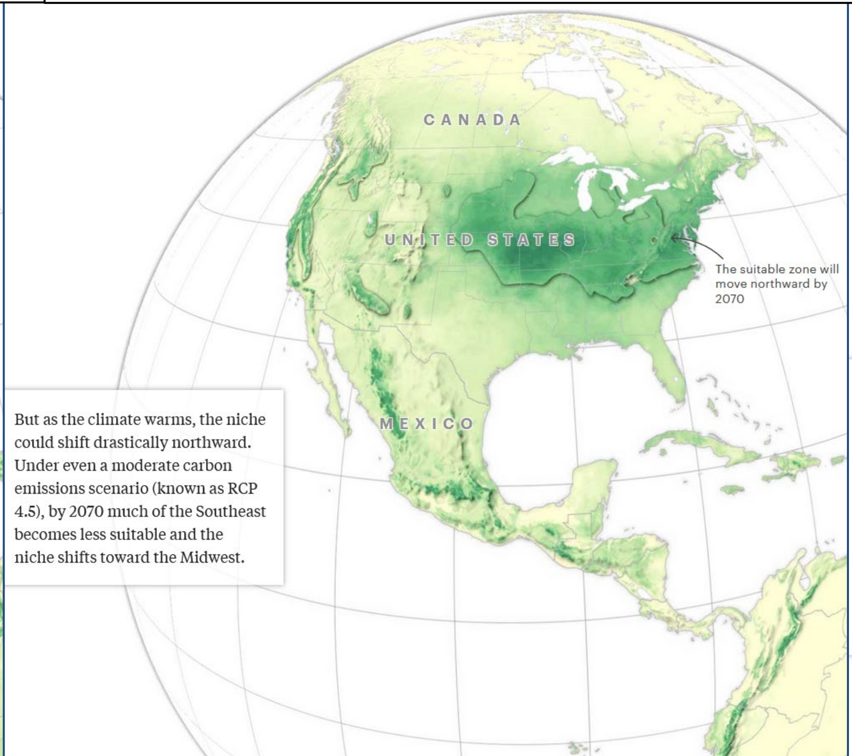
Percent Decline in Yields - Crops



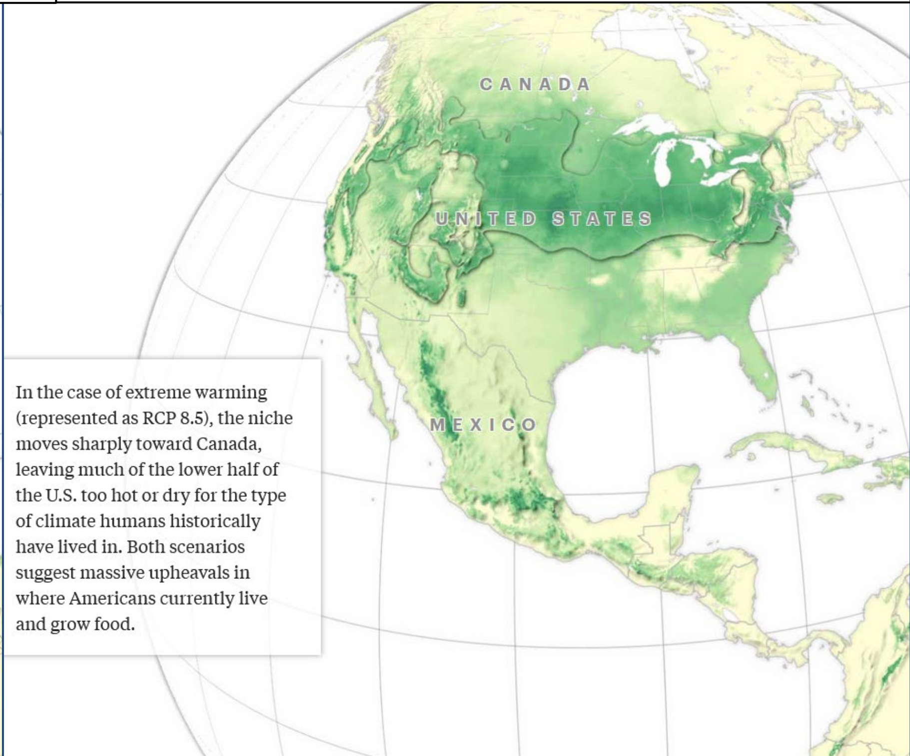
Corn and soy production is more sensitive to heat than drought, and it will decrease for every degree of warming. By midcentury, North Dakota (A), which already harvests millions of acres of both crops, will warm enough to allow for more growing days and higher yields. But parts of Texas and Oklahoma (B) may see yields drop by more than 70%.



In a paper published in the Proceedings of the National Academy of Sciences, a team of researchers modeled the human climate “niche”: the regions where temperature and precipitation have been most suitable for humans to live in over the past 6,000 years.



But as the climate warms, the niche could shift drastically northward. Under even a moderate carbon emissions scenario (known as RCP 4.5), by 2070 much of the Southeast becomes less suitable and the niche shifts toward the Midwest.



In the case of extreme warming (represented as RCP 8.5), the niche moves sharply toward Canada, leaving much of the lower half of the U.S. too hot or dry for the type of climate humans historically have lived in. Both scenarios suggest massive upheavals in where Americans currently live and grow food.

Stony Brook University researchers suggest that human migration due to droughts will increase by at least 200% but up to 500% through the 21st Century.

Based on a series of both climate and social science modeling systems and other social science data, the study findings imply that migration may force the need to adjust sociopolitical policies to offset widespread human displacement.

- The team also identified a large group of people who will want to migrate but fail to do so as droughts cover large areas of land making possible destinations difficult to get to or inferior to their land of origin. The segment of immobile people is estimated to increase by 200-600%.
- The largest number of people displaced by drought under unmitigated change would occur in these countries: Nigeria, Egypt, China, Turkey, Algeria, Mexico, Morocco, and Venezuela. The projected largest number of immobile persons would be those in Turkey, Mexico, Morocco, Algeria, Brazil, Mali, and China.
- Parts of Angola, Namibia, Zimbabwe, Mozambique, and Madagascar face a food crisis due to low rainfall.
- The dry spell in southern Africa will continue well into March, the end of the rainy season, resulting in crops wilting and reduction in production prospects in many areas. Permanent wilting and crop moisture stress have already been noted in Mozambique and Zimbabwe.
- Affected Angolans are migrating to the northern parts of Namibia, where they are housed in refugee camps.
- Pakistan had over 680,000 estimated climate migrants in 2020 and this number may increase to 2 million by 2050.Pakistan is consistently ranked among the top 10 most climate-vulnerable countries in the world.
- According to a joint Asian Development Bank and World Bank study, Pakistan is losing around $3.8 billion annually because of climate change.

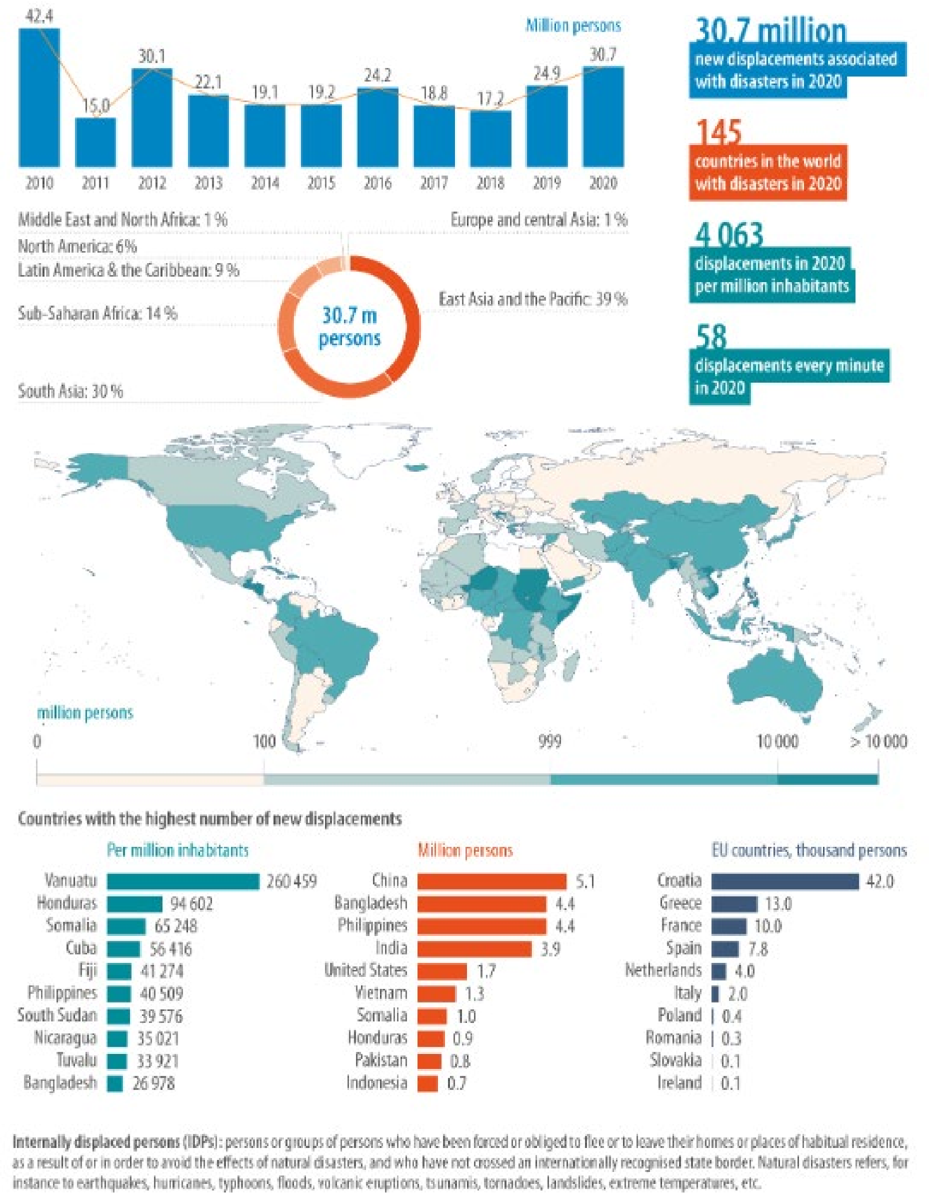
Recent research estimates over 18 million people in South Asia have already been forced to migrate due to sea-level rise, water stress, crop yield reductions, ecosystem loss, and drought.

- By 2050, the number of people displaced due to climate stresses is expected to grow to 63 million.

https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/698753/EPRS_BRI%282021%29698753_EN.pdf
https://journals.sagepub.com/doi/abs/10.1177/01979183221079850?journalCode=mrxa

EPRS | European Parliamentary Research Service

Figure 1 – Internal displacement of people due to natural disasters



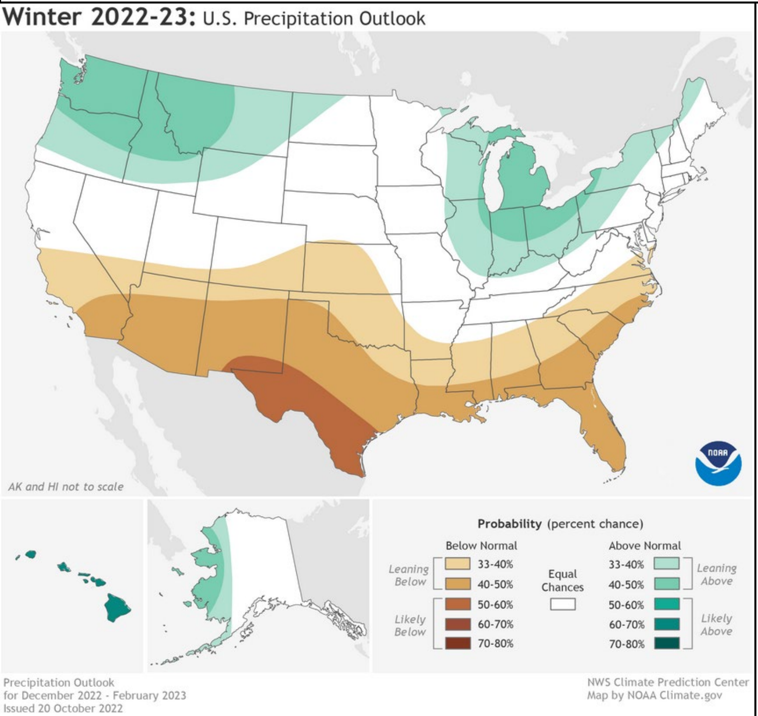
Data sources: Global Report on Internal Displacement, IDMC, 2021 and World Bank, World Development Indicators, 2021. Graphic update by Samy Chahri and Gyorgyi Macsai, based on an original infographic by Giulio Sabbati, EPRS.

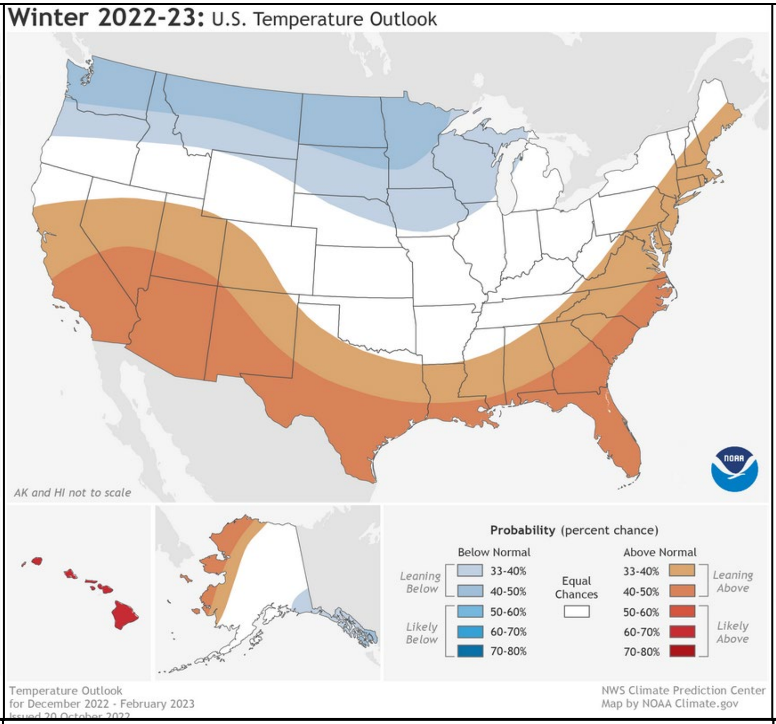
NOAA Winter Forecast – Third Consecutive Winter with La Niña present

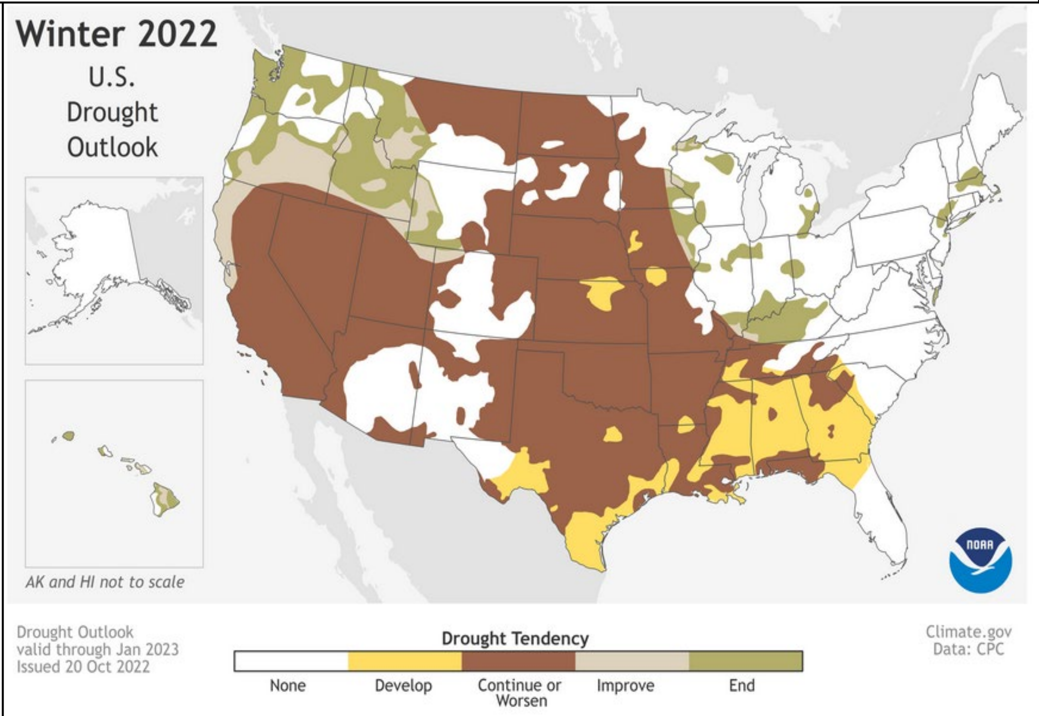
Starting in December 2022 through February 2023, NOAA predicts drier-than-average conditions across the South with wetter-than-average conditions for areas of the Ohio Valley, Great Lakes, northern Rockies and Pacific Northwest.

