RUTGERS–NEW BRUNSWICK
New Jersey Climate Change Resource Center

State of the Climate

New Jersey 2023

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Foreword

The *New Jersey State of the Climate Report* annually summarizes updated scientific information on climate trends and projections that can be used by state and local decision-makers, researchers, hazard planning and climate resilience professionals, and residents. The *New Jersey State of the Climate Report* is developed by Rutgers University though its hosting of the New Jersey Climate Change Resource Center. The report provides end users with the information they need to monitor changing climate conditions to prepare for future impacts.

This report is organized in the following sections:

1. An Executive Summary of New Jersey climate trends from 1895 to 2023 and climate projections through 2100.

2. A brief discussion of global climate trends that affect conditions in New Jersey.

3. A synopsis of outstanding 2023 weather events, followed by an in-depth analysis of historical climate data and future projections for New Jersey, with a focus on temperature, sea-level rise, precipitation, and extreme events, such as tropical storms.

4. A discussion of the summer 2023 Canadian wildfires that impacted air quality throughout New Jersey and how wildfires may be exacerbated with continued climate change.

Acknowledgments

We would like to thank Dr. Daniel Leathers (Delaware State Climatologist, University of Delaware) for providing peer review of this report and providing helpful comments and guidance.

Cover photo by Anthony Quintano. Wildfire smoke shrouds NJ Turnpike, June 2023 (CC BY 2.0 DEED, https://creativecommons.org/licenses/by/2.0/).
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Contents

Executive Summary

This report focuses on changes in temperature, sea-level rise, precipitation, and extreme events:

Temperature – Like most locations globally, New Jersey has seen increases in annual and seasonal temperatures in recent decades. New Jersey's annual temperatures have risen by approximately 4 °F since 1900 – roughly twice the global (over land and ocean surface) average and about 1.4 times the global over land average. This warming trend is expected to accelerate with further climate change, leading to increased heat stress-related health conditions, especially among vulnerable populations; more widespread damage to built infrastructure, such as roads and electrical wires; and exacerbation of conditions contributing to wildfires. By 2100, the annual average temperature in New Jersey is projected to be 3.7–6.2 °F or 7.4–11.7 °F above the 1991–2020 normal with moderate and very high greenhouse gas emissions, respectively.

Sea-level rise – Sea level has been perennially increasing along New Jersey at about 0.17 inches/yr (~18.6 inches since the early 1900s) due to global sea-level rise and land subsidence. Heightened sea levels present a greater likelihood of flooding during coastal storms or very high tides and can salinate freshwater ecosystems and resources. By the end of the century, the likely probabilistic range of sea levels in New Jersey is projected to be as much as 4.0–6.3 ft above the year 2000 mean sea level across low- to high-emissions scenarios.

Precipitation – The total annual rainfall within the state has increased by ~7% since the early 1900s, with the most intense events generating more rainfall compared to historical episodes. Future conditions are expected to see an increase in total annual rainfall of about 3–13% by the end of the century with moderate greenhouse gas emissions; additionally, extreme 24-h rainfall is projected to increase about 5–15%. In addition to contributing to increases in rainfall, rising temperatures also increase water demand and evaporation, increasing the likelihood of dry soil conditions.

Extreme events –In June 2023, New Jersey was blanketed in wildfire smoke from Quebec province, Canada. Throughout May to June 2023, more than 32 million acres of Canadian land burned, producing hazardous air pollutants like fine particulate matter that was subsequently carried by winds to New Jersey and much of the northeastern U.S. Particulate matter can trigger asthma and heart attacks, and the smoke from these wildfires led to a 17% increase in emergency department visits for asthma in the U.S. Warmer temperatures will likely cause greater evaporation, increasing vegetation scorch, and creates optimal conditions for increases in the size and frequency of wildfires that can exacerbate harmful air quality.

Global Climate

The increased atmospheric concentration of greenhouse gases (e.g., carbon dioxide [CO_2], methane [CH_4]) has caused an increase in global temperatures and changes in the global climate system. [1] In 2022, CO_2 and CH_4 concentrations accounted for approximately 64% and 19% of the observed global heating, respectively. [2] Most of the remaining 17% of the observed warming can be attributed to nitrous oxide (N_2O, 5.7%) and long-lived compounds like chlorofluorocarbons (CFCs) and other halocarbons (8.1% and 3.2%, respectively). [2] Since the 1960s, the growth rate of atmospheric CO_2 concentration has accelerated from roughly one part per million per year (ppm/yr) to over two ppm/yr in the 2010s. The current atmospheric concentration of CO_2 is above 420 ppm (Figure 1), the highest it has been in at least 800,000 years. [3] The growth rate of atmospheric CH_4 concentration has increased from 7.6 parts per billion per year (ppb/yr) over the period of 2011–2016 to 12.0 ppb/yr over 2017–2023. [2] Atmospheric N_2O has increased at a rate of about 1.1 ppb/year over the past decade and the concentration of CFCs has been declining since the year 2000. [2]

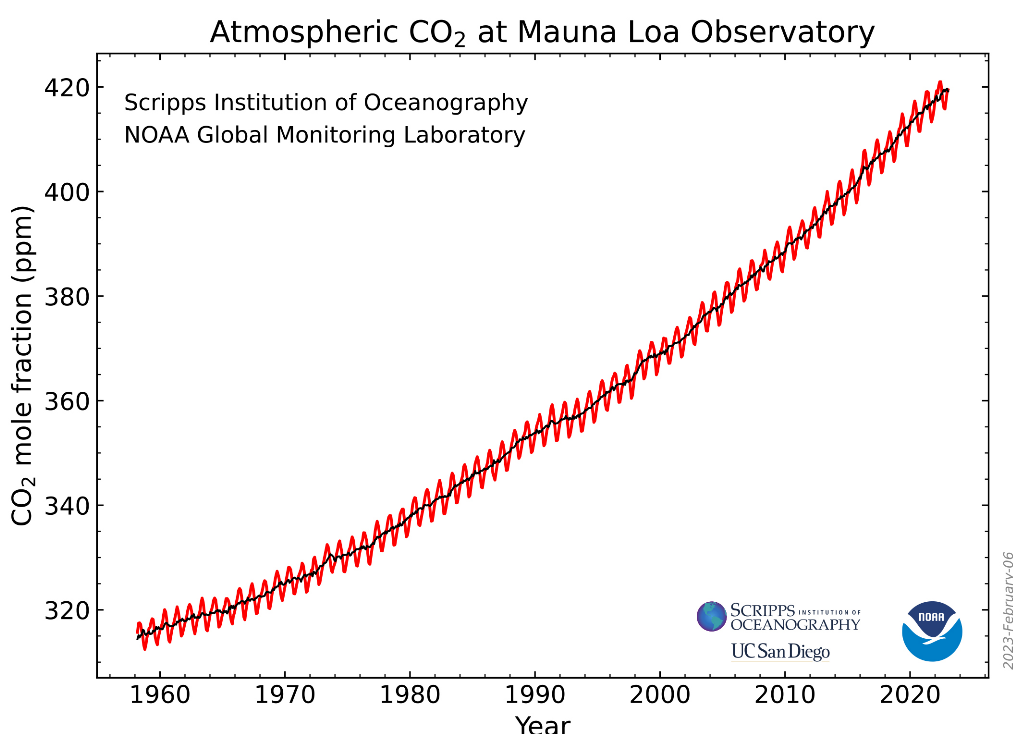


Figure 1. Atmospheric carbon dioxide concentrations in parts per million (ppm) measured at Mauna Loa, Hawaii. Red: monthly values; Black: 12-month running average. [NOAA Earth System Research Laboratory] [4]

2023 was the warmest year on record. The period 2014–2023 was the warmest ten years on record since 1880.