“Drought conditions are now present across approximately 59% of the country, but parts of the Western US and southern Great Plains will continue to be the hardest hit this winter,” said Jon Gottschalck, chief, Operational Prediction Branch, NOAA’s Climate Prediction Center. “With the La Niña climate pattern still in place, drought conditions may also expand to the Gulf Coast.”

NOAA’s Climate Prediction Center updates the three-month outlook each month. The next update will be available November 17.







The 2022-2023 U.S. Winter Outlook map for precipitation shows wetter-than-average conditions are most likely in western Alaska, the Pacific Northwest, northern Rockies, Great Lakes and Ohio Valley. Drier-than-average conditions are forecast in portions of California, the Southwest, the southern Rockies, southern Plains, Gulf Coast and much of the Southeast. (NOAA)

The U.S. Winter Outlook 2022-2023 map for temperature shows the greatest chances for warmer-than-average conditions in western Alaska, and the Central Great Basin and Southwest extending through the Southern Plains. Below normal temperatures are favored from the Pacific Northwest eastward to the western Great Lakes and the Alaska Panhandle. (NOAA)

This seasonal U.S. Drought Outlook map for November 2022 through January 2023 predicts persistent widespread drought across much of the West, the Great Basin, and the central-to-southern Great Plains. (NOAA) Drought is expected to impact the middle and lower Mississippi Valley this winter. Widespread extreme drought: the West, the Great Basin, and the Great Plains. Drought development is expected to occur across the South-central and Southeastern U.S., while drought conditions are expected to improve across the Northwestern U.S. over the coming months.

ENSO consist of three phases, El Niño (positive phase), Neutral, and La Niña (negative phase). Each phase is determined by sea surface temperatures and how they compare to the long-term average along with stronger atmospheric circulations over the equatorial Pacific.

This La Niña season will be different than a typical year. It will be the third time the climate pattern has repeated for three years in a row in the 73 years the NWS has tracked it.

The climate pattern appears when the sea surface temperature in the east-central Pacific Ocean is cooler than the long-term average by at least 0.5 degrees Celsius.

Most models suggest La Niña will transition to neutral between January-March 2023.

Sea Surface Temperatures across the equatorial Pacific influence the strength/positions of the jet stream in the Northern Hemisphere.

La Niña patterns result in variable polar/pacific jet streams which can bring cooler and wetter conditions to the northwest and warmer and drier conditions to the south.

El Niño and La Niña typically last nine to 12 months but can last for years. El Niño and La Niña occur every 2-7 years, on average. Generally, El Niño occurs more frequently than La Niña.

During La Niña, waters off the Pacific coast are colder and contain more nutrients than usual.

Third Triple-Dip La Niña Season on Record

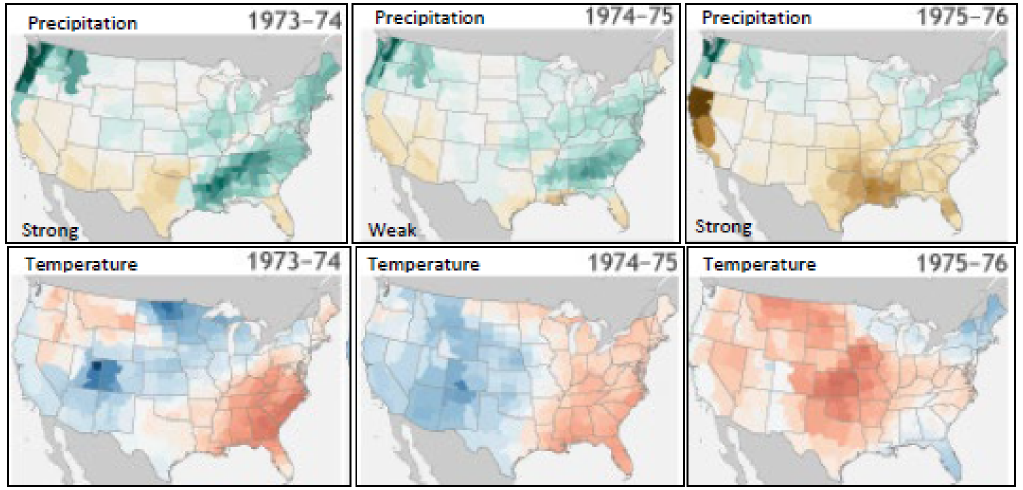
In general, the stronger the La Niña, the more reliable the impacts on the United States. The typical U.S. impacts are warmer- and drier-than-average conditions across the southern tier of the United States, colder-than-average conditions across the north-central Plains, and wetter-than-average conditions in the Pacific Northwest stretching into northern California.

- Current ENSO index forecasts a 'Triple Dip' La Niña. There have only been two other periods in recorded history with three consecutive years of La Niña, late spring 1973 to spring 1976, and late summer 1998 to early spring 2001. The current La Niña began late summer 2020-early spring 2023.

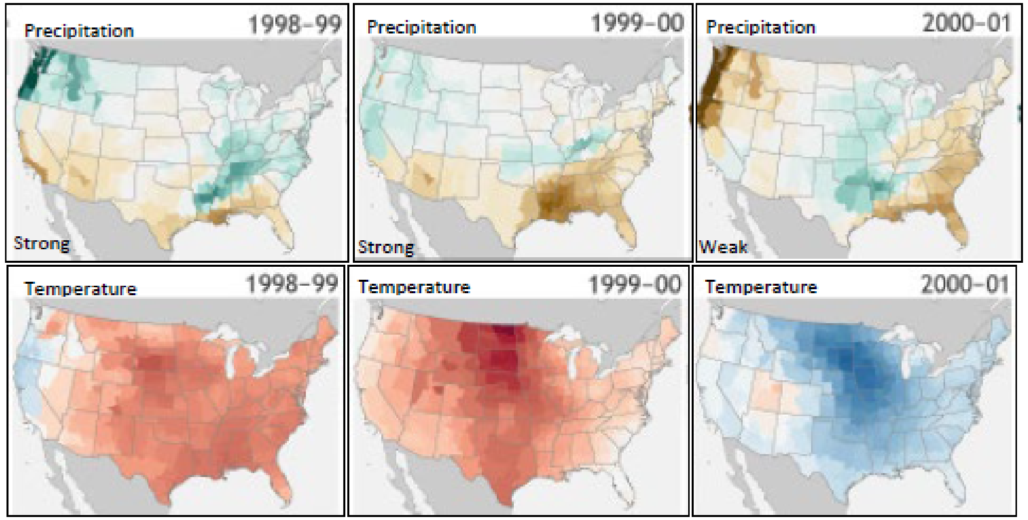
Temperatures: https://www.climate.gov/news-features/featured-images/temperature-patterns-during-every-la-ni%C3%B1a-winter-1950

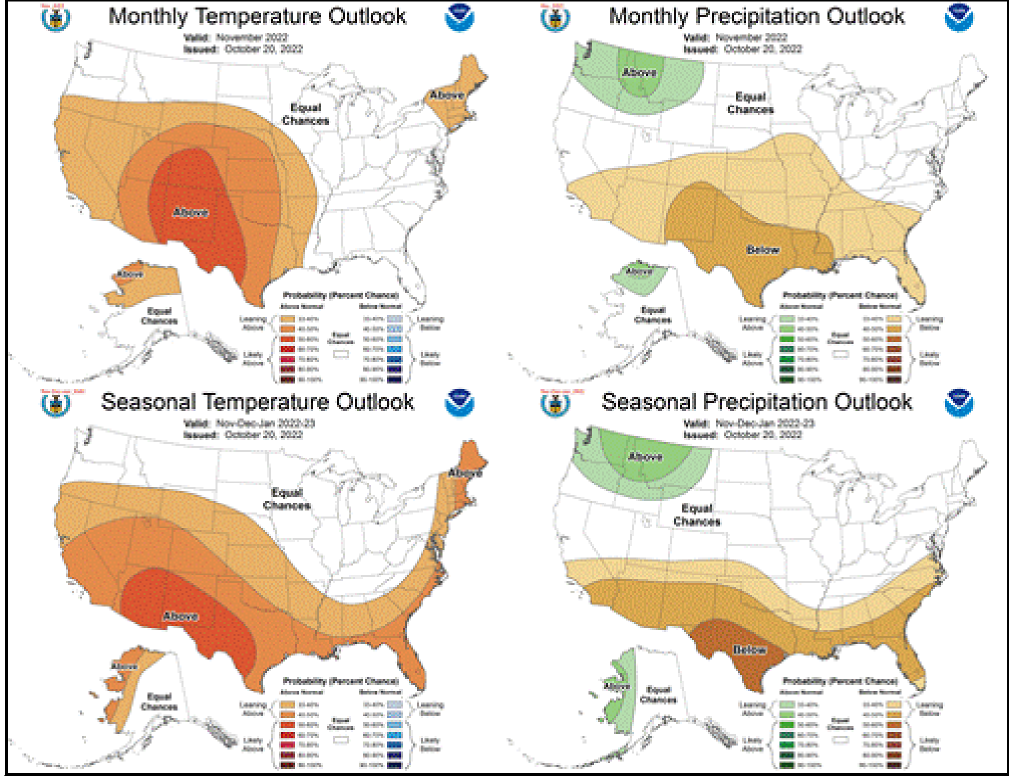
Precipitation: https://www.climate.gov/news-features/featured-images/precipitation-patterns-during-every-la-ni%C3%B1a-winter-1950

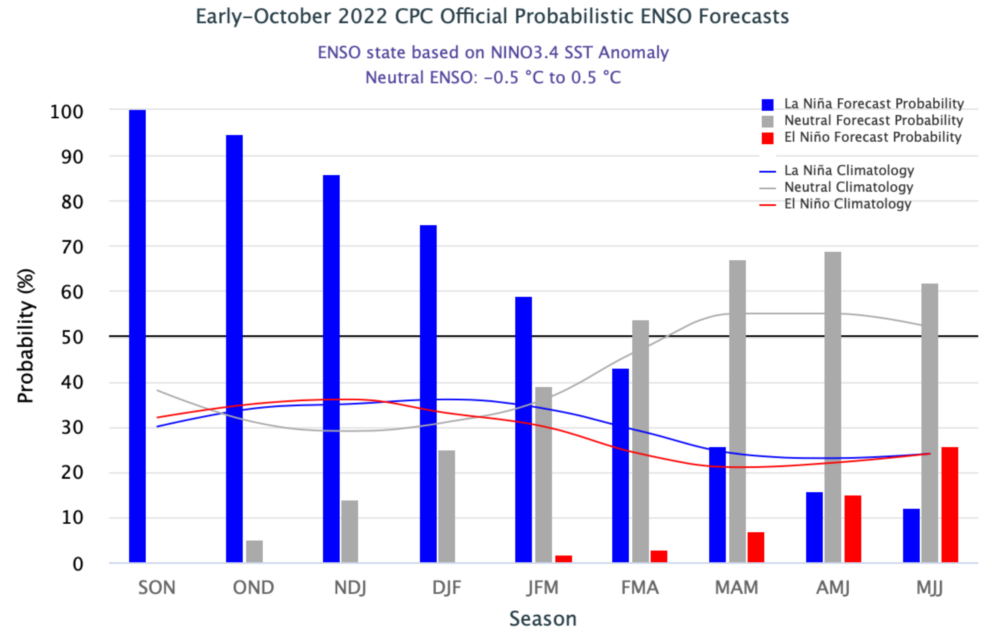
'Triple-Dip' La Niña WINTER National Climatology: Dec-Feb of 1973-1976



'Triple-Dip' La Niña WINTER National Climatology: Dec-Feb of 1998-2001





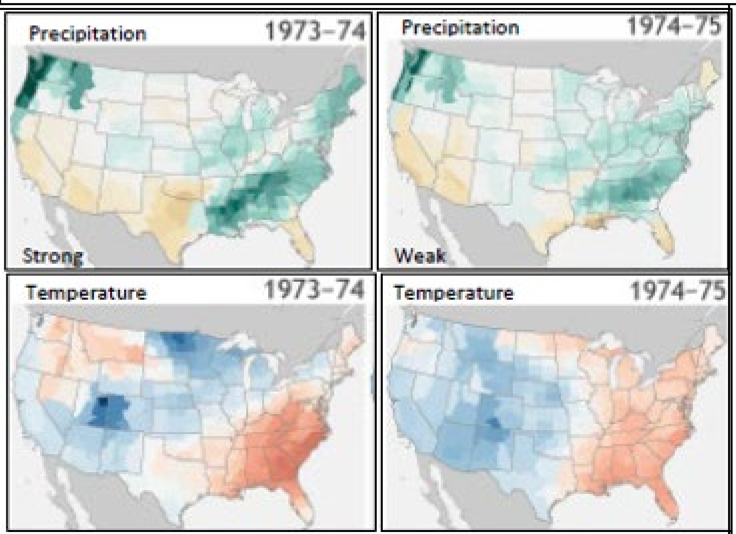


NOT AFFILIATED WITH NWS/NOAA/NHC/NASA
CISA ISD Meteorological Engagement Effort

WINTER SEASON FORECAST 2022-2023

Comparing the winter season's baseline temperature over the past two years, the 2020-2022 period, the warmer than normal winter and lack of precipitation in the south more closely resembles the 1998-2000 period of triple-dip La Niña. The winter in that set had significantly less precipitation to the Northwest and Northeast than normal, but more in the South-Southeast, and colder overall temperatures through the entire season widespread. Using this prior setup to forecast for this winter, widespread drought is worse this year than historically and will worsen as freezes set in.

Comparing Years 1-2 of La Niña for Forecasting Year 3 of 2022



1973-1975 (Winter Period)

- The 1973-1975 period had overall cooler than normal years for initial two years in the Central and Western US, followed by a third year which was warmer in that area, essentially flipping the pattern.
- The precipitation stayed to the same regions where the storm flow would follow for a La Niña flow. The third year maintained the pattern but saw less overall precipitation in the southern half of the US.

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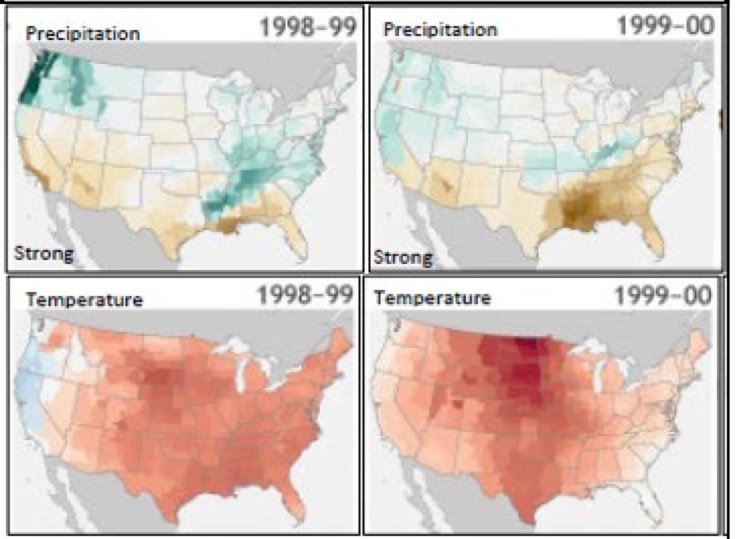
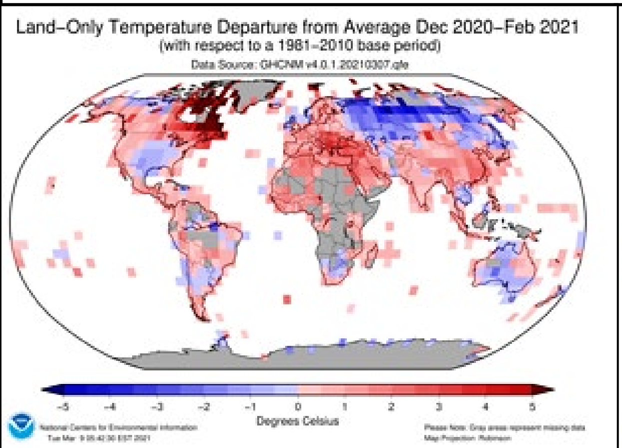
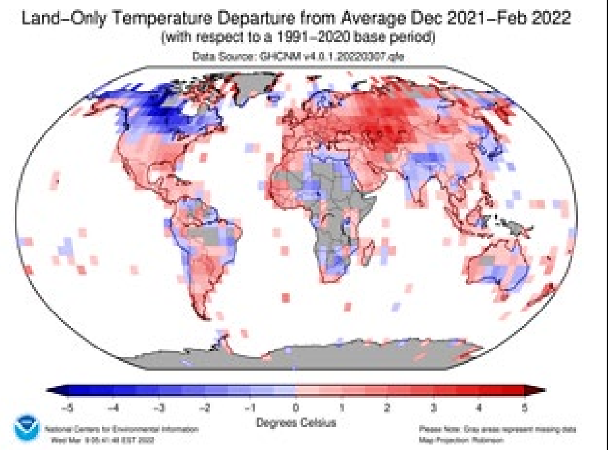


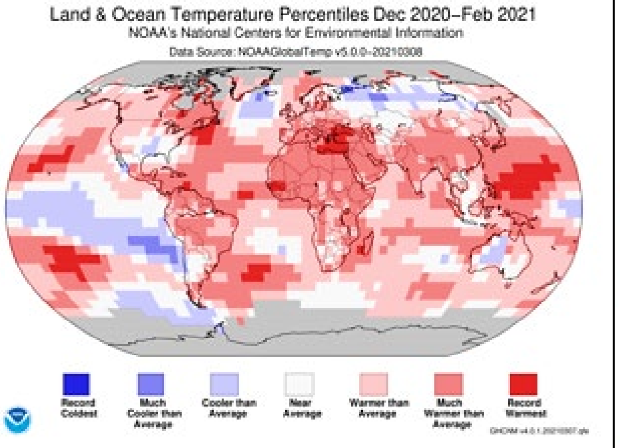
1998-2000 (Winter Period)

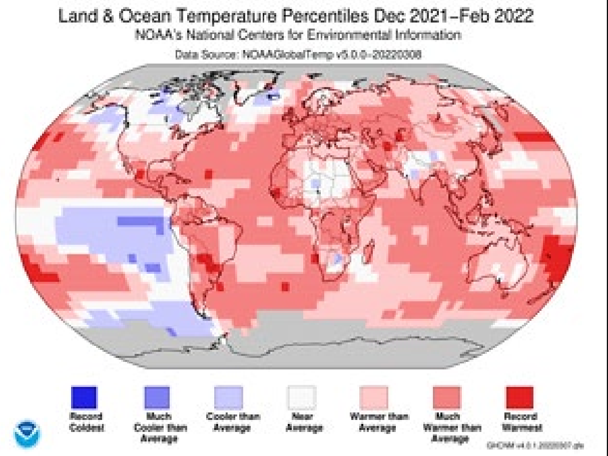
- The 1998-1999 period had overall warmer than normal years for the initial two years across most of the US, followed by the third year where the temperatures dropped nationally.
- The precipitation across the southern half of the US was significantly lower than the 1973-1975 period for the initial two years, the third year the dry conditions spread to the northwest and the northeast.

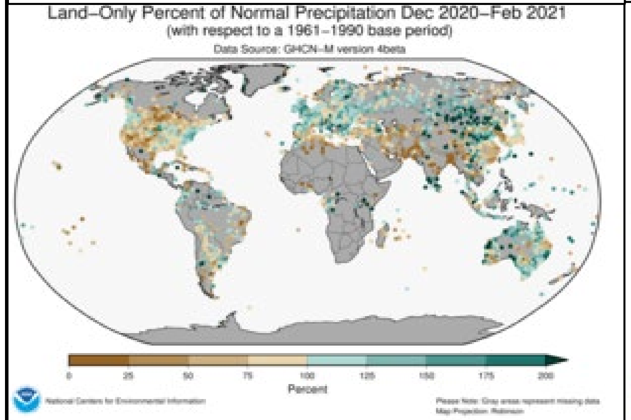
Winter of 2020-2021 - Winter of 2021-2022

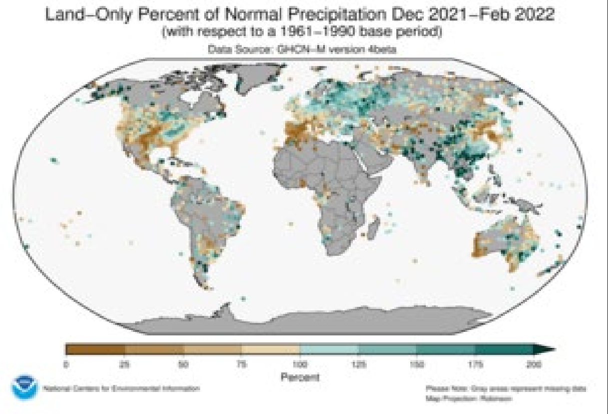








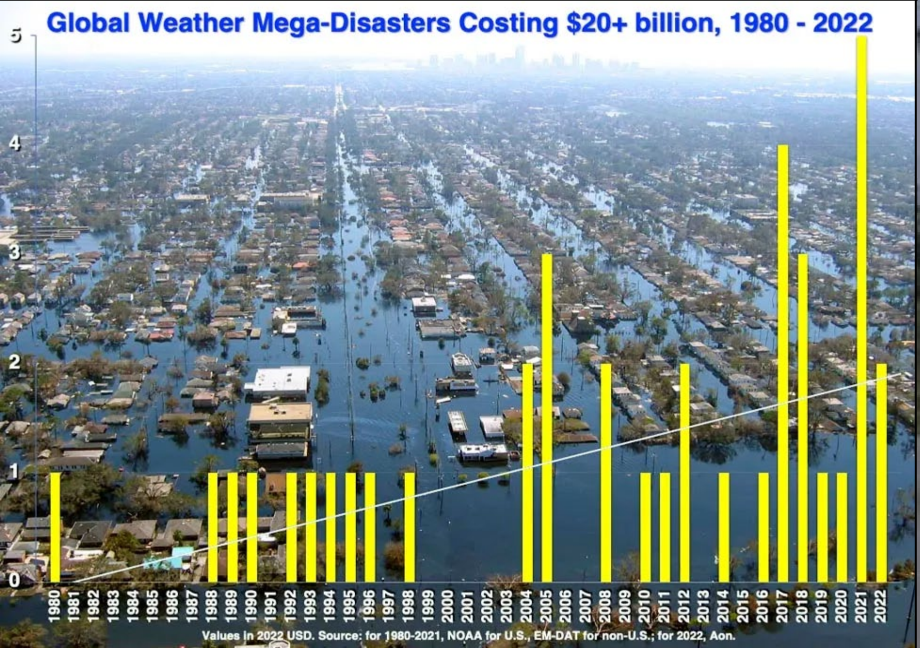




Extreme Weather Impacts

As extreme weather events increase globally, shortages of certain materials necessary in the repairs of critical infrastructures will become widespread. Example: accessing chlorine when multiple countries are reporting half the area is in drought and half is flooded will cause supply chain issues globally as demand rises rapidly.

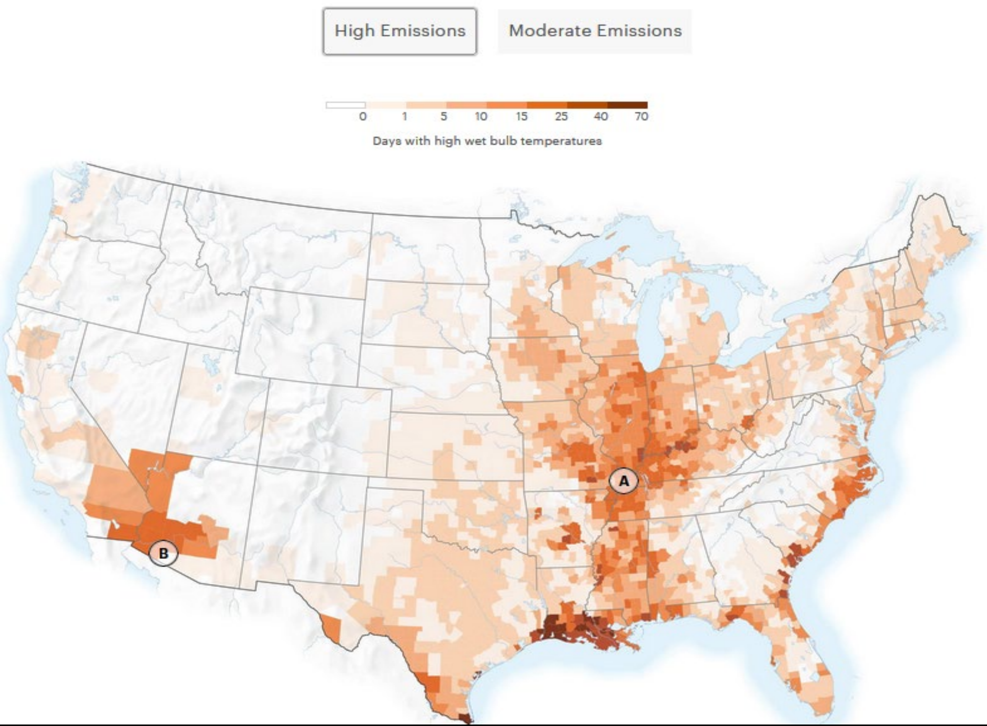
1) Drought damages are already $30 billion globally and will surely rise. When considering drought losses for an entire year, this figure already gives 2022 the 15th-highest drought damages of the past 48 years.
2) Only three billion-dollar tropical cyclones have occurred in 2022: Hurricane Ian and Hurricane Fiona in the Atlantic, and Typhoon Nanmadol in the western Pacific.
3) Two weather mega-disasters costing over $20 billion have hit Earth in 2022: Hurricane Ian in the US, and the European drought and heat wave. There has been a substantial rise in $20-billion-plus mega-disasters in recent years.

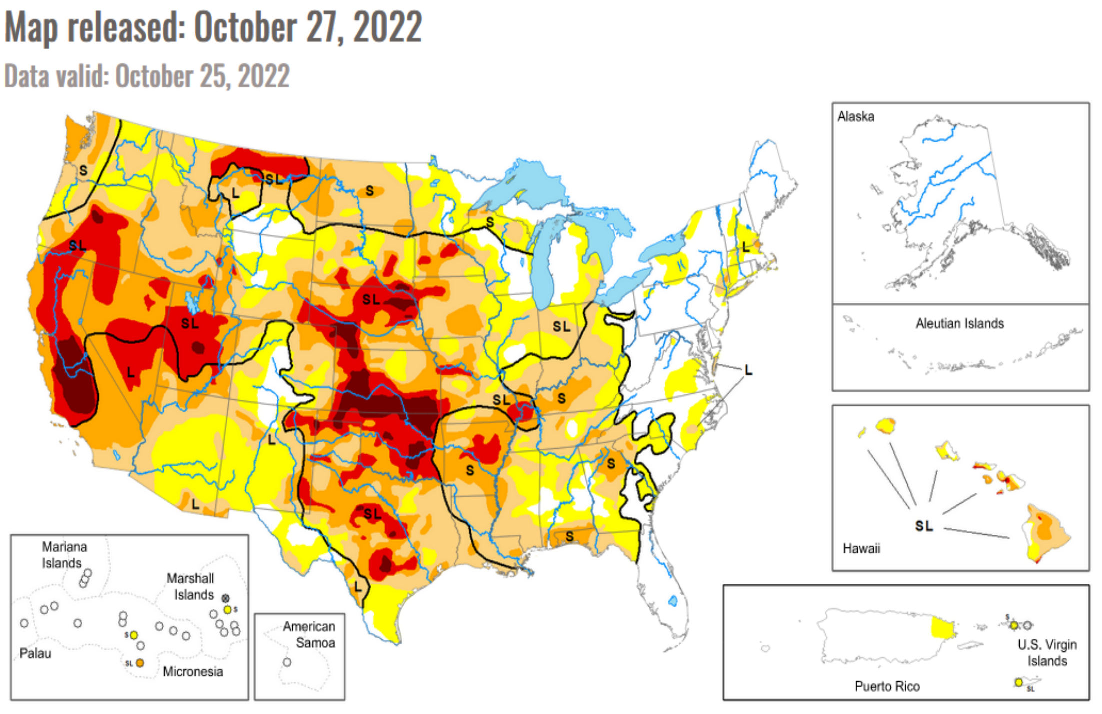


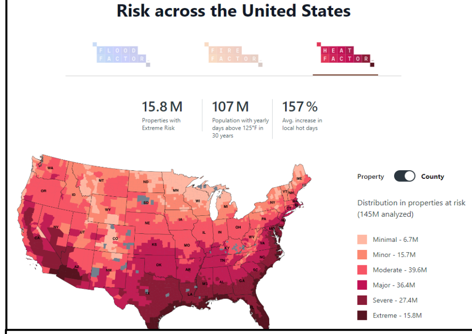
Billion-Dollar Weather Disasters, Jan.-Sep. 2022