From the late 19th century to today, global temperatures have increased by roughly 2 °F [5] and have been rising more rapidly since the 1970s (Figure 2). 2023 was the warmest year on record, 2.12 °F above the century average, and the period of 2014–2023 represents the warmest ten years on record dating back to 1880. The average rate of temperature increase has accelerated from roughly 0.11 °F/decade from 1880 to the present to an average rate of 0.36 °F/decade since 1982. [6] According to the Intergovernmental Panel on Climate Change (IPCC), it is unequivocal that human activity, mainly the burning of fossil fuels, is the primary cause of increased greenhouse gas concentrations and this observed warming. [1]

While global temperatures have consistently increased since the 1970s, year-to-year temperature changes are variable. For example, two recent strong El Niño years, 2016 and 1998, exhibited significantly warmer global temperatures relative to surrounding years (Figure 2). 2023 also experienced a shift to an El Niño phase by June 2023, helping increase temperatures. [6] Additionally, temperature change varies by location. The Arctic has experienced more than twice the amount of warming than the global average [8] due to sea ice loss and other processes. [9] It should be noted that land areas generally warm more than regions over the ocean at the same latitude, particularly at high northern latitudes. [10]

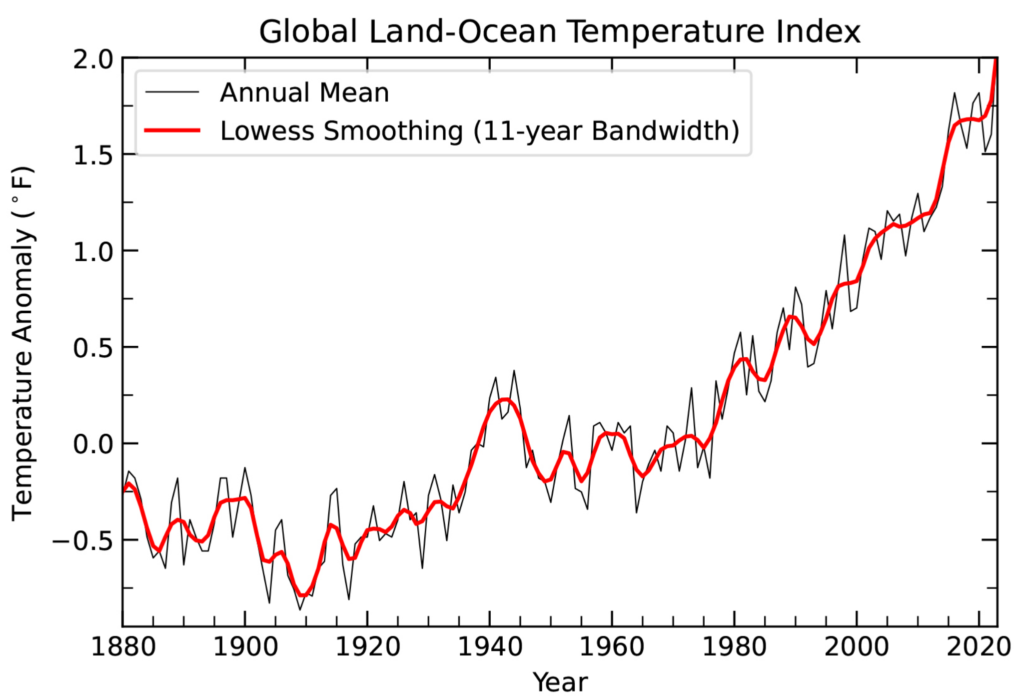


Figure 2. Global land-ocean temperature index anomalies relative to 1951–1980 average temperatures. [NASA's Goddard Institute for Space Studies (GISS)] [7]

As global greenhouse gas emissions continue to rise, temperatures are expected to continue increasing. Under the lowest IPCC greenhouse gas emissions scenario from the Sixth Assessment Report (AR6), which would require a drastic reduction of carbon emissions (and net negative emissions – more sequestration of CO_2 than gross greenhouse gas emissions measured in CO_2 equivalent units), temperatures would change by -0.2 °F to +1.2 °F by the end of the 21st century (1.8 °F to 3.2 °F above pre-industrial levels). The very high emissions scenario, with heavily increasing greenhouse gas emissions, projects temperatures to rise an additional 4.0 to 8.3 °F by the end of the century (6.0 °F to 10.3 °F above pre-industrial levels). [1]

[Note, throughout the remainder of this document, discussion of emission scenarios and analyses will be made in reference to both the recent IPCC AR6 [1] and the prior IPCC AR5 [11]. While projected climate change effects related to emission scenarios from the current IPCC AR6 report [1] are available for New Jersey, they have yet to be fully analyzed. Therefore, AR5 information will be presented where AR6 projections have not yet been fully analyzed.]

Warming temperatures have raised the global mean sea level by increasing ocean temperatures and melting glaciers and ice sheets. As the ocean warms, it expands, increasing volume and mean sea level. Simultaneously, melting glaciers and ice sheets raise sea level through water runoff into the ocean. Since 1979, Antarctic Ice Sheet melt is estimated to have contributed 0.55 inches to global sea-level rise [12] and the Greenland Ice Sheet loss has caused approximately 0.54 inches of sea-level rise since 1972. [13] Global sea level has risen about 7.6 inches since the early 20th century [14] and ~3.2 inches in the last 22 years alone with a rate of 1.8 inches/decade over the period of 2013 to 2022. [15,16] AR6 projections indicate an increase of 0.28–0.55 m by 2100 relative to 2005 with very low greenhouse gas emissions and 0.63–1.01 m with very high greenhouse gas emissions. [1]

Is Global Warming Accelerating?

Global temperatures in 2023 reached new heights. According to the National Aeronautics and Space Administration (NASA), 2023 was the warmest year in 144 years of records, with the global average temperature 1.18 °C (2.12 °F) above the 1951–1980 baseline period. [95] The temperature jumped by 0.28 °C (0.48 °F) relative to 2022, the largest one-year increase in the NASA global temperature record.

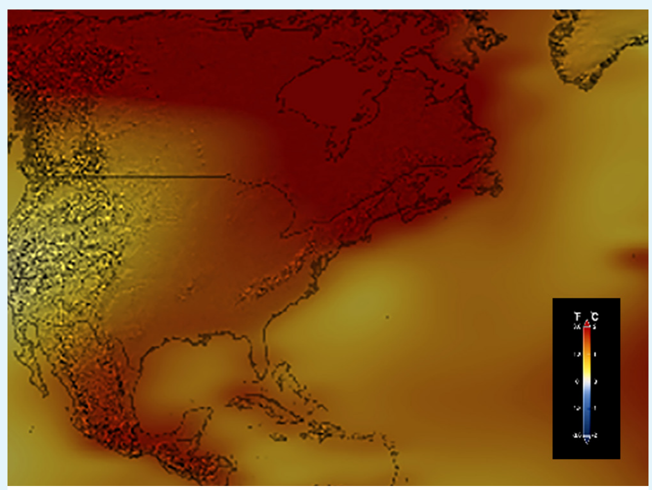
One contributor to the unusual warmth in 2023 was the development of a moderately strong El Niño event. El Niño is a natural phenomenon in which interactions between the tropical atmosphere and ocean cause the waters of the central and eastern equatorial Pacific Ocean to become warmer than average. El Niño events follow an irregular cycle, with warming episodes typically separated by 3–7 years, and they almost always result in an increase in global air temperature.

Despite this association between El Niño events and upward spikes in global temperature, there are several reasons why El Niño may not be the only cause of the unusual warmth in 2023. First, the year-to-year increase in global temperature was larger than in any previous El Niño event, even though there have been several such events that were stronger. Furthermore, the highest global temperatures usually occur in the year following the start of an El Niño, as it takes 3–6 months for the warming to spread to other parts of the tropics. Finally, the unusual warmth in 2023 developed in late spring and early summer – well before the peak warming in the equatorial Pacific – and included unusually high sea surface temperatures outside the tropics.

Dr. James Hansen of Columbia University has suggested that the record temperatures in 2023 may be indicative of an increase in the rate of global warming. [96] He has cited recent increases in Earth's energy imbalance – the difference between the sunlight absorbed by the Earth and the heat energy radiated back to space – in support of the accelerated warming hypothesis.

The ongoing warming of the Earth is driven by its energy imbalance, and an increase in the imbalance will lead to an increase in warming rate. A possible driver of the increased energy imbalance is a reduction in sulfur dioxide (SO_2) pollution. Because SO_2 emissions promote the formation of small particles in the atmosphere that can reflect sunlight, a reduction in such emissions allows more solar energy to be absorbed.

The accelerated warming hypothesis is controversial. Accurately measuring Earth's energy imbalance is challenging, and there are technical disagreements among climate scientists about the evidence for a recent increase in the imbalance. Another complicating issue is that the global temperature record is replete with short-term ups and downs, even in the absence of the effects of El Niño (and La Niña, its cooler counterpart), which make it difficult to determine if the warming rate has increased. Global temperature data over the next several years, in conjunction with measurements of Earth's energy imbalance, may eventually allow us to answer the question posed in the title of this sidebar.