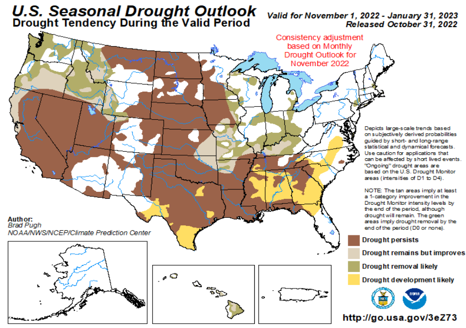
Rank	Disaster	Location	Dates	Damage	Deaths
1	Hurricane Ian	U.S. (FL, SC, NC), Cuba	Sep. 27-Oct. 1	>$20 billion	137
2	Drought	Europe (W, S, Central)	Yearlong	$20 billion	N/A
3	Flooding	China	Jun. 1-Sep. 30	$12 billion	239
4	Drought	China	Yearlong	$8.4 billion	N/A
5	Flooding	Eastern Australia	Feb. 23- Mar. 31	$7.5 billion	22
6	Flooding	Pakistan	Monsoon season	$5.6 billion	1693
7	Windstorm Eunice	Europe, Western & Central	Feb. 18-19	$4.3 billion	17
8	Drought	U.S.	Yearlong	$4.0 billion	N/A
8	Drought	Brazil	Yearlong	$4.0 billion	N/A
10	Hurricane Fiona	Caribbean, Canada	Sep. 18-25	$3.1 billion	31
11	Flooding	South Africa	Apr. 8-15	$3.0 billion	455
12	Severe Weather	U.S. Plains, Midwest	May 11-12	$2.6 billion	5
13	Severe Weather	Europe, Western & Central	Jun. 19-24	$2.3 billion	3
14	Severe Weather	U.S. Plains, Midwest	Apr. 10-14	$2.2 billion	1
15	Severe Weather	U.S. South, Midwest, NE	Jun. 11-17	$2.0 billion	3
15	Drought	Somalia, Ethiopia, Kenya	Yearlong	$2.0 billion	N/A
17	Flooding	India	Monsoon season	$1.8 billion	1883
17	Severe Weather	U.S. Plains, South, Midwest	May 19-22	$1.8 billion	2
17	Severe Weather	U.S. Plains, Midwest	May 9-10	$1.8 billion	0
20	Severe Weather	Europe, Western & Central	Jun. 2-6	$1.6 billion	0
21	Severe Weather	Canada	May 21	$1.4 billion	12
21	Severe Weather	U.S. Midwest, Mid-Atlantic	Jun. 4-8	$1.4 billion	0
23	Severe Weather	U.S. Plains, South	Mar. 29-Apr. 1	$1.2 billion	2
23	Severe Weather	U.S. Plains, South	Apr. 4-7	$1.2 billion	3
23	Severe Weather	Europe, Western & Central	Jun. 26-29	$1.2 billion	2
23	Typhoon Nanmadol	Japan	Sep. 18-21	$1.2 billion	4
23	Severe Weather	U.S. Mid-Atlantic, Midwest	Jul. 21-25	$1.2 billion	0
23	Flooding	U.S. (MO, KY)	Jul. 25-28	$1.2 billion	28
29	Severe Weather	U.S. Plains, Midwest	May 1-3	$1.1 billion	0

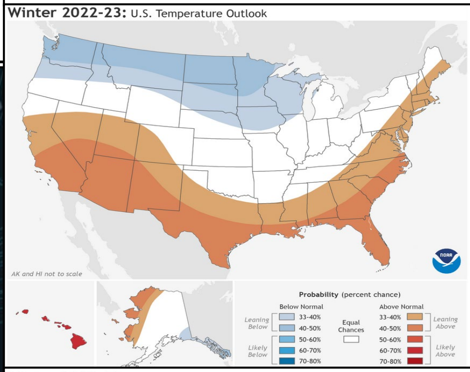
Background image: Flooding in New South Wales, Australia, February 2022. Image credit: NSW Police Force

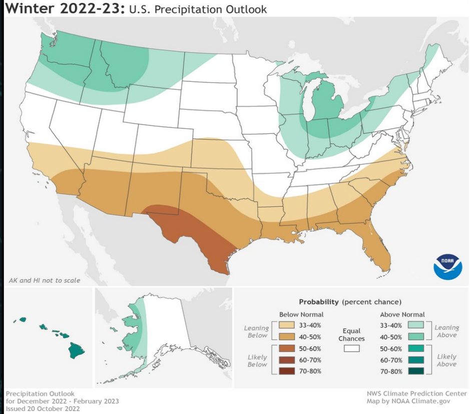

High Emissions
Moderate Emissions
0 1 5 10 15 25 40 70
Days with high wet bulb temperatures
A
B

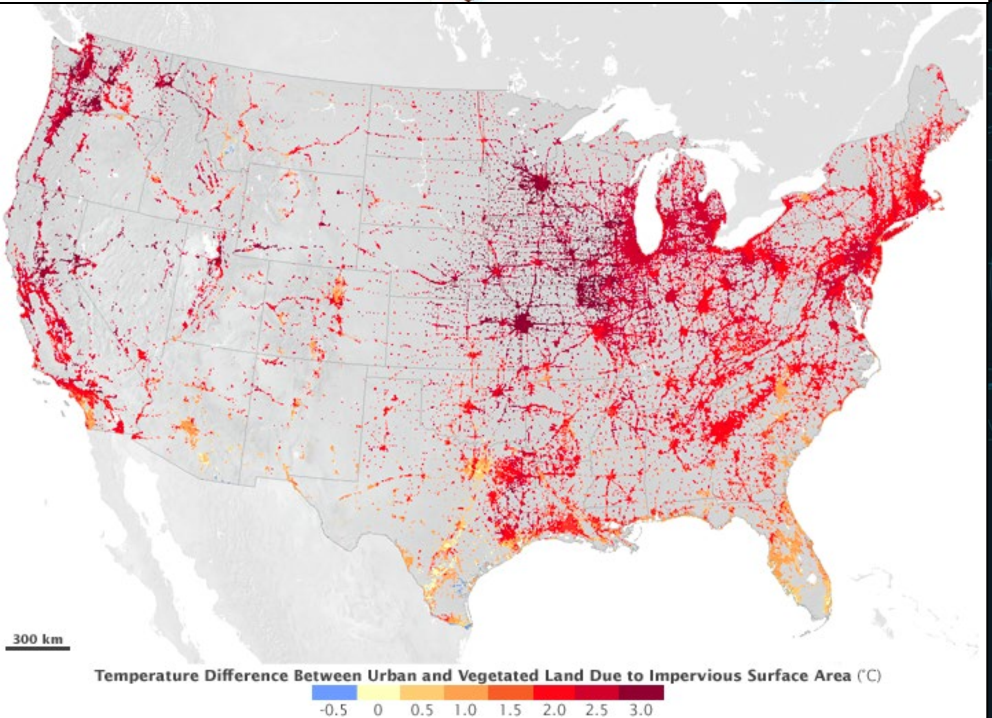

Map released: October 27, 2022
Data valid: October 25, 2022
Alaska
Aleutian Islands
Hawaii
Mariana Islands
Marshall Islands
Palau
Micronesia
American Samoa
Puerto Rico
U.S. Virgin Islands

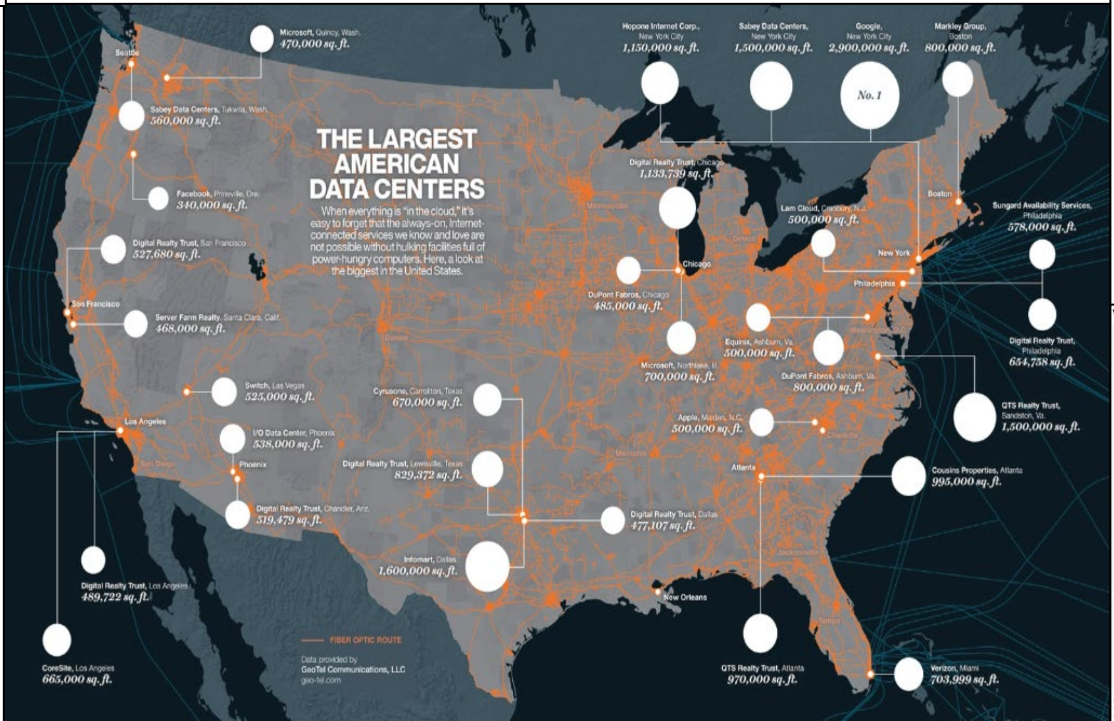

Risk across the United States
15.8 M
107 M
157 %
Property
County


U.S. Seasonal Drought Outlook
Drought Tendency During the Valid Period
Valid for November 1, 2022 - January 31, 2023
Released October 31, 2022
Consistency adjustment based on Monthly Drought Outlook for November 2022
Drought persists
Drought remains but improves
Drought removal likely
Drought development likely
http://go.usa.gov/3eZ73


Winter 2022-23: U.S. Temperature Outlook
Probability (percent chance)


Winter 2022-23: U.S. Precipitation Outlook
Probability (percent chance)


300 km
Temperature Difference Between Urban and Vegetated Land Due to Impervious Surface Area (°C)
-0.5 0 0.5 1.0 1.5 2.0 2.5 3.0


THE LARGEST AMERICAN DATA CENTERS
When everything is "in the cloud," it's easy to forget that the always-on, Internet-connected services we know and love are not possible without hulking facilities full of power-hungry computers. Here, a look at the biggest in the United States.
No. 1

Extreme Heat

Potential Options for Consideration

Increase independent emergency energy capabilities to reduce exposure to involuntary load reductions

Install generators for unplanned outages at critical sites

Albedo adjustments – painting surfaces white to reduce radiative heat storage at surface

Shading near infrastructure to prevent direct sunlight – trees and shrubs provide natural shade and can be partnered with sponge sidewalks

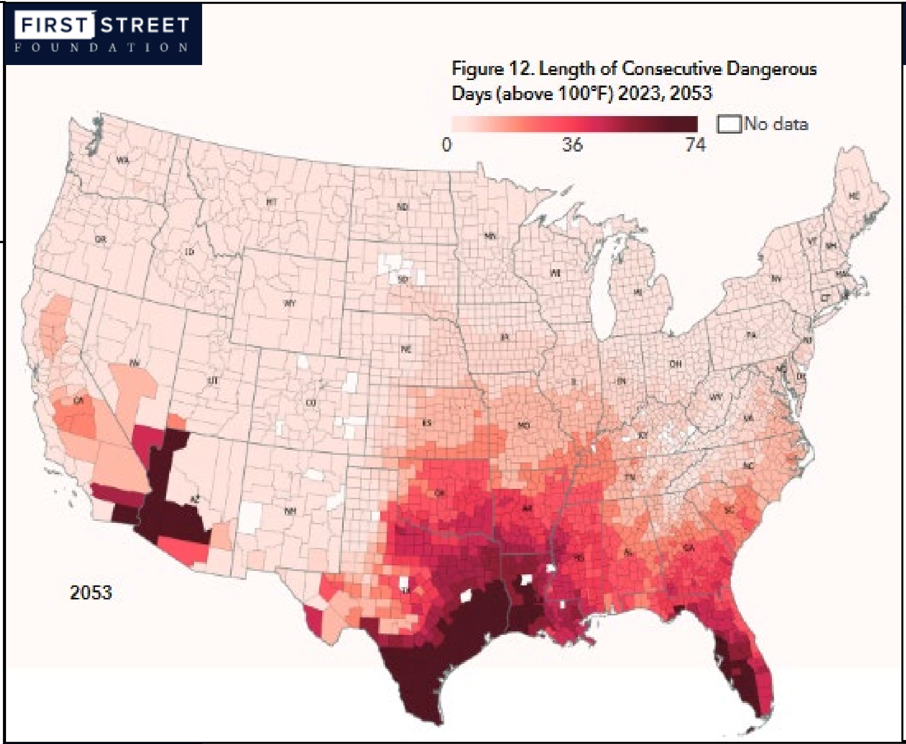
Shifting buildings to heat pumps to reduce energy needs during max heating periods

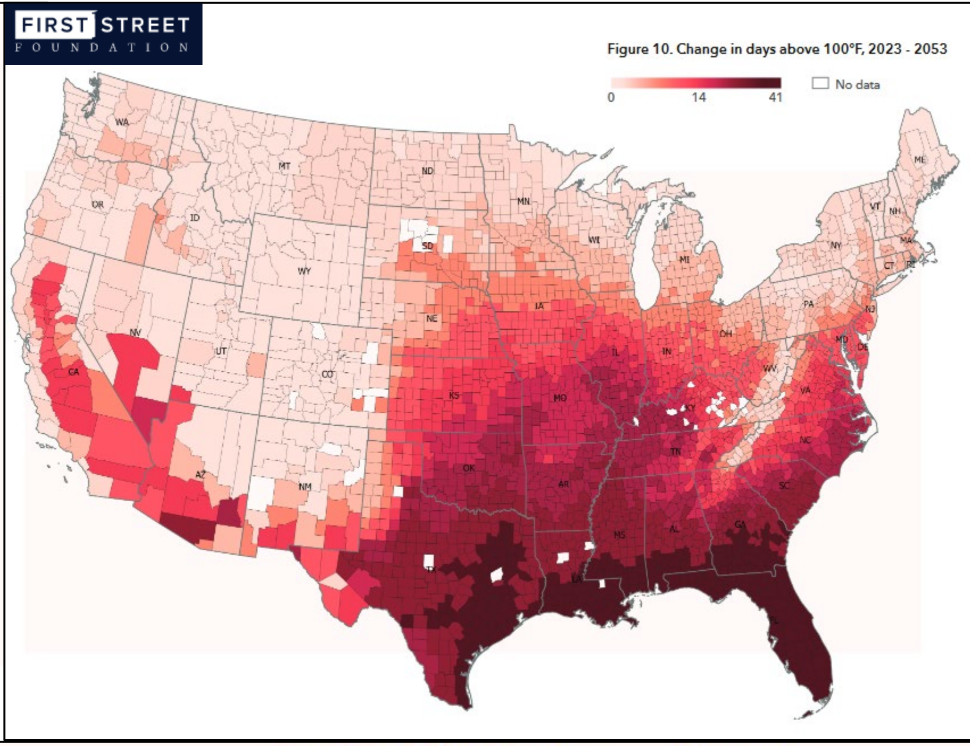
Increasing cover crops, vertical farming, and shifting to more greenhouse use

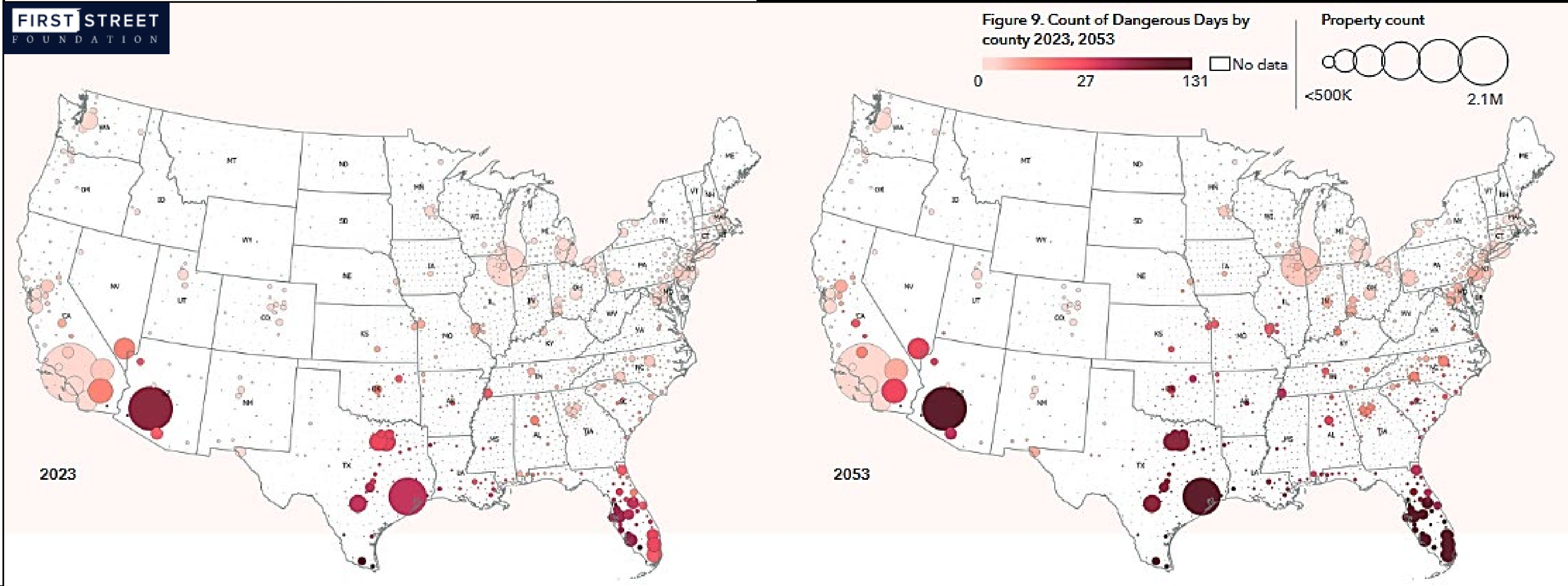
Covering open-air water sources to reduce heat exposure and increased evaporation rates

Rail tracks can be placed on reinforced concrete slabs to prevent buckling, airport runways face similar buckling issues and can be mitigated with higher albedo paint

Increased provision of HVAC systems to low-income regions, cooling center expansion, and improving insulation







Expansive Drought

In February 2022, a new UCLA-led study found that the 22-year-long southwest North American megadrought is the region's driest in at least 1,200 years.

- From 2011 through 2020, the United States experienced nine droughts, each causing at least $1 billion in damages.

<u>Potential Options for Consideration</u>

Drip irrigation and water recycling for agricultural regions vs flooding fields

Covering canals and reservoirs to prevent evaporation and dust impacts

Retrofitting low-flow water systems and wastewater processes throughout critical infrastructure, industrial buildings, and large residential communities

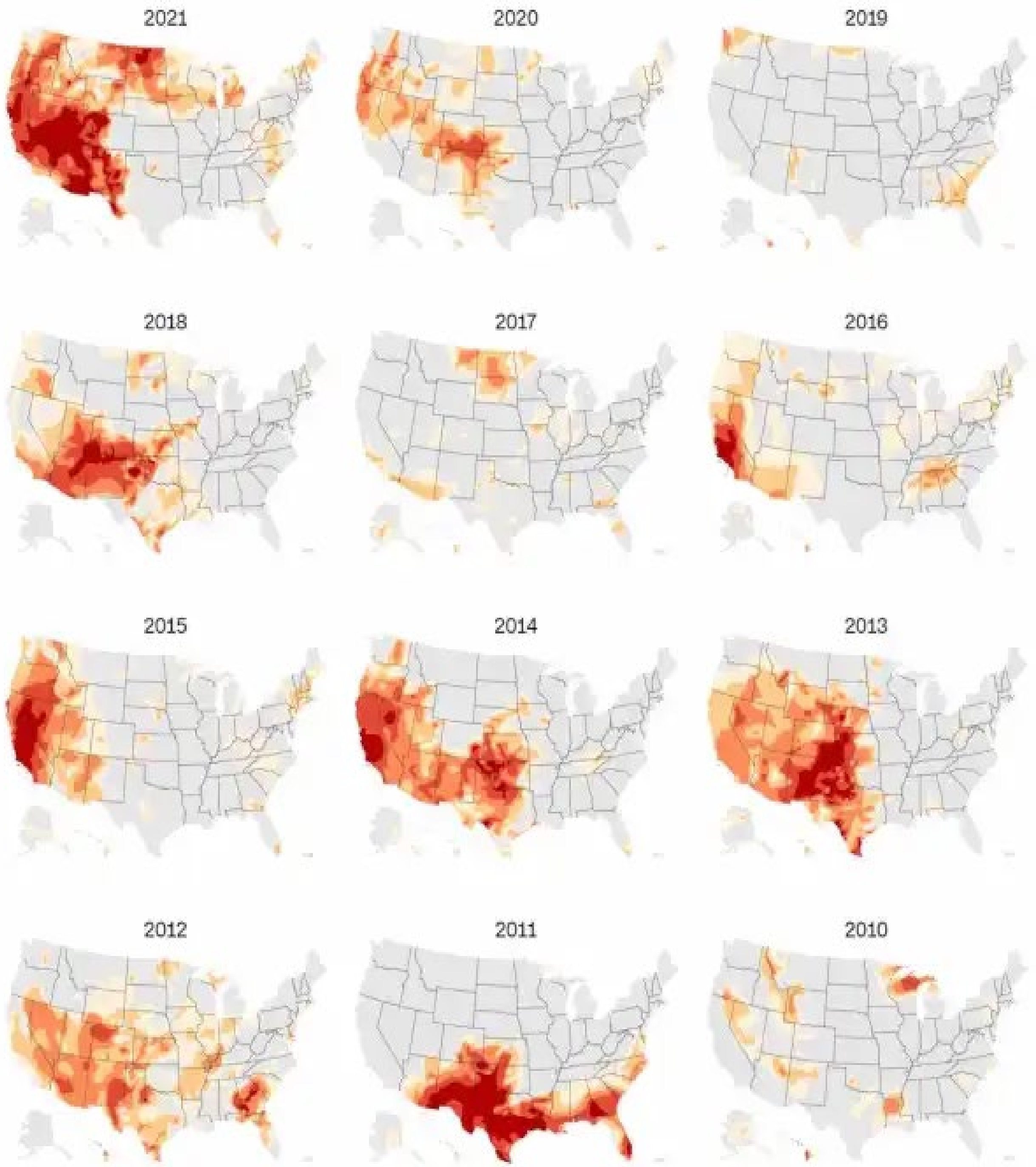
Storing reservoir water underground in contained systems to be accessed during major heat/drought events

Utilizing coal mines for pumped storage hydropower offset and reducing or removing above ground water storage susceptible to atmospheric threats

Black or Grey Water installation for critical sites and communities to create localized closed-loop water systems

Increased seasonal staffing for water agencies in drought and heat dome areas with greater threats of water main breaks due to high temperatures, increased water use, and potential water thefts – lock water access points

Installing surface well monitoring systems to reduce overpulls and safety of water consumption by locals through automated water testing sensors



Torrential Flooding

A flood caused by heavy or excessive rainfall in a short period of time, generally less than 6 hours. Torrential floods are usually characterized by raging torrents after heavy rains that rip through riverbeds, urban streets, or mountain canyons sweeping everything before them. A torrent is a lot of water falling or flowing rapidly or violently.

- For each 1°F increase in temperature the atmosphere can hold 4% more water which translates to a significant increase in the amount of rainfall per storm system merging due to the increased moisture field. More areas will begin reporting 1-3 months of rain falling in single storm events.

<u>Potential Options for Consideration</u>

Raising infrastructure foundations to adjust flood plain low-lying threats

Bridge and underpass repairs to reduce water retention – permeable surfaces or shrubs

Improved early warning systems for residential alerts, runoff access to underground well storage to maximize reservoir refill, and green roof systems to reduce urban flooding

Stormwater storage systems integrated into city sidewalks to reduce urban flooding into the water systems through use sponge sidewalk systems

Rooftop and residential surface water catchment basins through plants or piped funnels

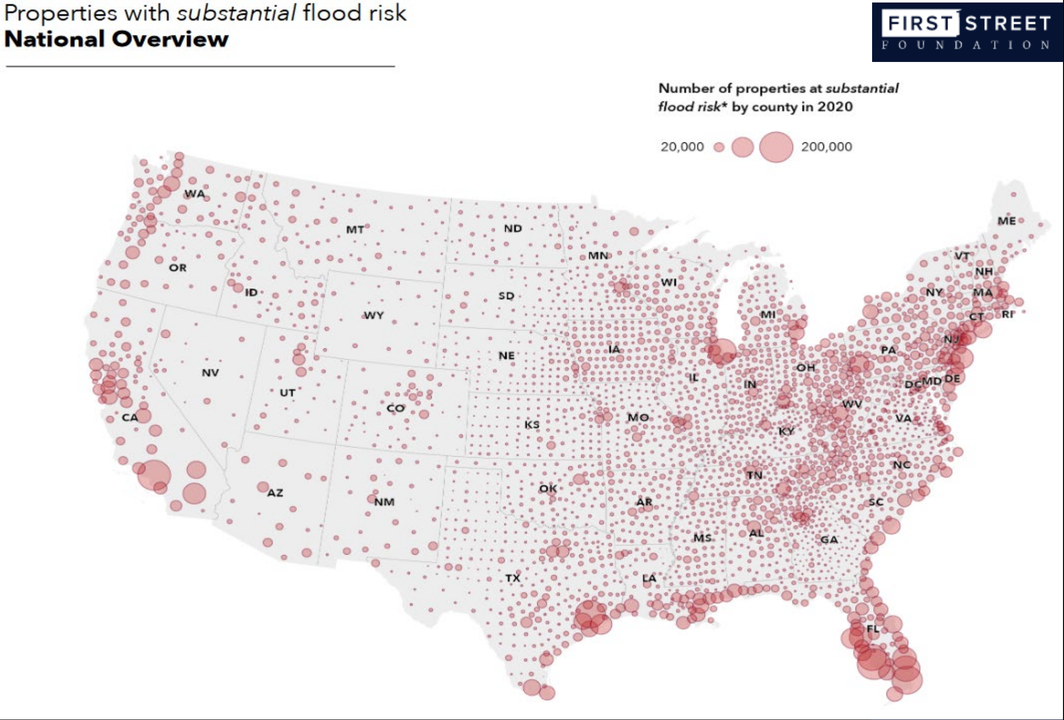
Adding tree and plant systems back into the cityscapes enable water absorption during urban flood events and improve pollution removal, working to decrease the flood cause

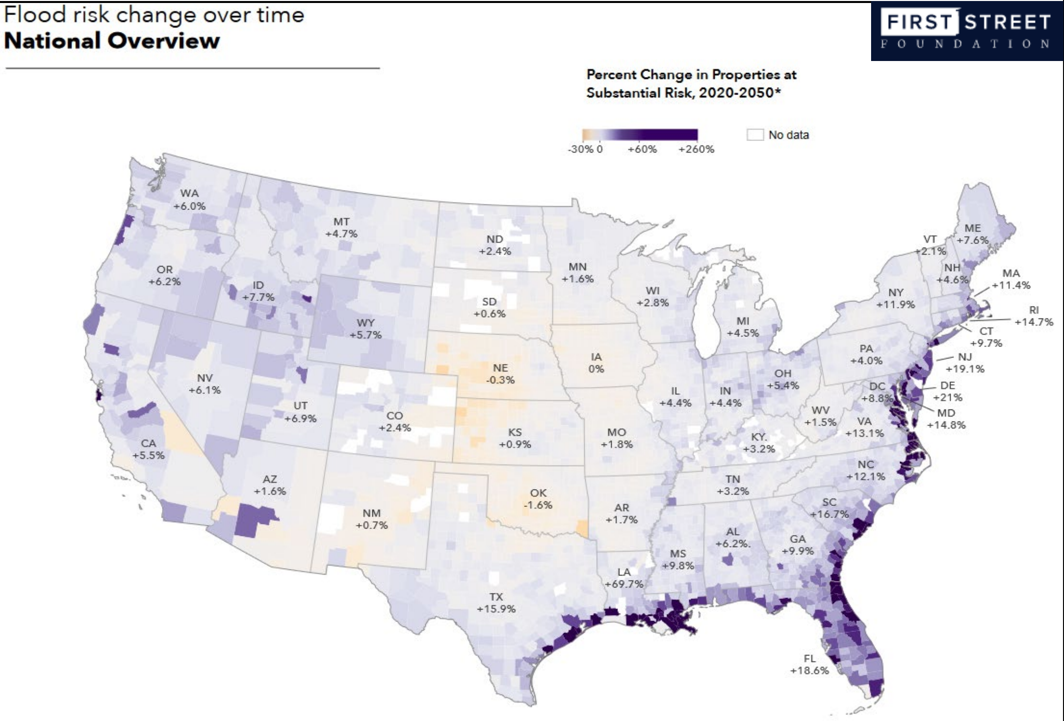
Investing in flood mapping overlays with elevated roadways for emergency service plans

Increasing the number of river gauges with debris monitoring and flow reporting for releasing upstream water more effectively without overwhelming the downstream

Locally deployable flood guards for infrastructure entrances, inflatable or installable

Increasing use of stabilizing soil to reduce erosion threats or mudslides around critical infrastructure sites, utilizing natural barrier development vs soil sealing methods





Larger Wildfires

According to NOAA, damage associated with wildfires has grown substantially, with $81.7 billion, or 66% of all direct losses since 1980, occurring in the last five years.

Across the country, there are 49.4M properties with minor wildfire risk; 20.2M properties with moderate risk; 6.0M with major risk; 2.7M with severe risk; and 1.5M properties with extreme.

- In total, approximately 71.8 million homes have some level of wildfire risk in 2022, growing by 11.1% to 79.8 million by 2050.

Studies indicate burn scar impacts to regrowth of vegetation could result in large areas of the forested parts of the Rocky Mountains seeing only 50% recovery post major-burn activity.

- Satellite imagery and state/federal fire history records from 28,000 fires in 1984-2018 showed more fires occurred in the past 13 years than the previous 20 years. On the West and East coasts, fire frequency doubled. In the Great Plains, fire frequency quadrupled.

<u>Potential Options for Consideration</u>

Tilling soil after a fire to prevent hydrophobic layers then planting seedlings for mature, fire-resistant vegetation

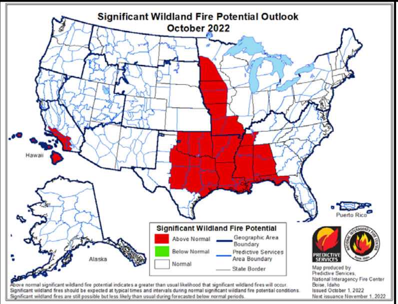
Reducing overgrowth, underbrush, and invasive plants

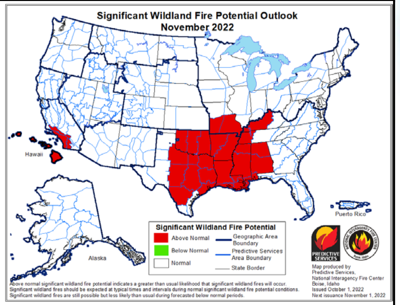
Interagency hotspot monitoring and energy loss reporting

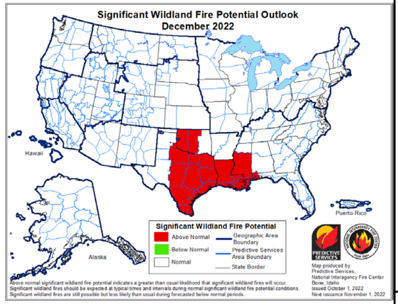
Creating compacts for rail and freight reroutes across states

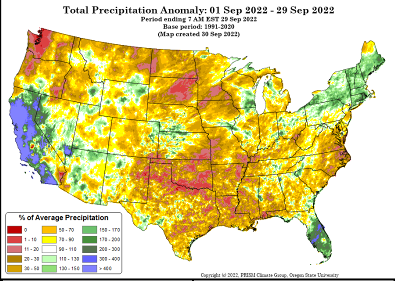
Improving water filtration using reusable filtration processes