A NASA visualization shows how much warmer or cooler each region of the planet was in 2023 compared to the average from 1951 to 1980. Higher-than-normal temperatures are shown in red and orange. [NASA's Scientific Visualization Studio]

New Jersey Climate

The Office of the New Jersey State Climatologist (njclimate.org) serves as New Jersey's primary resource for statewide weather and climate data. Unless otherwise indicated, all observed data presented in the remainder of this report are from the Office of the New Jersey State Climatologist. New Jersey climate data are also archived at NOAA's National Centers for Environmental Information (ncei.noaa.gov).

2023 Weather Summary

Based on 129 years of records, 2023 was the 3rd warmest year with an average annual temperature of 55.4 °F, continuing the trend of increased warming in recent decades throughout New Jersey. The 2022/2023 winter season (December 2022–February 2023) contributed greatly to this trend, being the 2nd warmest winter on record. January 2023 was the warmest January on record since 1932, with average temperature of 41.2 °F. Eight months in 2023 had above average monthly mean temperatures, with four months (January, February, April, and December) being in the top 5 warmest on record for their respective months based on observations from 1895 to the present.

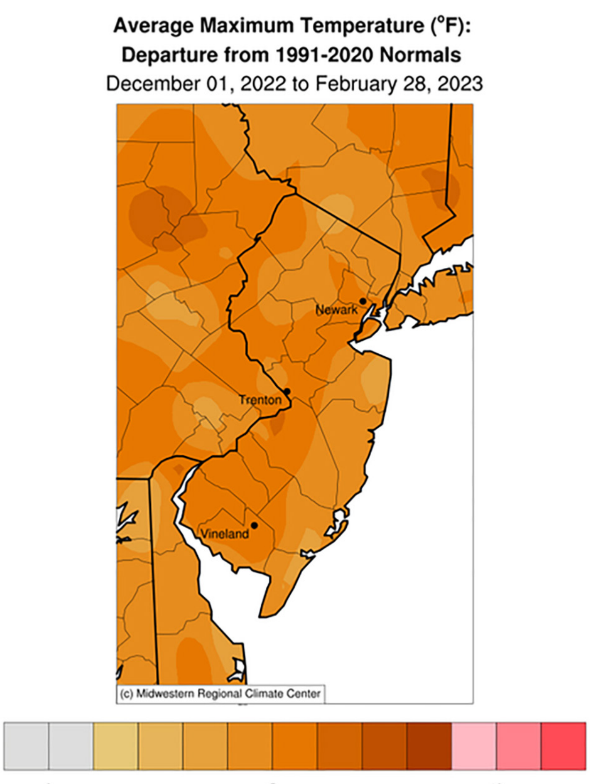


Figure 3. Interpolated contour map of the 2023 winter average maximum daily temperature anomaly (°F) in New Jersey as a departure from the 1991–2020 winter maximum daily temperature normal. Figure generated from NOAA Midwestern Regional Climate Center's Cli-MATE MRCC Application Tools Environment (https://mrcc.purdue.edu/CLIMATE/).[17]

Average precipitation throughout the state was 50.45 inches, 2.89 inches above the 1991–2020 normal of 47.56 inches. The 2022/23 winter season had the 4th least amount of snowfall for New Jersey since 1895. There was a considerable delay in measurable snowfall in 2023, with some areas of New Jersey not seeing snow until February. Ending the year, New Jersey experienced its wettest December on record, 4.37 inches above normal statewide averages with an average of 8.37 inches. The heaviest rainfall event occurred December 17th–18th, 2023, resulting in large rainfall totals throughout the state. Oakland in Bergen County received as much as 5.68 inches of rain over the two days, with many other areas throughout New

What Are Emissions Scenarios?

How the future drivers of climate change, such as carbon dioxide emissions, will evolve by 2100 is unknown because they are rooted in global-scale technological, economic, population, and policy changes over the current century. To assist in projecting how the climate may change, scientists use a range of illustrative scenarios to span the range of potential development of greenhouse gas emissions that vary based on socioeconomic assumptions, climate change mitigation strategies, and air pollution controls. [1] No one scenario is likely to completely predict future greenhouse gas emissions, but the range provides a series of guidelines on how the climate may evolve with enhanced or reduced anthropogenic emissions.

Jersey getting 3.00 to 5.00 inches. This event caused flooding in the Passaic and Raritan basins, measuring the 9th highest crests on record at both primary river gauges. The storm generated wind gusts between 40 and 56 mph throughout the state. Other significant December rainfall events include 1.00–3.00 inches statewide with Bradley Beach (Monmouth County) measuring 3.61 inches from the 10th to the 11th and 3.45 inches in Bernards Township (Somerset County) from the 27th to the 28th. During these events, wind gusts reached 40 mph near the coast and higher northwestern areas, and there was minor to moderate flooding in the Passaic and Raritan basins.

In addition to a wet December, remnants of tropical cyclone Ophelia hit New Jersey in late September, bringing heavy rains and wind gusts. Toms River (Ocean County) received as much as 5.23 inches of rain between September 22nd and 24th, and surrounding coastal areas experienced 40 to 60 mph gusts. Ophelia continued north, leaving Montague Township (Sussex County) with 2.46 inches of precipitation. Ophelia also generated coastal flooding from the 23rd to the 26th, with a full moon contributing to enhanced flooding. Ophelia stalled and merged with a cold front on the 28th and 29th, generating 10.40 inches of rainfall in Bradley Beach and 9.00 inches in Neptune along the Monmouth County coast. Post-tropical storm Ophelia, paired with a merging cold front from the west, played a large role in making the month New Jersey's 6th wettest September on record.

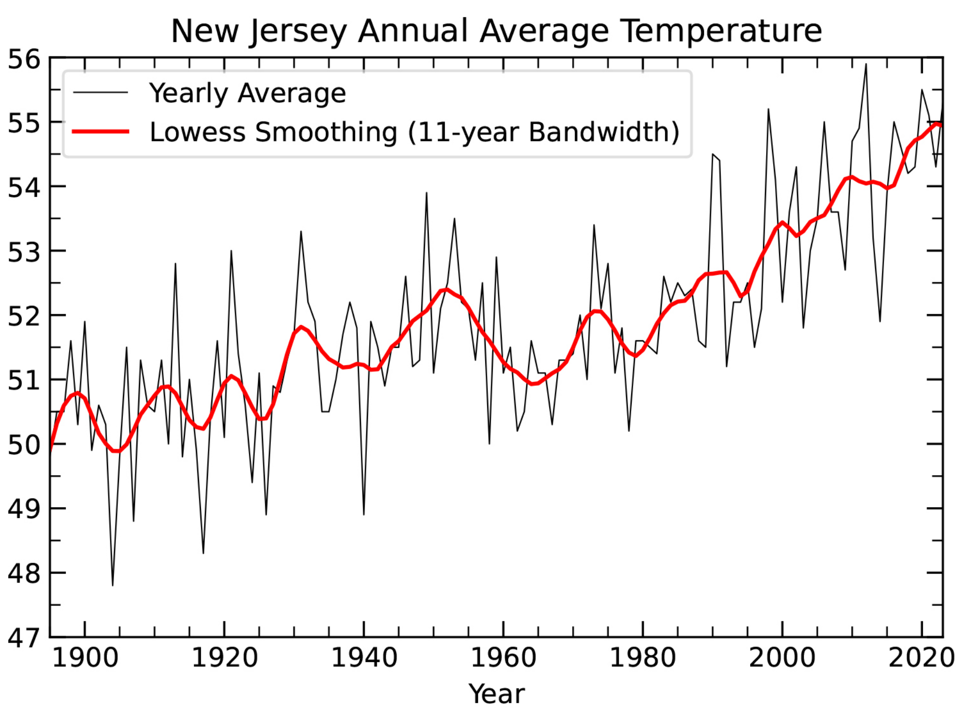
2023 tied with 2021 for the 2nd most tornadoes in a year for New Jersey since 1950, the most occurring in 1989. Out of the 13 tornadoes recorded, 4 were of EF2 strength, a strong tornado classification with winds reaching 111–135 mph. One of the EF2 tornadoes on February 21st damaged 10 homes and caused other property damage in Lawrence Township and West Windsor. [19] April 1st saw seven tornadoes touching down in a single day, being only the second time this many was recorded in one day in New Jersey since 1950 with the other day being November 16th, 1989. [19] Of the seven tornadoes, two were EF2s and five were EF1s.

Finally, one of the standout weather events of the year was the smoke that blanketed New Jersey in June from the summer Canadian wildfires. Winds brought the smoke from the burning fires in Quebec, Canada, south to the Mid-Atlantic region, with June 7th presenting the most significant episode in New Jersey. Many parts of the state (especially the northern and central regions) were blanketed by orange skies, and air quality was extremely unhealthy.

Temperature

Average annual temperatures in New Jersey have increased by nearly 4.0 °F since the end of the 1800s (Figure 4). The increase in New Jersey temperatures has been about twice the global land and ocean average and about 1.4 times the global over land average. [20] Between 1900 and 2023, New Jersey's annual average temperature has increased at a rate of 0.33 ± 0.03 °F/decade. There has been limited evidence that New Jersey warming has been partly fueled by greater offshore sea surface temperatures, [21] but scientific consensus has not yet been reached.

Figure 4: Average annual temperatures in New Jersey (°F). [Office of the New Jersey State Climatologist]



Higher temperatures degrade air quality by increasing pollutants such as ground-level ozone, creating dry conditions conducive for wildfires that generate fine particulate matter, and extend/strengthen the pollen allergy season. [22] Poor air quality can lead to higher rates of asthma, allergies, and deaths from respiratory-related illnesses. [23,24] Vector-borne diseases (such as West Nile virus) are also expected to have expanded ranges with increased temperatures (and humidity) as vector species, such as mosquitoes, spread to new locations. [22] Heightened temperatures will affect the agriculture sector by decreasing yields, reducing the viability of some crops (such as blueberries and cranberries) within New Jersey, and promoting the expansion of pest and weed species. [25] Variations in seasonal temperature have a large impact

SEASON	TIME PERIOD			
	1900–2023		1970–2023	
	Linear Rate (°F/decade)	Calculated Increase (°F)	Linear Rate (°F /decade)	Calculated Increase (°F)
Winter (December–February)	0.44 ± 0.07	5.4 ± 0.9	0.97 ± 0.24	5.1 ± 1.3
Spring (March–May)	0.28 ± 0.05	3.4 ± 0.6	0.52 ± 0.15	2.7 ± 0.8
Summer (June–August)	0.29 ± 0.03	3.5 ± 0.4	0.57 ± 0.10	3.0 ± 0.6
Fall (September–November)	0.26 ± 0.04	3.3 ± 0.5	.56± 0.13	3.0 ± 0.7

Table 1. Average seasonal changes in New Jersey temperatures calculated by linear regression for 1900–2023 and 1970–2023 with temperature increases calculated using the linear fit rate and its standard deviation.

on agriculture. In recent years, New Jersey has experienced elevated early spring temperatures, causing plants to bloom early (i.e., blueberries, cranberries, and peaches) and harming their production due to damage from spring frost events. [26]

Since 1970, New Jersey average temperatures have increased at a rate of 0.66 °F/decade (Figure 4), the equivalent rate of 6.6 °F/century. The warmest year on record is 2012 (55.9 °F) and the coldest is 1904 (47.8 °F). Despite relatively large year-to-year variability, recent temperatures have been consistently increasing. Out of the 20 warmest years since 1895, 15 have occurred since 2000 (2023 was the 3rd warmest year on record). Furthermore, none of the top ten coldest years occurred after 1940.

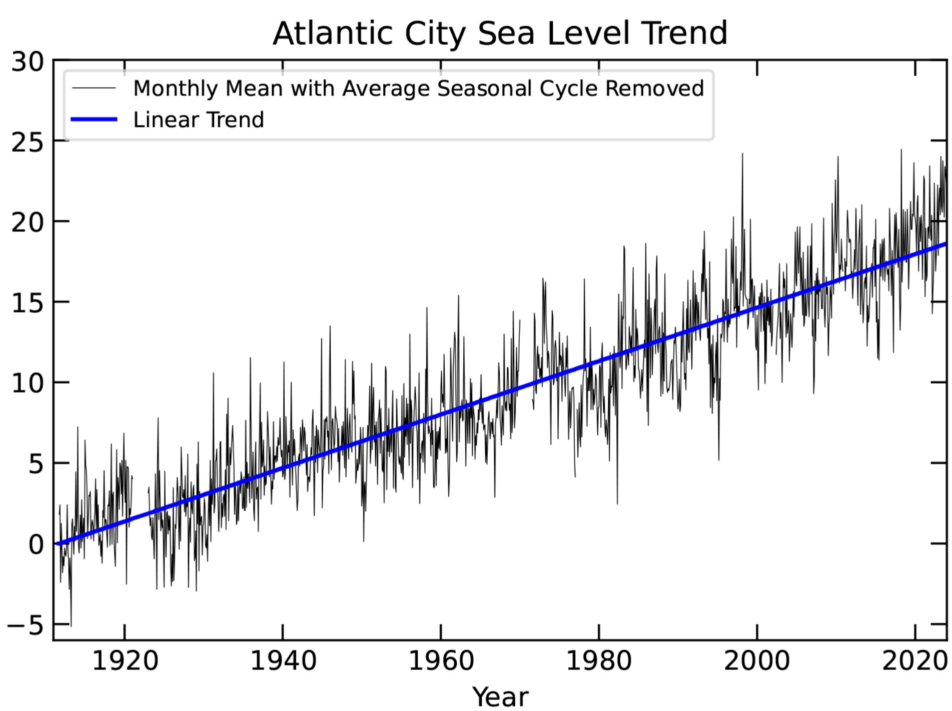
As average annual temperatures rise in New Jersey, changes in seasonal temperatures vary substantially and are summarized in Table 1.

Average temperatures during each season rose at higher rates over the past 53 years compared to the 123 years since 1900. Notably, the linear trend in winter temperatures increased by 5.1 °F ± 1.3 °F since 1970, a rate of 9.7 °F ± 2.4 °F/century, consistent with the U.S. northeast regional trend of winter temperatures warming at a higher rate than other seasons. [27] As the latest manifestations of this trend, winter of 2023 ranked as the 2nd warmest on record, averaging 38.5 °F (4.4 °F above the 1991–2020 normal).

Temperatures in New Jersey are expected to continue increasing as global greenhouse gas concentrations rise. Under a moderate emissions scenario (SSP2-4.5 as detailed under the IPCC AR6 [1]), average annual temperatures in New Jersey are projected to increase 3.7–6.2 °F (10th–90th percentile of model projections) by the end of the 21st century relative to the 1991–2020 average. [28–30] Under a very high emissions scenario (SSP5-8.5), temperatures are expected to increase 7.4–11.7 °F by 2100, [29,30] comparable with but somewhat higher than northeast regional projections from the prior generation AR5 of about a 10.1 °F increase with high emissions by the end of the century compared to the 1971–2000 average. [27] These New Jersey-specific projections are consistent with regional projections of increased temperature extremes (e.g., daily maximum temperatures or the number of days above 90 °F or days with a heat index above 100 °F) in the northeast by the middle and end of the century. [31,32] The range of projected temperatures in response to greenhouse gas emissions indicates that national- to global-scale emission policies will greatly influence New Jersey's future climate over the next century.

In addition to heightened average temperatures, heat stress caused by extreme heat events becomes more concerning with climate change. Heat stress is the leading cause of weather-related deaths in the United States. [33] Under high emissions, it is expected that approximately 70% of summers in New Jersey will be warmer than any prior to 2006 by the middle of the 21st century, growing to 90% by the end of the century. [34] Higher temperatures combined with high humidity can lead to a higher risk of heat stress because the body's natural cooling from sweating becomes less effective in more humid conditions. In Atlantic City, summer dew point temperatures have risen by more than 3 °F since 1980, [35] creating more humid summers and increasing the potential for heat stress. Increased heat stress is expected to cause greater incidences of heat-related illnesses, hospital admissions, and deaths among vulnerable populations. [22,36] Extreme heat can also overburden building cooling systems or cause power outages, and high humidity keeps temperatures warmer overnight, limiting people's ability to find reprieve, worsening health outcomes. These effects are amplified in urban sectors where paved surfaces and lack of vegetation contribute to the urban heat island effect that heightens local temperatures compared to surrounding regions. [22]

Figure 5: Relative sea level trend (inches) at the Atlantic City Tide Gauge. [37]



Sea-Level Rise

Between 1911 and December of 2023, sea level rose approximately 18.6 inches at Atlantic City (Figure 5), more than double the global average. [14] The New Jersey coastline has exhibited a greater sea-level rise rate compared to the global average due in part to land subsidence. In New Jersey, subsidence, or the vertical sinking of the land surface, contributes to relative sea-level rise due to a slow vertical readjustment to the