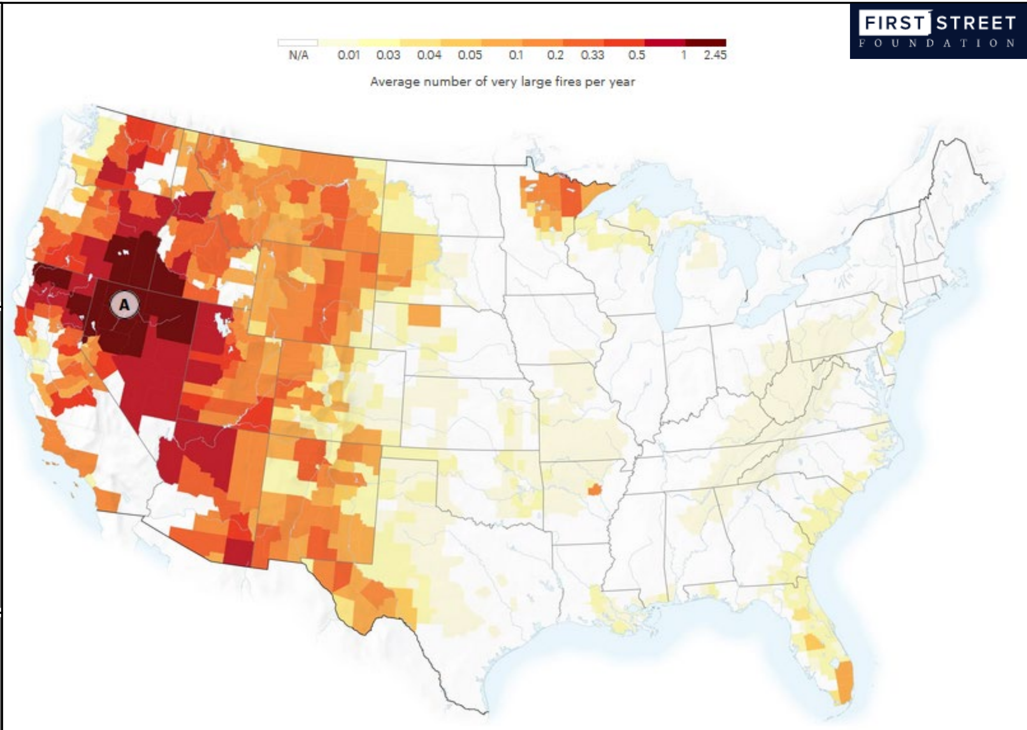
Soot/ash aerosol removal to prevent snowpack degradations



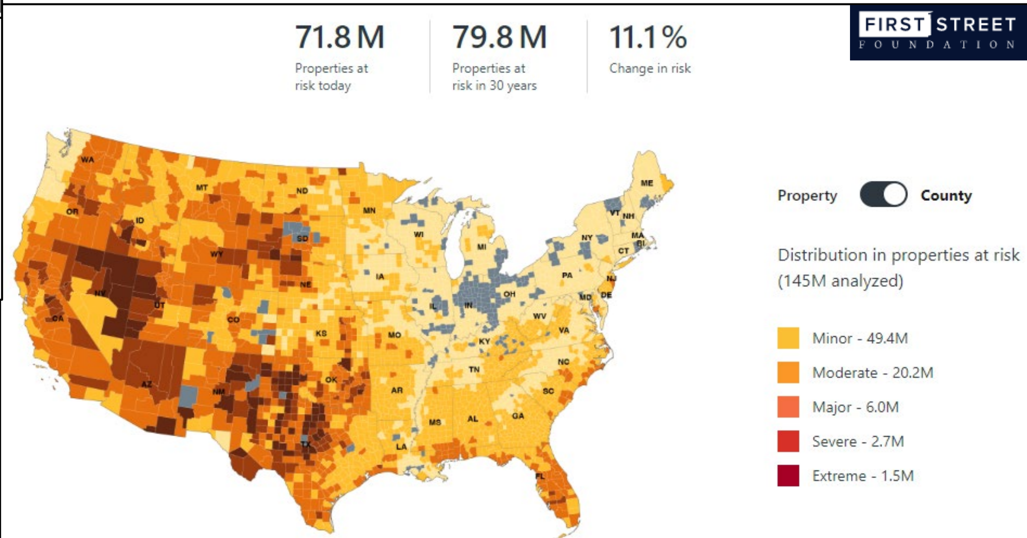








By midcentury, the northern Great Basin, though not a densely forested region, will become the epicenter of large wildfires (A). These large, remote counties in Nevada and Oregon see cycles of wet and dry weather that turn the grassland into the fuel for fires that can easily rip through 10,000 acres a day with strong winds, said John Abatzoglou, one of the authors of the study.



Tropical Cyclones

A recent assessment by hurricane experts correlates an increase in intensity and the proportion of the most intense storms, as well as increase in the occurrence of storms resulting in extreme rainfall rates over 3-hour timeframes which increased by 10% while 3-day total rainfall accumulations increased by 5% for tropical storm strength to hurricane strength systems.

- Extreme rainfall rates when focusing on *hurricane strength only* saw increases for 3-hourly rainfall rates of 11% and 3-day total accumulated rainfall by 8%. Damaging winds associated with tropical low centers are also expected to increase.
- A study in February 2022: “Extreme Atlantic Hurricane Seasons are made twice as likely by ocean warming” with data indicating overactive seasons are now twice as likely as they were in the 1980s.

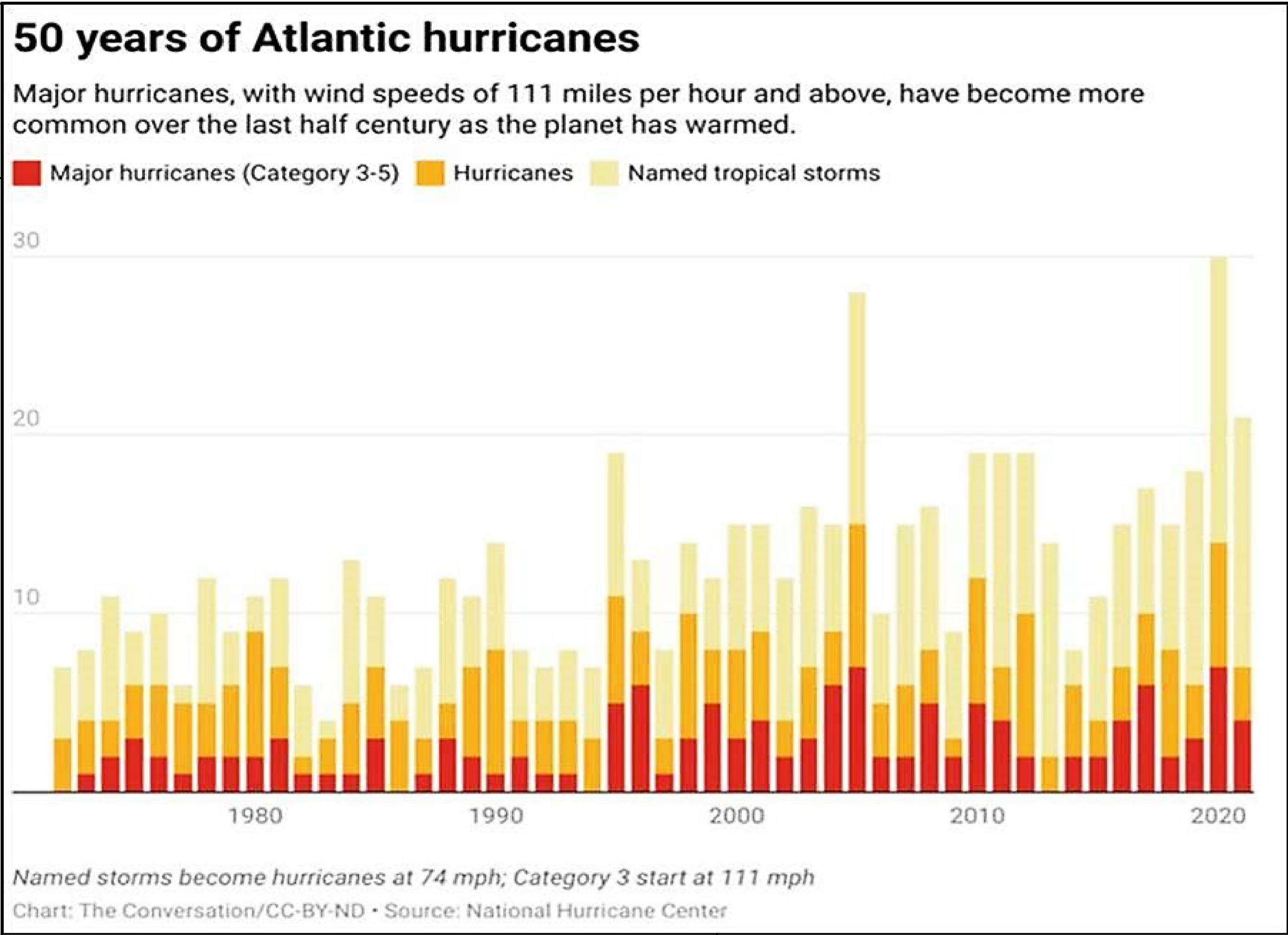
<u>Potential Options for Consideration</u>

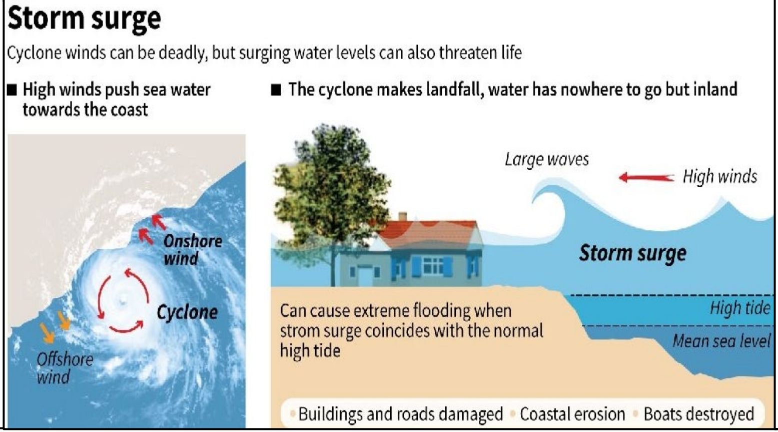
Utilizing community solar fields to offset periods of loss during widespread damage to powerlines

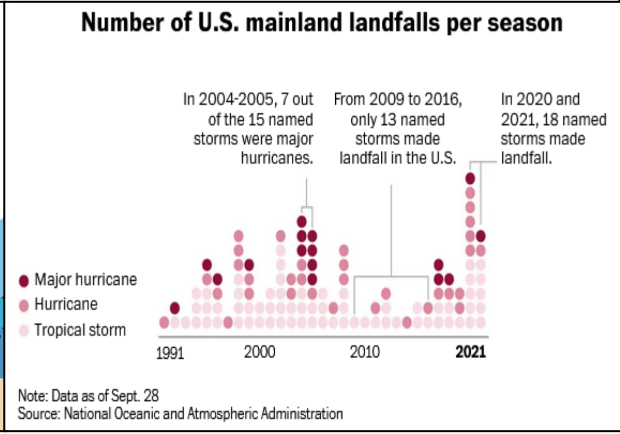
Enhancing coastal areas and barrier islands with natural barriers such as reefs, mangroves, and elevating soil slopes

Improving vegetation in urban areas through green roof systems, planters along roadways, and permeable sidewalks

Increasing state mapping of critical resources to offset immediate need of emergency use through local engagement







Sea Level Rise

Over 8.6 million Americans live in areas susceptible to coastal flooding, which happens when winds from a coastal storm, such as a hurricane or nor'easter, push a surge of water from the ocean onto land.

- High tide floods (also known as "sunny day" floods) occur when the sea washes up and over roads and into storm drains as the daily tides roll in.

Extreme flooding will continue to be concentrated in regions where humans have built on floodplains or low-lying coastal regions.

Oceans are about 7-8 inches higher than they were in 1900 (3 inches were added since 1993). The rate of rise this past century was greater than any other century in the past 2,000 years.

- NOAA's projects that, due to regional factors such as ocean currents, coastlines like the East Coast could see seas up to 9.8 feet higher by 2100.

<u>Potential Options for Consideration</u>

Raising sea walls, improving barrier islands, installing flood gates, and moving infrastructure to floatable foundations

Investing in foundation shifts to water-resilient platforms and inundation canals for increasing nuisance flooding

Mapping elevation of critical infrastructure to invest in sculpting hills and canals for coastal flooding channeling

Community investment in permeable surfaces and elevation mapping to install local canal systems to safeguard homes

Installing natural filtration barriers at river mouths and intakes

Rise in inches, compared to 1980-2010 average.

+5 in.

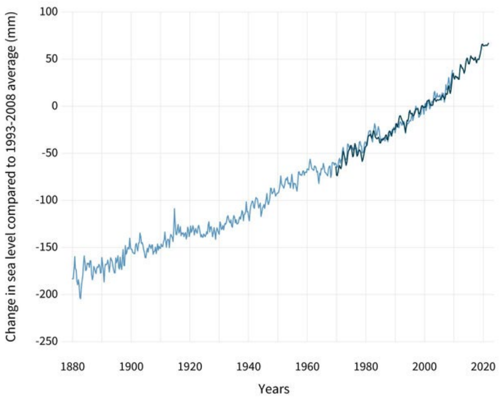
Place with highest sea level rise (inches)

14.4	Grand Isle, LA
10.3	Galveston Pier 21, TX
9.4	Ocean City Inlet, MD
9.1	New Canal Station, LA
8.7	Lewisetta, VA

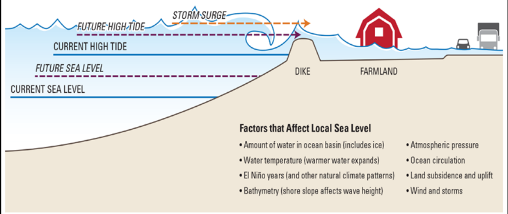
13.1 million people in the United States alone would be living on land that will be considered flooded with a sea level rise of six feet by 2100.

Source: Kopp et al, 2017. Evolving Understanding of Antarctic Ice-Sheet Physics and Ambiguity in Probabilistic Sea-Level Projections.

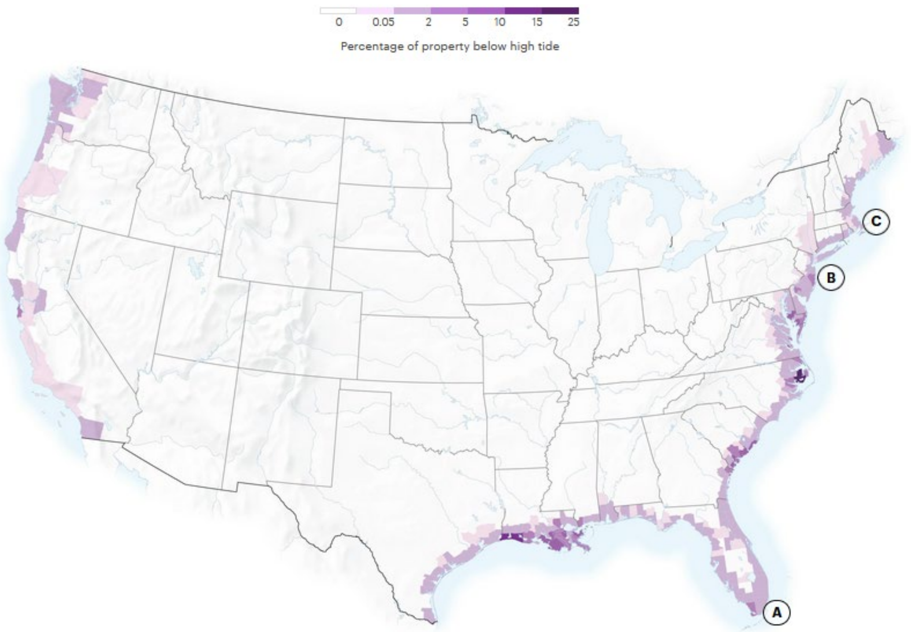
GLOBAL SEA LEVEL



Rising Sea Levels & Storm Surge



NOTE: Sea, tide, and storm surge levels are for illustrative purposes only and do not depict actual or projected levels.



Some 50 million Americans live in eight of the largest U.S. metro areas — Miami (A), New York (B) and Boston (C) among them — which all lie in some of the most affected counties in the U.S.