Sea level rose approximately 18.6 inches at Atlantic City between 1911 and 2023, more than double the global average. The rate of sea-level rise is accelerating.

melting of ice sheets from the last ice age, natural sediment compaction, and groundwater withdrawal. [14] The average rate of sea-level rise since the early 20th century has been 0.17 inches/yr. [14,37] However, 8.2 inches of the total 17.6 inches of relative sea-level rise in Atlantic City (as of 2019) were observed since 1979, [14] a rate of 0.2 inches/yr, indicating that local sea-level rise is accelerating, and this rate has effectively continued through 2023. Higher sea levels can permanently inundate parts of the land, consuming property, infrastructure, and homes in low-lying locations near the coast. [38] Coastal flooding events become more frequent and larger as storm surges and wave effects are enhanced by a higher base sea level. [39] Sea-level rise can also enhance saltwater contamination of freshwater resources used for crop irrigation, salinate soils from coastal storm flooding, and threaten freshwater ecosystems by pushing salt water farther upstream in estuaries. [40]

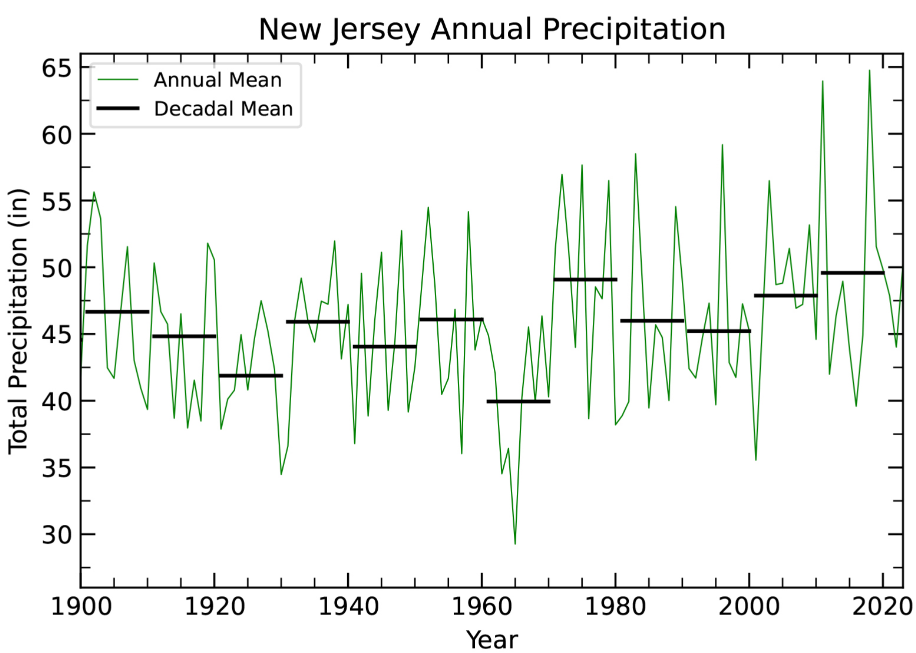
Sea-level rise is expected to continue accelerating over the next century. Following results from the Rutgers-led Scientific and Technical Advisory Panel (STAP) 2019 report, relative to the 1991–2009 baseline, sea level is projected to increase 0.5–1.1 ft by 2030 and 0.9–2.1 ft by 2050. [14] During this time frame, projections are largely independent from greenhouse gas emission scenarios, but after 2050, projections deviate depending on emission levels. In a low emissions scenario, [14] projected sea-level rise at 2100 is expected to be 1.7–4.0 ft compared to the year 2000. Under a high emissions scenario, sea level is projected to rise 2.3–6.3 ft. [14] These projected ranges in New Jersey sea-level rise are based on projections from the prior IPCC AR5 report and the 2019 STAP report. These ranges are expected to be reevaluated in the next STAP report which will be informed by projections from the IPCC AR6 and updated emissions scenarios.

As a result of increased sea level, New Jersey's coast has become more subject to tidal flooding, also known as "sunny day" or "nuisance" flooding. Tidal flooding occurs when high tides cause flooding that is not associated with storm surge or extreme wave effects. Tidal flooding can disrupt roadways, damage buildings, reduce property values, and help overwhelm combined storm and wastewater systems, leading to public health concerns. [39] For example, in Atlantic City, the number of tidal flooding days has been increasing. From 2007 to 2016, the average number of yearly tidal flooding events was eight, while the average during the 1950s was less than one event per year. This range can vary considerably. For example, 2007 experienced only four tidal flooding days while 2009 saw 18. [14] This trend is expected to continue and accelerate with sea-level rise. With moderate emissions, by 2030, 17 to 75 days per year are projected to experience tidal flooding, 85 to 315 days by 2060, and at least 240 days by the end of the 21st century. [14] Note that these ranges are large and correspond to the upper and lower bounds of the likely probabilistic range (17th–83rd percentile) of projected sea-level rise in Atlantic City as calculated in the 2019 STAP report. While there is some level of uncertainty in the rate of sea-level rise as expressed by these ranges, what is clear is that Atlantic City's tidal flooding will increase and is likely to occur on most days of the year by 2100 across low to high emission scenarios.

Precipitation

Increasing temperatures allow the atmosphere to hold more water vapor, increase evaporation rates, and potentially produce more precipitation. Due to the large year-to-year variability of precipitation, this report uses decadal averages to analyze long-term trends. Decadal average precipitation in New Jersey increased roughly 3–5 inches (~7%) since the early 1900s (Table 2, Figure 6). From 1901 to 1960, the average decadal precipitation was constrained between 42 and 46 inches/yr. In the 1960s, the mean fell (coincident with drought conditions) to 40 inches/yr. From 1971–2020, the decadal means were generally within a slightly higher range of 45–49 inches/yr. Downscaled AR6 climate model data (accessed via the Applied Climate Information System, rcc-acis.org, managed by the Northeast Regional Climate Center, Cornell University)[30] project New Jersey to experience an increase in mean annual precipitation of 3–13 % by the end of the century for moderate emissions, similar to observed historical trends, and 7–20% for very high emissions compared to the 2001–2020 average. [28,29] Projected changes in annual precipitation by 2100 are smaller than the historic year-to-year variations in precipitation in New Jersey. So, while projections indicate a small increasing trend in

Figure 6: New Jersey annual precipitation (inches). [Office of the New Jersey State Climatologist]



annual precipitation, the high natural variability decreases confidence in the exact amount of projected increase.

Observed increased precipitation magnitude has been coupled with an increase in interannual rainfall variability (Figure 6). Pre-1970, the average of the top 5 rainiest years was 54.14 inches and post-1970 it was 60.81 inches (Table 3). The average of the driest 5 years was 34.15 inches and 38.15 inches for each time period, respectively. This simple comparison elucidates that not only has annual rainfall been increasing, but that the range between rainiest years and driest years has also increased on average by ~2.66 inches. In effect, these measurements indicate that interannual rainfall has become more variable, with some years fairly dry and others seeing excessive rainfall. This trend is expected to continue, and the U.S. Northeast will become wetter and experience greater precipitation variability by the end of the century.[41] A warming climate intensifies the hydrologic cycle, increasing precipitation variability globally, which can affect regional agricultural production, drought frequency, and flood conditions. [42] It should also be noted that precipitation patterns are naturally subject to high interannual, interdecadal, and locational variability, so recent increases in precipitation amounts may not be solely attributed to climate change.

Table 2 (right). Decadal averages of New Jersey average annual precipitation from 1901 to 2020 [Office of the New Jersey State Climatologist]

Decade	Average Precipitation (inches/yr)
1901–1910	46.66
1911–1920	44.83
1921–1930	41.88
1931–1940	45.92
1941–1950	44.05
1951–1960	46.09
1961–1970	39.95
1971–1980	49.08
1981–1990	45.99
1991–2000	45.21
2001–2010	47.88
2011–2020	49.58

Table 3 (below). The 5 highest and lowest annual New Jersey precipitation amounts in inches pre- and post-1970 with averages of each and the range between average highs and lows [Office of the New Jersey State Climatologist]

	Rank	1	2	3	4	5	Average	Range
Pre-1970	High	55.64	54.49	54.16	53.65	52.74	54.14	19.99
	Low	29.27	34.48	34.53	36.04	36.43	34.15	
Post-1970	High	64.76	63.95	59.18	58.50	57.66	60.81	22.66
	Low	35.55	38.20	38.66	38.88	39.46	38.15	

New Jersey yearly precipitation has increased more rapidly over the past 50 years compared to prior decades. Prior to 1961, annual precipitation amounts were effectively stable, displaying a small decreasing rate of 0.27 ± 3.40 inches/century. Since 1970, the linear rate has shifted to an increase of 2.25 ± 5.96 inches/century and 14.16 ± 7.57 inches/century since 1980. In general, the uncertainty ranges around each linear trend are large compared to the central value, emphasizing that large year-to-year rainfall variability is a dominant characteristic of New Jersey rainfall (Figure 6). The 1961–1970 period is not included in this analysis due to the large drought early in the decade over-influencing the long-term trend. The top five wettest years since statewide records commenced in 1895 have all occurred since 1975, with a maximum of 64.76 inches in 2018. The lowest recorded yearly precipitation was 29.27 inches in 1965 (drought conditions). When assessing these precipitation trends and their societal impacts, it is important to consider the balance between evaporation and precipitation. Evaporation also increases with higher temperatures, transferring water back into the atmosphere more rapidly, making less rainfall available for water storage, agriculture, and other uses. Although it is projected that rainfall may increase in New Jersey on average, increasing temperatures and water demand will result in drier soils less suitable for agriculture and more conducive for wildfires in forest environments. As temperatures are projected to increase, so is evapotranspiration by as much as 0.83%/decade by 2100 under a very high warming scenario with surface soil moisture decreasing by about the same rate (Marvel et al., 2021). [43]

In the Northeast, summer precipitation is not projected to change substantially. Combined with higher temperatures and evaporation rates, the duration of future summer dry spells is expected to increase. Ultimately, while the frequency of extreme precipitation has increased in New Jersey [44] and is expected to continue, [32,45,46] the periods between rainfall events in the summer are projected to be longer and therefore drier (i.e., reduced water resources), resulting in more short-term drought conditions and with greater average annual water deficits and lower capability to fulfill vegetation requirements. [47,48] Due to increased temperatures, these more frequent dry periods could require increased irrigation and residential water usage, risking saltwater intrusion in New Jersey aquifers due to freshwater pumping. [25,47]

While the frequency of extreme precipitation has increased in New Jersey and is expected to continue, the periods between rainfall events in the summer are projected to be longer.

Understanding Return Periods

Extreme events (primarily precipitation and flooding) are typically described in terms of return periods/intervals, such as the "x-year event." A 100-year event, typically referring to a flooding or extreme weather event, has a 1% or 1/100 probability of occurring each year at a specific location. Similarly, a 50-year event has a 2% or 1/50 probability of occurring each year at that location.

A common misconception is that if a 100-year event occurred one year, it will not happen again for another 100 years or so. However, the probability remains at 1% each year no matter what happened in preceding years. A 100-year rainstorm on one day does not change the probability of receiving the same amount of precipitation the next. [51]

Return period events are defined for a specific geographic scale (such as a point versus a county). For example, in a given year, multiple 100-yr rainfall events may be recorded throughout New Jersey. Those events characterize the specific locations in which the rainfall occurred but not the state as a whole. Finally, with climate change, a 100-year intensity event may become a 50- or 20-year event in the future as extreme event frequencies change. Note that what return level event is considered "extreme" is subjective and depends on the type of event, but the 100-year event is a common threshold used within scientific and planning assessments when a storm hits. The more saturated the ground, the less moisture it can accept, so more water will run off and accumulate in streams. Other factors influencing runoff include the type of ground cover and vegetation, terrain, storm duration, and precipitation intensity.

The extreme events described by the return period projection can be singular, such as the return period of a river flood elevation, but they can also include the event duration. For example, the measured rainfall over 24 hours and the rainfall measured over 2 days at a location may both present extreme conditions and different amounts. But each measured timeframe (24 hours vs. 2 days) will have a separate set of return periods (e.g., the 10-yr return period of the 24-hour rainfall event is distinct from the 10-yr return period of the 2-day rainfall event). Finally, a 100-year rainfall event does not necessarily result in a 100-year flood because flooding is affected by several factors besides rainfall – the most important being ground saturation during a storm.

A map of FEMA flood zones generated by NJ FloodMapper delineates 1% (blue) and 0.2% (orange) Annual Chance Flood Hazards, also known as 100-year and 500-year floodplains, in the area around Oceanport, N.J.

Extreme Events

Extreme events can be defined as weather or climate events whose severity, magnitude, or impact rank above or below a (often subjective) threshold near the upper or lower ends of that type of event's historic range of intensity within a specific region.

As sea level rises in New Jersey, so does the risk of coastal flooding from storms. Storm surges induced by tropical cyclones and nor'easters and their potential damage are magnified by an increasing base sea level. For example, it has been estimated that approximately 12.8% of the total property damage from Hurricane Sandy in New Jersey can be attributed to human-caused sea-level rise, representing about $3.7 billion. [49] Following this trend, a coastal storm affecting New Jersey today would cause more flooding damage than the same storm 50 years ago, and today's 100-year intensity coastal flooding event is projected to occur five times as often by 2050. [50]

Extreme precipitation events in the northeast U.S. are becoming more frequent and intense. [32,52,53] Common practice is to use the NOAA Atlas [14] precipitation frequency estimates [54] for planning and design standards; however, this dataset ends in 2000. Incorporating data through 2019, most long-term weather stations throughout New Jersey have seen increases in the 2-, 5-, 10-, 25-, 50-, and 100-year return period precipitation events compared to the 2000 dataset. [44] At most locations, extreme precipitation amounts were found to be more than 2.5% greater than the 2000 dataset estimates. [44] This shift, by adding an additional 19 years of data, challenges a major assumption: that the past climate can accurately inform future expectations of extreme events. [55] It is therefore necessary that forward-looking metrics of extreme precipitation using historical data be supplemented by model projections to account for future climates.

More intense precipitation events will lead to more frequent and larger floods [47] that can cause loss of life and property/infrastructure damage in New Jersey. Flooding has compounding indirect effects through avenues such as carbon monoxide poisoning (personal power generator use after a flood) or contaminating food and water supplies. [22,48] Extreme rainfall can increase surface water turbidity and bacteria contaminants that can be ingested, causing gastrointestinal illnesses. [22] Frequent and intense precipitation can also lead to worse agricultural outcomes such as reduced plant growth, delayed planting, and soil saturation. [25,56]

There are multiple ways in which extreme precipitation can be quantified and many studies offer different metrics to describe how the frequency of extreme precipitation has increased in recent decades. In New Jersey, the frequency of individual precipitation events producing more than two inches of rain has generally increased compared to the long-term 1900–2014 average since the late 1960s, though with substantial variability. This trend has resulted in the five-year period of 2010–2014 presenting the most extreme precipitation (>2 inches) events between 1900 and 2020 (Figure 7). [57] The duration of these events can range from a few hours to several days. Shifting to a related metric but using a duration of 24 hours and defining extreme precipitation as receiving more than 2 inches within that 24-hour period, the total number of days receiving extreme precipitation has increased over the past 50 years compared to the 1901–2020 average (Figure 7). From 2005–2014, the number of 2-inch precipitation days was generally above average, with 2010–2014 being about 50% greater than the 1900–2020 average of 2.3 days. [57]

The observed increase in extreme precipitation is not unique to New Jersey. Nationally since the 1990s, individual precipitation events exceeding the 5-year return period have occurred 20–40% more frequently, and over 40% more frequently between 2006 and 2016. [45] Looking at this trend another way, the northeastern U.S. has seen a 49% increase in the number of days with more than 2 inches of rainfall compared to the long-term 1958–2022 average and an 84% increase in days with more than 4 inches of rainfall compared to the long-term 1958–2022 average. [32] At most U.S. weather stations, increasing extreme precipitation can be directly related to increasing temperatures. [58] Nationally, extreme precipitation events are projected to become more intense and frequent over mid-latitude regions (most of the continental U.S.), where warming is expected to occur at higher rates. [1]

Future projections of extreme rainfall within New Jersey indicate continued intensification of extreme 2-yr, 10-yr, and 100-yr 24-hour rainfall events. [46] The 24-hour event is the amount of rainfall that is accumulated in a 24-hour period. The 2-yr, 10-yr, and 100-yr return periods here represent the frequency at which the accumulated rainfall for a given 24-hour period is expected to occur. Assuming moderate emissions, the median projection for the magnitude of the 100-yr 24-hour rainfall event will increase modestly by 2.5–10% in central and coastal New Jersey and by a larger 20-25% in northern New Jersey by the end of the century. Higher frequency events, such as the 2-year and 10-year 24-hour rainfall events, are projected to have an average increase in rainfall of 7.5–15% by 2100. [46] It should be noted that these increases in rainfall are median estimates of large ranges of possible change. Regardless of the magnitude of the projected changes, the likely trend throughout the rest of the century is for large rainfall events (such as the 100-yr 24-hour rainfall event) in New Jersey to increase in magnitude.