Severe Storms

Severe storms account for 46 percent of all the billion-dollar extreme weather events that NOAA has ever recorded.

- In 2020 alone, these storms made up 59 percent of the year's 22 extreme weather events and cost $34.8 billion, well above the average annual cost of $7.3 billion

Intense thunderstorms became more frequent in much of the US between 1948 and 2006. Winter storms have also increased in frequency and intensity since the 1950s, and their tracks have shifted northward.

<u>Potential Options for Consideration</u>

Rural cover crops improve topsoil resiliency for heavy rains

Increasing surface water collection from the less frequent but heavier rainfall events

Identifying subsidence regions for new low-lying threats from flash flood events which may reach into new areas

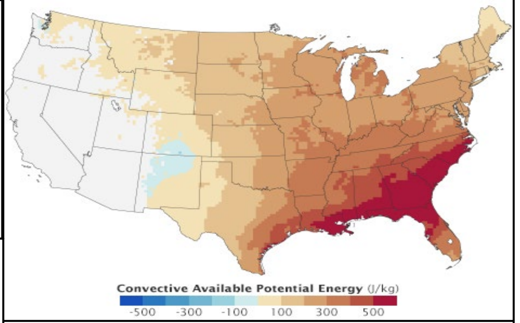
Floodwater reporting mechanism for residential databases

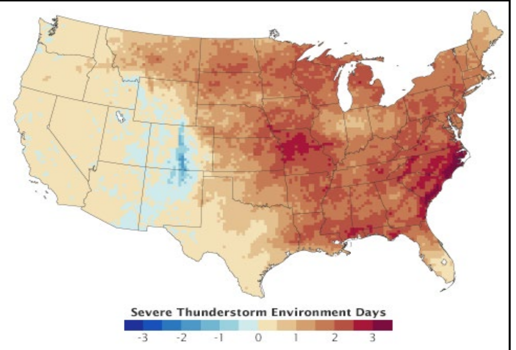
Increasing lightning protection system presence in rural areas

Rating infrastructure by damage from windspeeds and adjusting structural integrity to match damaging gusts

Increasing sturdy tree coverage in open spaces both urban and rural to decrease wind gusts and persistent winds

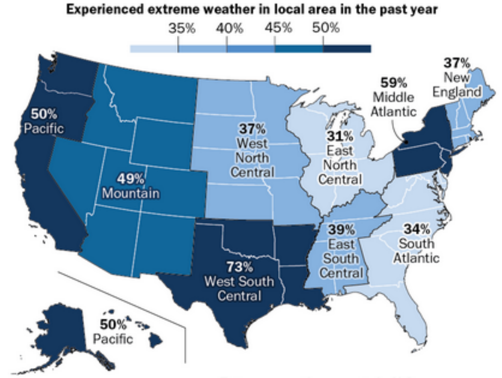
Integration of geodesic domes for critical infrastructure future builds and utilizing hardened materials for winds +140 mph





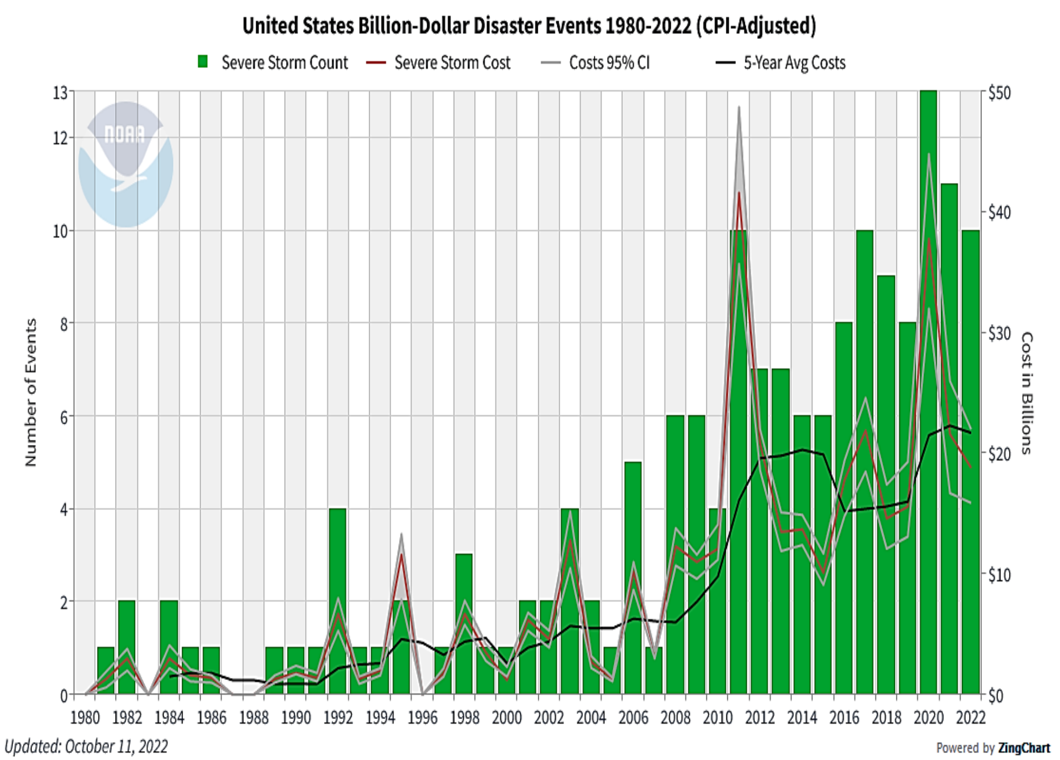
Two-thirds of U.S. adults see extreme weather events happening more often

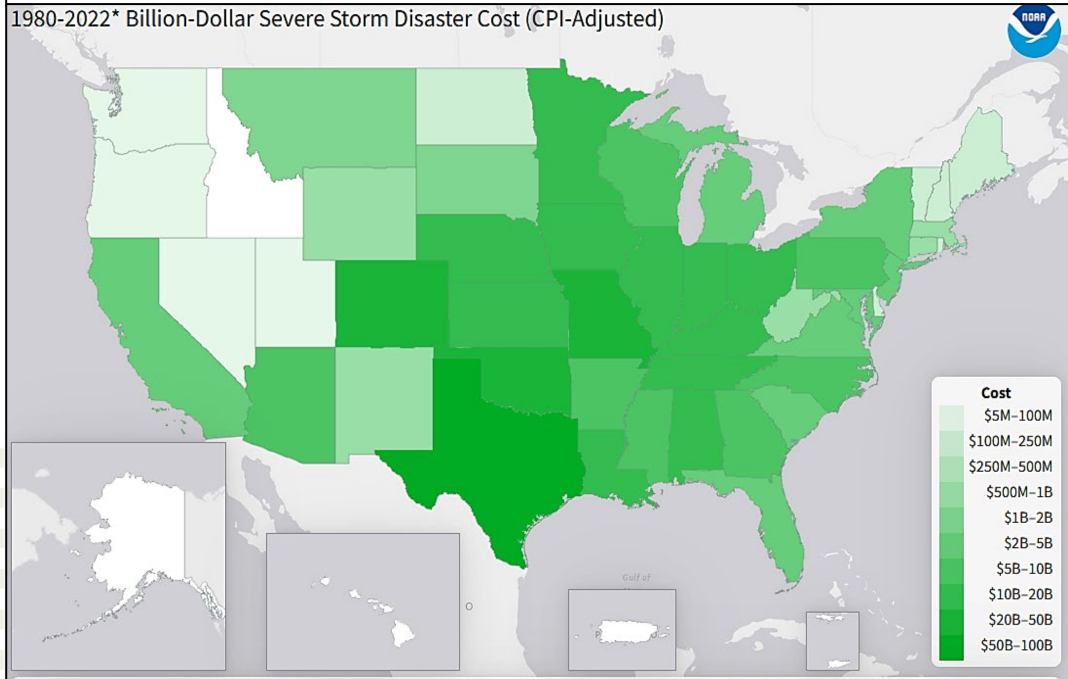
% of U.S. adults who say ...



Extreme weather events in U.S. are happening ___ than in the past

	More often	About as often	Less often
U.S. adults	67%	28%	4%
CENSUS DIVISION			
New England	78	20	2
Mid-Atlantic	72	25	3
East North Central	65	31	4
West North Central	63	32	4
South Atlantic	64	31	5
East South Central	56	37	7
West South Central	70	26	4
Mountain	60	35	5
Pacific	74	21	4





Extreme Cold

On average, winters are getting warmer and shorter, with fewer places experiencing extremely cold temperatures.

- As the warmer atmosphere holds more moisture, blizzards are more likely to occur and be more severe in places where temperatures are still cold enough for snow. Over the next 5-10 years winter trends will continue to hit extremes.
- The impact to the typical flow of storms will also shift temperature extremes with rapid freezes more likely.

NCEI reports freeze events have caused about $34.4 billion in impacts from nine events between 1980 to 2022 placing the average at $3.8 billion per event.

<u>Potential Options for Consideration</u>

Insulation of pipelines in areas where extended freezes were 'uncommon' historically, increased use of winterized fuels

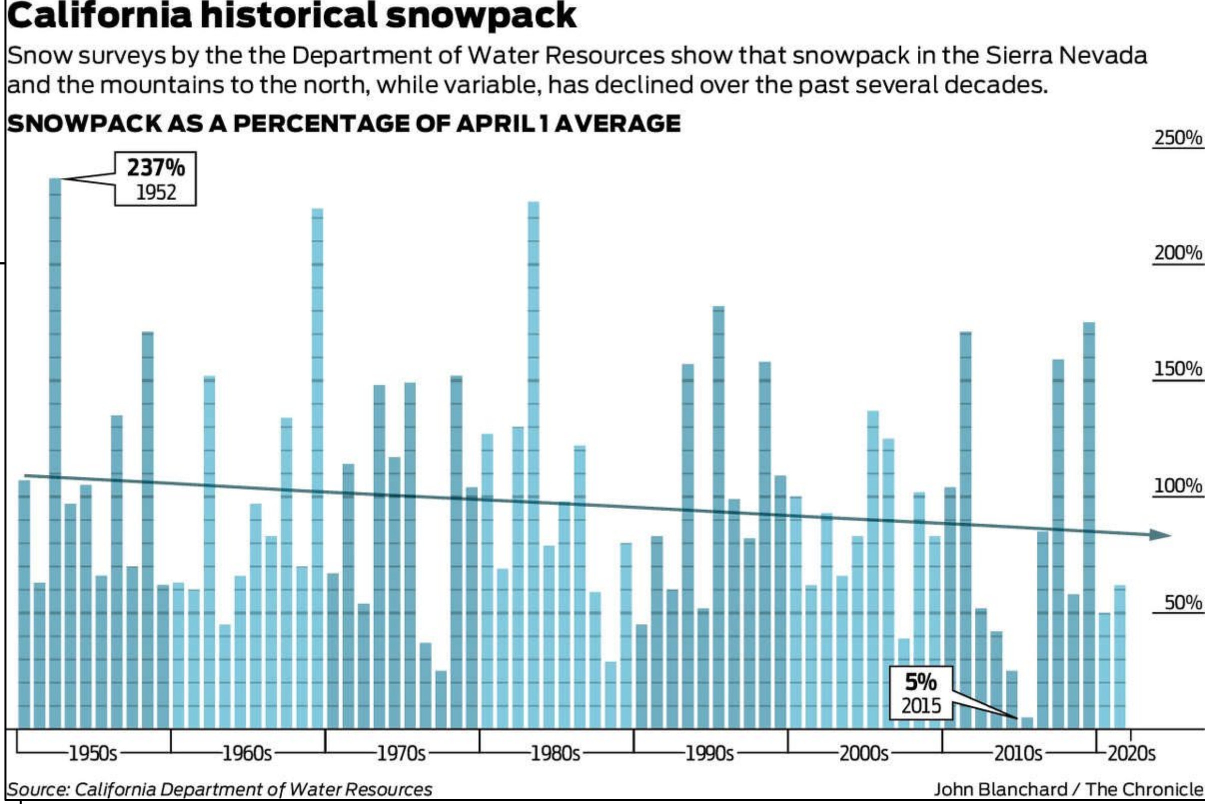
Increasing anti-freeze applications to motors/turbines, easier access to rapid use covers, and increasing automated temperature sensors to track onset of temperature shifts

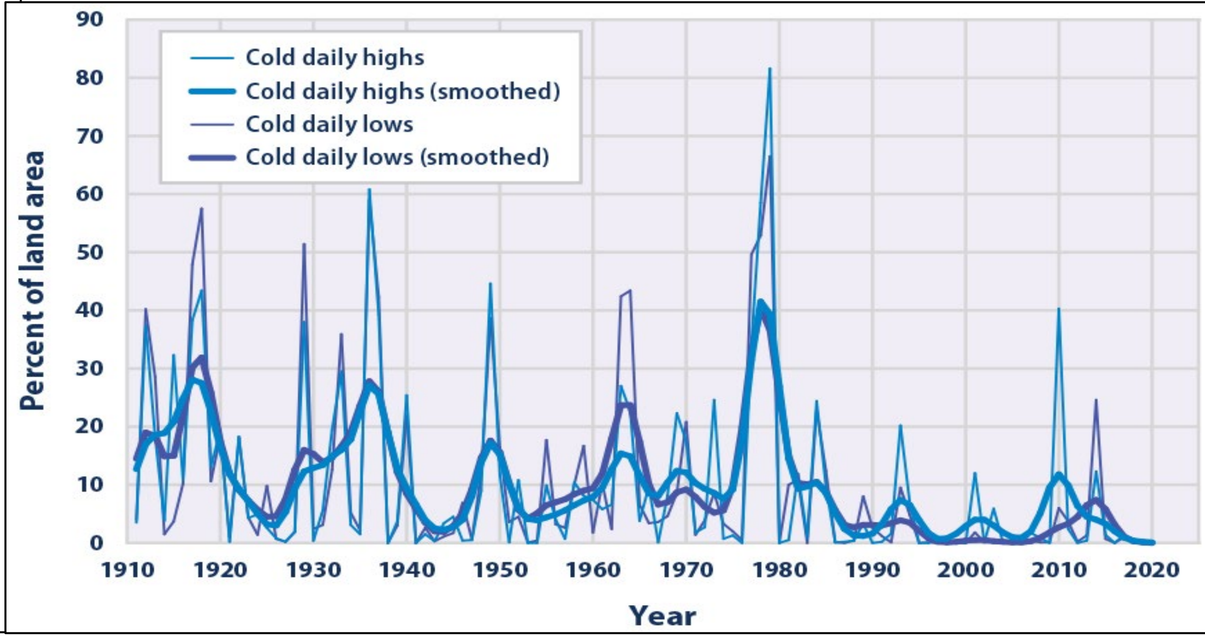
Post-drought review of canals, dams, and locks to identify cracks and damages ahead of first freeze events for use of aerated, winterized sealant

Improving structural integrity of buildings by rating winds addressing wind-profiles of critical infrastructure sites

With heavier precipitation expected, weight load maps enable forecast use to improve weight distribution on infrastructure

Pre-treating roads with salt mixtures to reduce salt use, salt enters waterways





Bridge Structure Threats

Warming is occurring in every season, particularly in winter and particularly at higher latitudes, at higher elevations, and inland.

- Heat waves may become more frequent, more intense, and last longer.
- Precipitation amounts are increasing, particularly in winter, with high-intensity events in summer.
- Snow is shifting to rain, leading to reduced snow cover extent and depth, as well as harder, crustier snowpacks.
- Stream flows are intensifying.
- Streams are warming.
- Thunderstorms may become more severe.
- Floods are intensifying, yet droughts are also on the rise as dry periods between events lengthen.

Additional resources for review

https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf

https://www.susquehannafloodforecasting.org/

https://livingatlas.arcgis.com/assessment-tool/explore/details

https://bridgemastersinc.com/protecting-bridges-flood-damage/

Option 3: Increase the Bridge Length

Lengthening a bridge by installing additional bridge openings or bridge spans can increase the flow volume below a bridge (Figure 1.4.4).

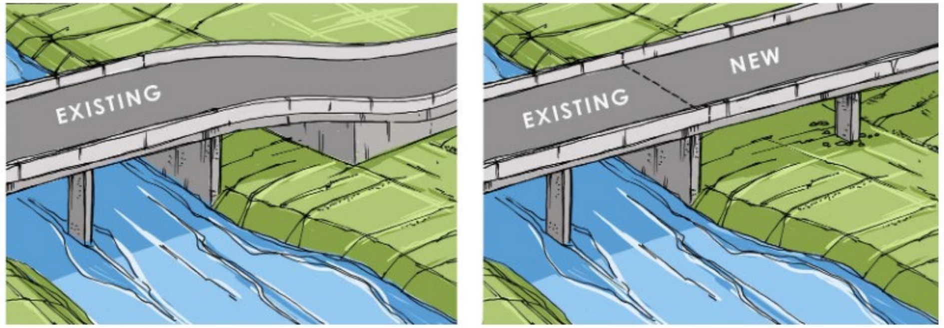


Figure 1.4.4. Lengthening a bridge can provide additional overflow capacity beneath the bridge.

Option 2: Elevate the Bridge Deck

Increasing the size of the bridge opening by raising the bridge deck will increase the space available for floodwater to pass through, which can decrease the likelihood of damage from flooding (Figure 1.4.3). Generally, if a bridge has been damaged by overtopping or fast water velocities in the past, it is a good candidate for increasing the size of the bridge opening. Make sure to raise the bridge deck and superstructure above the estimated level of the potential worst-case scenario future flood.

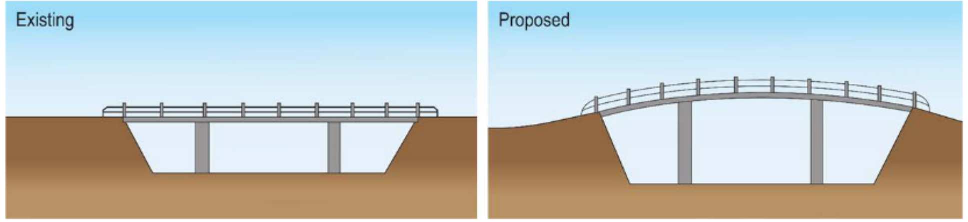


Figure 1.4.3. Increasing the size of a bridge opening by raising the bridge deck can increase flow volume under the bridge.

Option 1: Install Riprap

Placing riprap at bridge approaches, abutments and piers can reduce erosion during high-velocity water flow from flooding (Figure 1.4.7).

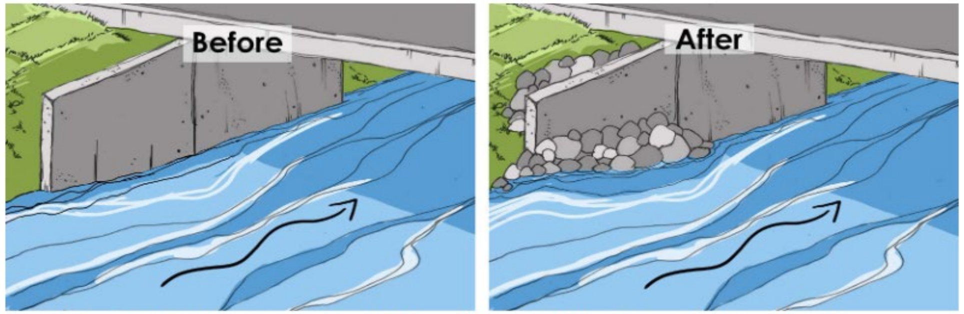


Figure 1.4.7. Riprap can protect bridge piers and abutments against erosion and scour.

Option 1: Replace Multi-Spans with a Single-Span Bridge

Replacing bridges built from multiple spans with one clear span eliminates the number of piers within the floodwater area (Figure 1.4.2), providing additional space for the water to flow.

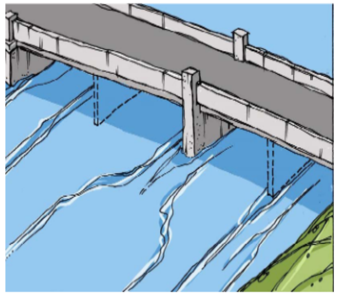


Figure 1.4.2. Reducing the number of spans can increase the flow amount under the bridge. In this figure, the dashed piers would be removed to accomplish this.

Option 4: Build a Relief Opening

Building one or more relief openings beneath the road surface and embankments (also known as the road prism) can increase the flow volume of the crossing. Place the extra opening at the appropriate height and location. The water level downstream of the bridge must not block water flowing through the crossing (Figure 1.4.5).

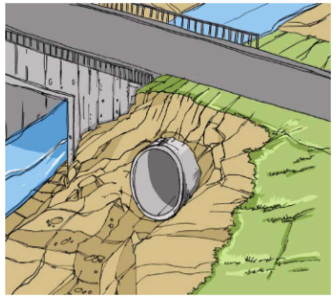


Figure 1.4.5. Building a relief opening can help prevent flooding of bridges.

Aging Infrastructure

<u>Concrete Deterioration Risk Analysis</u>: When was the structure constructed? What are the properties of the concrete (to the extent known)? What construction equipment and methods were used and what potential "defects" may have resulted from these methods? What are the environmental conditions and loading on the structure? What deterioration mechanisms (if any) may be acting on the structure? Is the structure resisting these deterioration mechanisms? What is the rate of deterioration? What dam failure modes are being affected by this deterioration? ***Seals, Gates, Valves, Composite Materials – What are the thresholds?***

Statistics: Over the last 20 years, the number of high-hazard-potential dams has more than doubled as development steadily encroaches on once-rural dams and reservoirs.

- A high-hazard-potential rating means that if failure were to occur, the resulting consequences would likely be a direct loss of human life and extensive property damage.
- The average age of us dams is about 62 years, but by 2030 70% of the dams in the US will be over 50 years old. This means they were built to the climate of the 1920-1940s.
- In 2017 the Association of State Dam Safety Officials' (ASDSO) cost estimate for the combined total to rehabilitate the nation's non-federal dams exceeded $66 billion. To rehabilitate just those high-hazard-potential dams would cost nearly $20 billion. Additional estimates show the need to rehabilitate federal dams is approximately $27.6 billion.
  - The 2022 update has risen to more than $75 billion, according to a 2022 update of a report from ASDSO. The cost to rehabilitate those dams where the risk is highest exceeds $24 billion. Current figures place the total cost estimated for non-federal dams at $75.69 billion, up from the 2019 estimate of $65.89 billion.

Aging infrastructure and weather event changes: Even as more dams establish Emergency Action Plans, the plans may not consider the full scope of the shift in weather. Areas marked for evacuation based off inundation may be significantly larger and response times for action could shorten. Freeze and heat events could become more damaging.

- Rivers flowing lower than normal will result in exposed materials which previously were kept cool and moist from the water levels prior to a multi-year-long prolonged drought.
  - Direct heating on exposed concrete which previously were under water could damage the material and freeze events can cause waters to freeze at lower levels than before as waterways become shallower potentially resulting in damages.
- Deeper low centers can bring more damaging weather events to supporting infrastructure like instrument buildings, the powerhouse, and residential homes for operators. Specific to the barge traffic, stronger storms could produce more damaging winds possibly increasing the amount of barge breakoffs during torrential rains and flooding with the barges floating downstream and colliding with bridges and other critical infrastructure like the lock systems.

Freeze-Thaw-Freeze Concerns: Ice expands about 9% upon freezing, causing forces of up to 30,000 lb/in2 , which **is** sufficient to crack concrete if it is not protected against this action.

- The earliest concretes made by Reclamation were not very frost resistant, failing in as few as 50 to 100 Freeze-Thaw cycles. Aerating was not used until the 1945.
- As the compressive strength of concrete increased, the Freeze-Thaw resistance increased, but the concrete still typically failed in about 200 cycles.
- Modern frost resistant concrete should normally resist well over 1,000 cycles of Freeze-Thaw. Dams build around 1945-1950 are possibly weak to expanding water.

As heavier rainfall events bring more runoff and debris, abrasion-erosion damage is likely increasing and damaging the water structures.

- Abrasion erosion damage can be quite severe in large dams and in the sandy rivers.

Association of State Dam Safety Officials Year	Funding Needs, Non-Federal Dams	Funding Needs, Non-Federal HHPD
2003	$34 billion	$10.1 billion
2009	$51.46 billion	$16 billion ($8.7b public, $7.3b private)
2012	$53.69 billion	$18.2 billion ($11.2b public, $7b private)
2016	$60.7 billion	$18.71 billion
2019	$65.89 billion	$20.42 billion
2022	$75.69 billion	$24.04 billion

Extreme Weather and Critical Infrastructure Planning How to make a difference

Adaptation actions for all four impact types fall into the following three categories:

- Reduce exposure to hazards (e.g. by providing more robust / better designed structures)
- Reduce the consequences of the hazard (e.g. by using the affected resource more prudently, by reducing other pressures, and through preparation and readiness)
- Improve recovery from the hazard impact (by investing in effective recovery procedures).

Highlighting which infrastructure takes damage from what event to what scale of degraded operations per site will take time but could produce the best use of forecast material in the future given the more hostile climate.

- If XY Building reports winds of 64mph have damaged power and telecommunication infrastructure at their site, where is it recorded that for future weather warnings the regional personnel see, they know to look at engaging that site for resource planning ahead of impact.
  - If ZZ is stored data per time the site goes down, a simple code highlighting the ‘if, then’ features could be more easily established. For example, drawing a hazard swath on a critical infrastructure map with the parameters of the storms largest threat being winds over 64 mph and rainfall of 3-4 inches within 6 hours. The swath would be able to isolate and only show those which match the criteria established for degraded operations which could be color coded to highlight the scale of impact at that threshold from minor impacts to total loss.
  - This prevents maps from merely stating “There are 8,360 cell towers in the threat landscape from this weather event” and shifting it to “There are 30 sites which have seen damage to the point of needing outside assistance from a similar storm in the past. Review of their site plans indicates 10 have done something to build back better, and the remaining 20 are being monitored as the system approaches and have been alerted.”
  - The CISA Extreme Weather Working Group aims to bring local, private sector, ISAC’s, interagency partnerships, every emergency management capacity willing to the table. The goal is rapid engagement of critical weather hazards to infrastructure across the nation and providing scope on international threats and shifts which may impact supply chain or global partnerships.

CISA Extreme Weather Working Group

The CISA Extreme Weather Working Group is a coordination and collaboration focused team of interagency partnerships, private sector industry leaders, local emergency management agencies and organizations to cross-pollinate climate resiliency efforts against increasingly more hostile extreme weather events.

The objectives of the working group focuses 2022's efforts to:

1. Provide improved climate education for regions and states seeking climate portfolio build-outs;
2. To produce extreme weather factsheets to assist identifying best practices and options for consideration for hardening infrastructure against a more hostile weather environment and aging infrastructure needs, and;
3. To communicate unmet needs from local, state, and federal partners to best pair solutions and action plans regarding hazardous weather cascading impacts.

Climate Summaries:

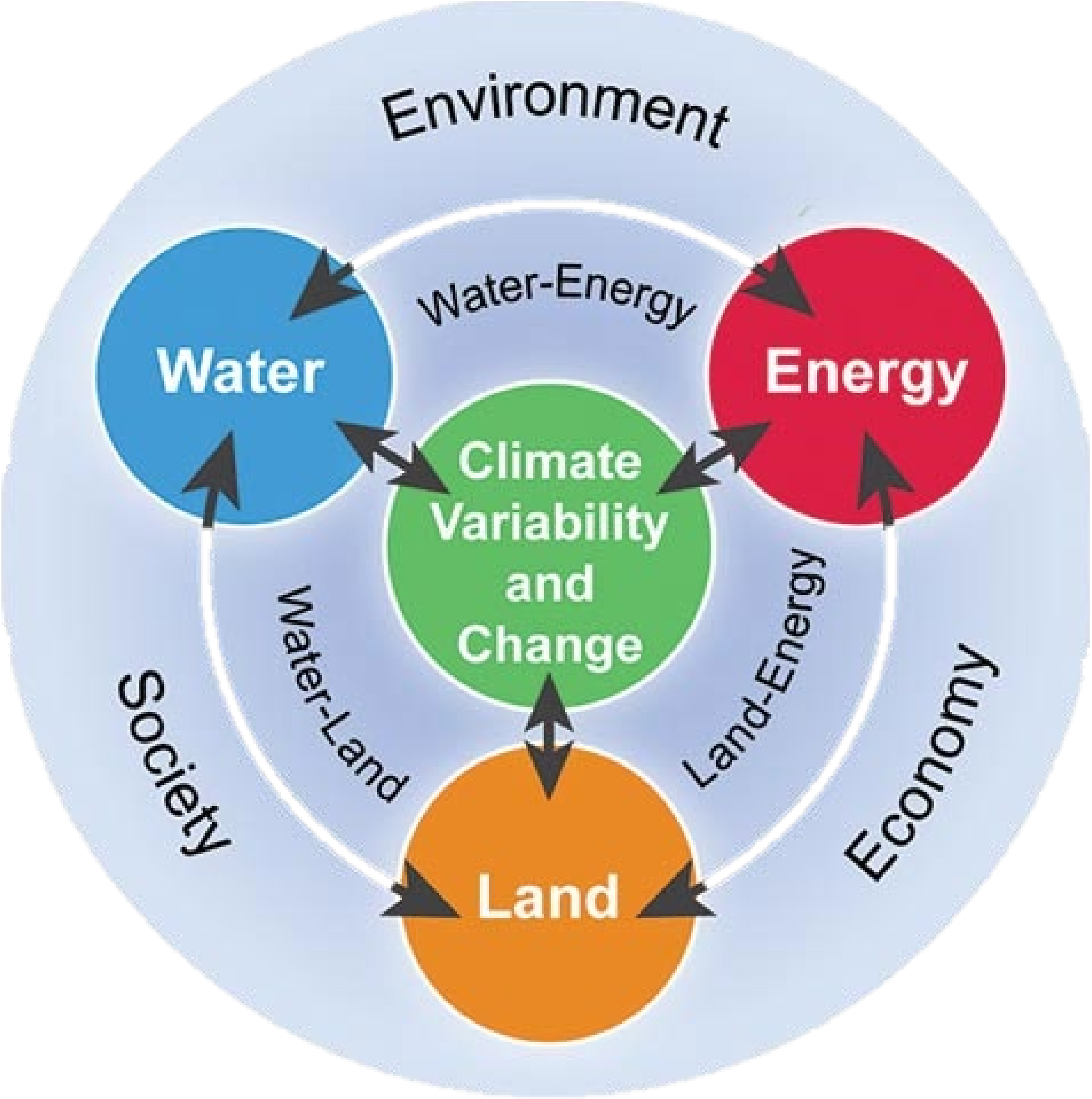
Abnormal Weather Events, Climate Headlines, Forecasted Threats, Global Impacts, Wildfire and Tropical Summaries, and Graphics for Use.

Working Group:

Regional Data Sharing, Upcoming Product Developments, Climate Education, Sector Impacts, Resiliency Best Practices, Bi-Weekly Touchpoints, and National Collaboration.

To join the distribution list for weekly National-International Climate Summaries **or** to join the Working Group please contact Sunny Wescott

Sunny.Wescott@cisa.dhs.gov



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“Climate change affects the natural, built, and social systems relied on individually and through connections to one another. These interconnected systems are increasingly vulnerable to cascading impacts, often difficult to predict, threatening essential services within and beyond the Nation’s borders.

Our Nation’s aging and deteriorating infrastructure is further stressed by increases in heavy precipitation events, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average precipitation and temperature. Without adaptation, climate change will continue to degrade infrastructure performance over the rest of the century, with the potential for cascading impacts that threaten our economy, national security, essential services, and health and well-being.” (Fourth National Climate Assessment)

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