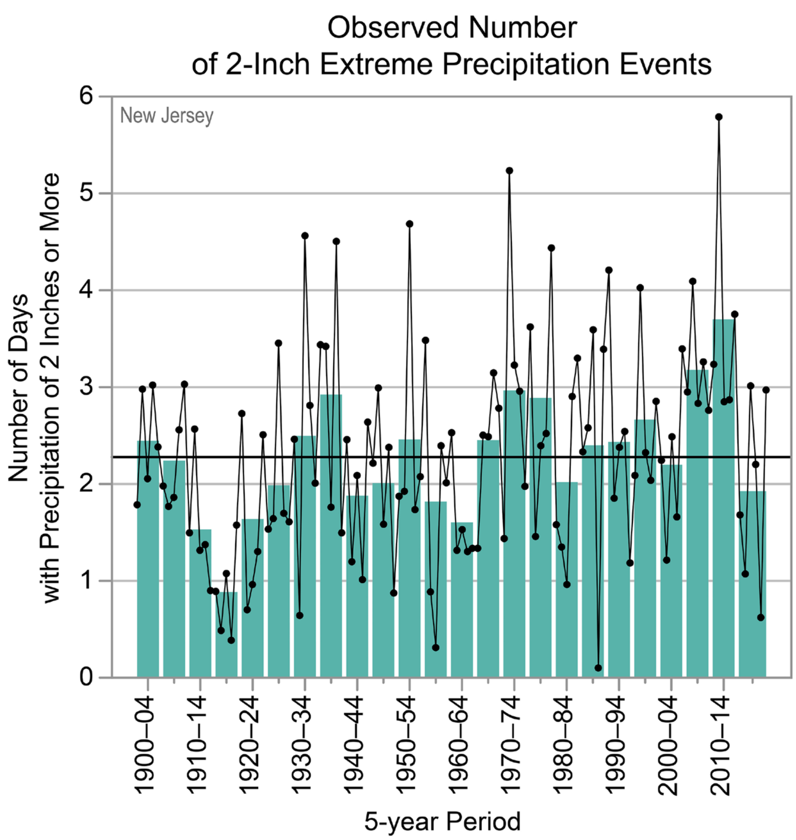


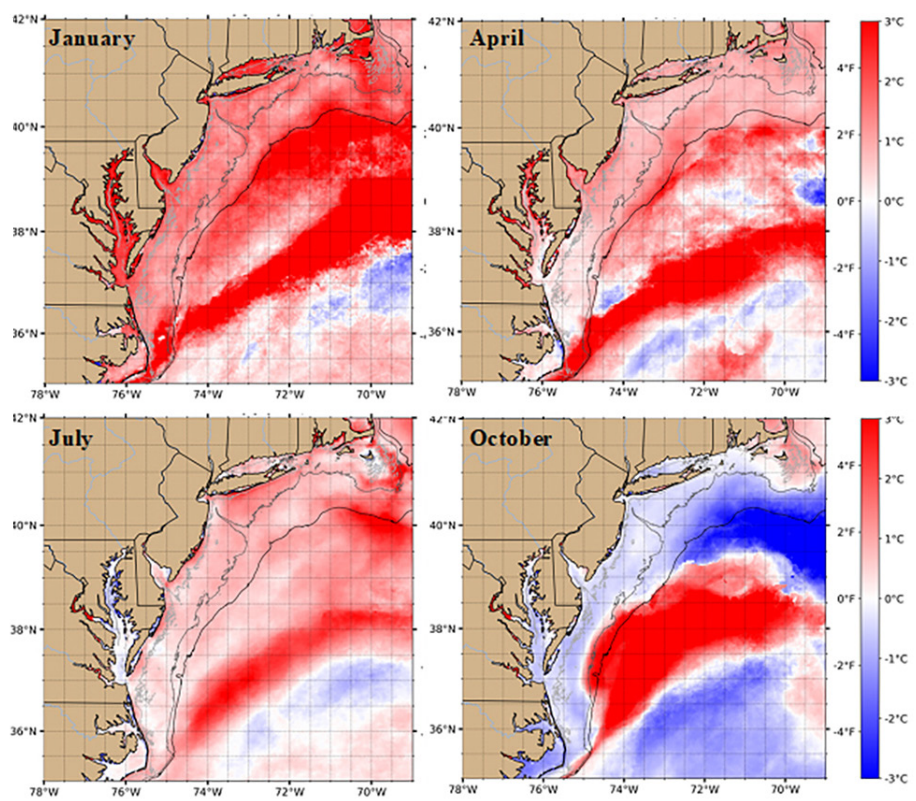
Figure 7. Annual number of days exceeding 2 inches of precipitation for New Jersey from 1900–2020. Bars show 5-year averages of the number of rainfall events, the black dots show the yearly values, and the black horizontal line represents the 1900–2020 average of 2.3 days per year where precipitation exceeds 2 inches. Reproduced from Runkle and others (2022). [57]

2023 Mid-Atlantic Temperatures and Stressors

2023 Seasonal Mid-Atlantic Ocean Temperatures
2023 was the warmest year on record globally for sea surface temperatures, and ocean temperatures along the Mid-Atlantic reflected this fact. Figure S1.1 displays a series of monthly ocean temperature measurements from 2023 relative to an average 2009–2017 baseline for each month. Winter, spring, and summer surface waters of the continental shelf off the coast of New Jersey were 1.8–3.6 °F (1–2 °C) above 15-year means for each season, with the warmest departures during the winter months prior to seasonal stratification (warm less dense water overlying colder, denser water) in the spring. In the fall (Figure S1.1 October), the largest difference occurred between shelf waters and the deeper, offshore waters of the continental slope. In fall 2023, the cooler waters of the shelf were likely a result from the passing of Hurricane Lee in early September that mixed the deep, cooler waters to the surface. This cooling is in direct contrast to the large warm anomaly to the southwest associated with a diversion of the Gulf Stream toward the north, causing the warming further offshore.

Summer 2023 Mid-Atlantic Multi-Stressor Event
From August to September 2023, the waters along the New Jersey coast from Sandy Hook to Tuckerton exhibited strong stratification: warm surface waters overlying cold bottom water typical for the late summer in this

Figure S1.1.
Maps of monthly averaged satellite derived sea surface temperatures in January (upper left; winter), April (upper right; spring), July (lower left; summer), and October (lower right; fall) relative to the 2009–2017 monthly average.



region. These temperatures were measured using autonomous underwater vehicles called gliders that dive and surface, measuring the water temperature and other ocean conditions close to the surface and at depth. However, during the 2023 summer, seasonally light winds reduced the mixing of cold bottom water and warm surface waters, strengthening the boundary between these two water masses. The sustained stratification and reduced mixing isolated much of the bottom water from the surface. This isolation led to low dissolved oxygen in this lower layer with concentrations less than 5 mg/L, pH values less than 7.75, and aragonite saturation states less than 1. Coast-wide, hypoxic levels of dissolved oxygen (concentrations < 3 mg/L) were observed at shallower, more inshore locations.

During this event when low dissolved oxygen, pH, and aragonite saturation state were observed, numerous mortalities of fish, lobsters, and crabs in the area were reported. The mortalities were observed in bottom waters primarily off the coast of Monmouth and Ocean Counties and included the Mud Hole, as far east as Lillian Wreck, and southward in Sea Girt and Axel Carlson Reefs and the surrounding areas. Mortalities were reported for American lobsters, Jonah crab, Atlantic rock crab, spider crabs, black sea bass, and tautog along the open bottom and not just in isolated pockets. This observation suggests that if low dissolved oxygen was responsible for these reported mortalities, the affected area may have been extensive enough that the mobile fish could not have easily escaped the unfavorable conditions. Healthy dissolved oxygen levels, pH, and aragonite saturation state were restored in bottom waters temporarily during the offshore passage of Hurricane Lee around September 16. Finally, a strong storm on September 24–26 drove fall water column turnover that restored consistent healthy bottom water conditions.

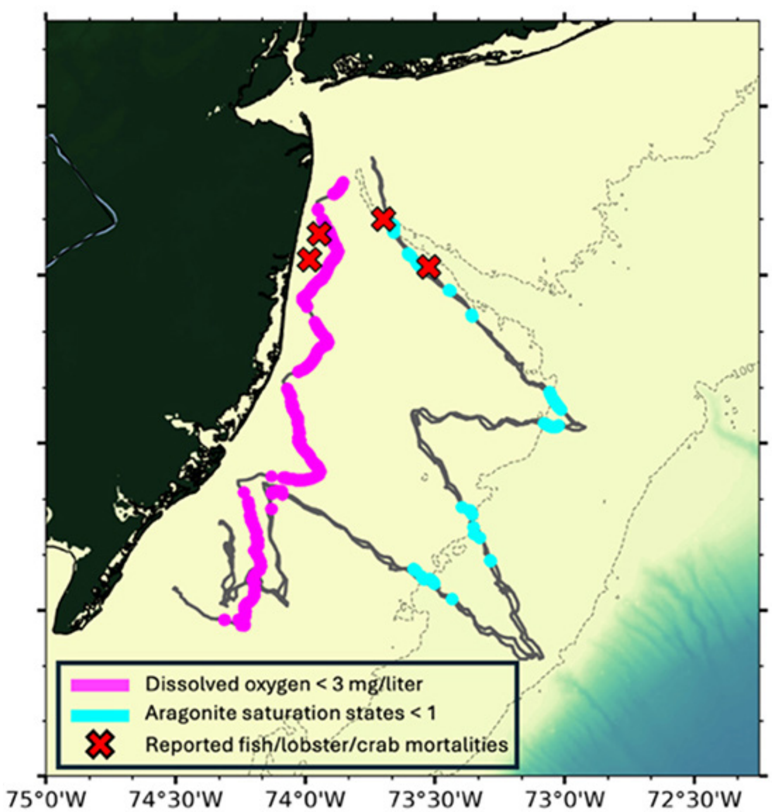


Figure S2 2. Locations of hypoxic levels of dissolved oxygen (magenta; < 3 mg/liter) and low aragonite saturation state (cyan; < 1) measured along the glider mission tracks and locations of reported fish, lobster, and/or crab mortalities (red X). Note: the nearshore glider did not measure pH or aragonite saturation state. Preliminary data presented here are the result of support provided by grants from the New Jersey Research and Monitoring Initiative (RMI) and New Jersey Department of Environmental Protection's Bureau of Marine Water Monitoring.

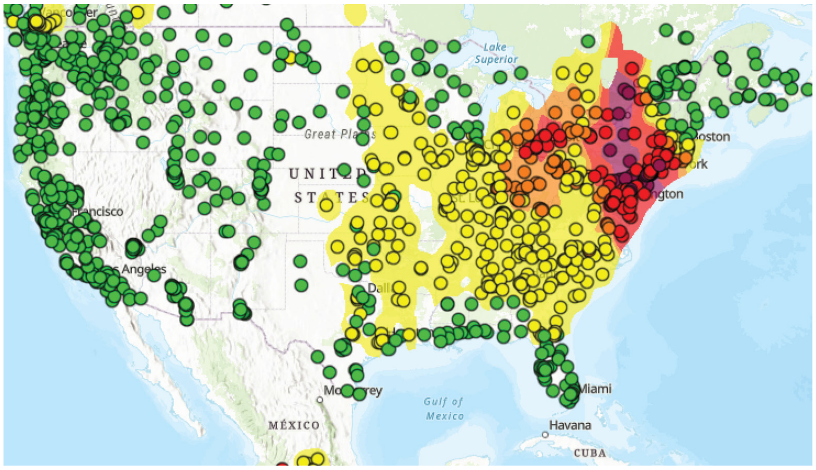
For more information about ocean acidification and how New Jersey communities can address ocean acidification impacts, please see: https://njclimateresourcecenter.rutgers.edu/resources/opportunities-to-address-ocean-acidification-impacts-in-new-jersey/

4. Extreme Events: Canadian Wildfires of Summer 2023

In 2023, Canada experienced its warmest May–June period since 1940. [59] Combined with these high temperatures, the humidity was low on a national scale, [59] meaning that Canadian forests were drier and more susceptible to wildfires due to the lack of water vapor in the air. Wildfires are unplanned and uncontrolled fires that occur in wildland vegetation. [60] Multiple wildfires occurred throughout Canada during this period. Across May and June 2023, over 32 million acres of Canadian land was burned, [59] producing immense amounts of smoke. Wildfire smoke can contain a number of air pollutants including fine particulate matter (PM2.5), carbon monoxide, nitrogen oxides, and volatile organic compounds. [62] Of these, PM2.5 is of particular concern for air quality and human health impacts. On June 1st, a lightning strike ignited a wildfire in Quebec Province that grew rapidly due to these dry conditions, continuous southeasterly winds, [59] and unusually high temperatures and drought. [60] This particular wildfire generated smoke and particulate matter that subsequently impacted New Jersey.

Figure 8. Smoke billows from wildfires in Quebec Province in June 2023. [European Union, Copernicus Sentinel-2 imagery]

The wildfire smoke was carried to New Jersey in two separate events in early and late June. These winds were caused by a prevalent low-pressure system over Nova Scotia [64] generating counterclockwise winds that broadly moved the smoke from Canada south into the U.S. and the New Jersey region. Air north of Nova Scotia was transported westward, picking up smoke from the fires in Quebec. Continuing the counterclockwise rotation, the



AQI Number:	Level of Health Concern:	Color:
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151-200	Unhealthy	Red
201-300	Very Unhealthy	Purple
301-500	Hazardous	Maroon

Figure 8. PM2.5 air quality index (AQI) for June 7, 2023 (circles) along with interpolated AQI values resulting primarily from the Canadian wildfires (shaded region). Air quality hazard ranges and related colors are provided in the table. Note the plume of more hazardous air quality arriving in the U.S. Mid-Atlantic from the north out of Canada. Reproduced from airnow.gov. [63]

smoky air mass moved south, covering much of the northeast United States. Figure 8 shows the extent of the decreased air quality from the associated wildfire smoke on June 7, 2023. [63]

How Did the Fires Affect New Jersey?

The U.S. Environmental Protection Agency (EPA) collects air quality data across the U.S., including multiple sites throughout New Jersey. [65] These sites measure multiple pollutants including PM2.5 and produce summary air quality indices (AQI) for each station that ranges from 0 (good) to 500 (hazardous) for easy interpretation. [66] AQI can be calculated using multiple pollutants or specific to particular pollutant (e.g., just PM2.5).

Figure 9 presents the maximum PM2.5 AQI reported for New Jersey due to the Canadian wildfire smoke on June 7th, using the AQI color hazard category descriptors from Figure 8. The very unhealthy AQI zone was recorded to be greatest around the center latitude of the state and extending to the southwest as far as the mouth of the Delaware River.

The first of the two smoke incidents covered New Jersey from June 6 to June 8 (Figure 9), with the highest average PM2.5 AQI occurring on June 7 close to 200, the "Very Unhealthy" category, and exceeding that mark at some locations. This day, Flemington had the maximum reported PM2.5 AQI for New Jersey at 237; note this station is not represented in the Figure 9 airnow.gov map, but its data are accessible through the EPA.

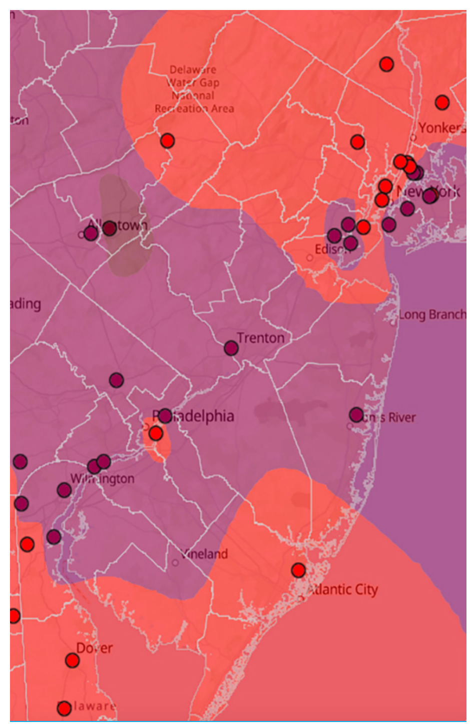


Figure 9. PM2.5 air quality index for June 7, 2023 (circles) along with interpolated AQI values zoomed in to the New Jersey region. Symbols and related colors are as in Figure 8. Reproduced from airnow.gov. Note that not all EPA sites used in analysis are represented in airnow.gov. [63]

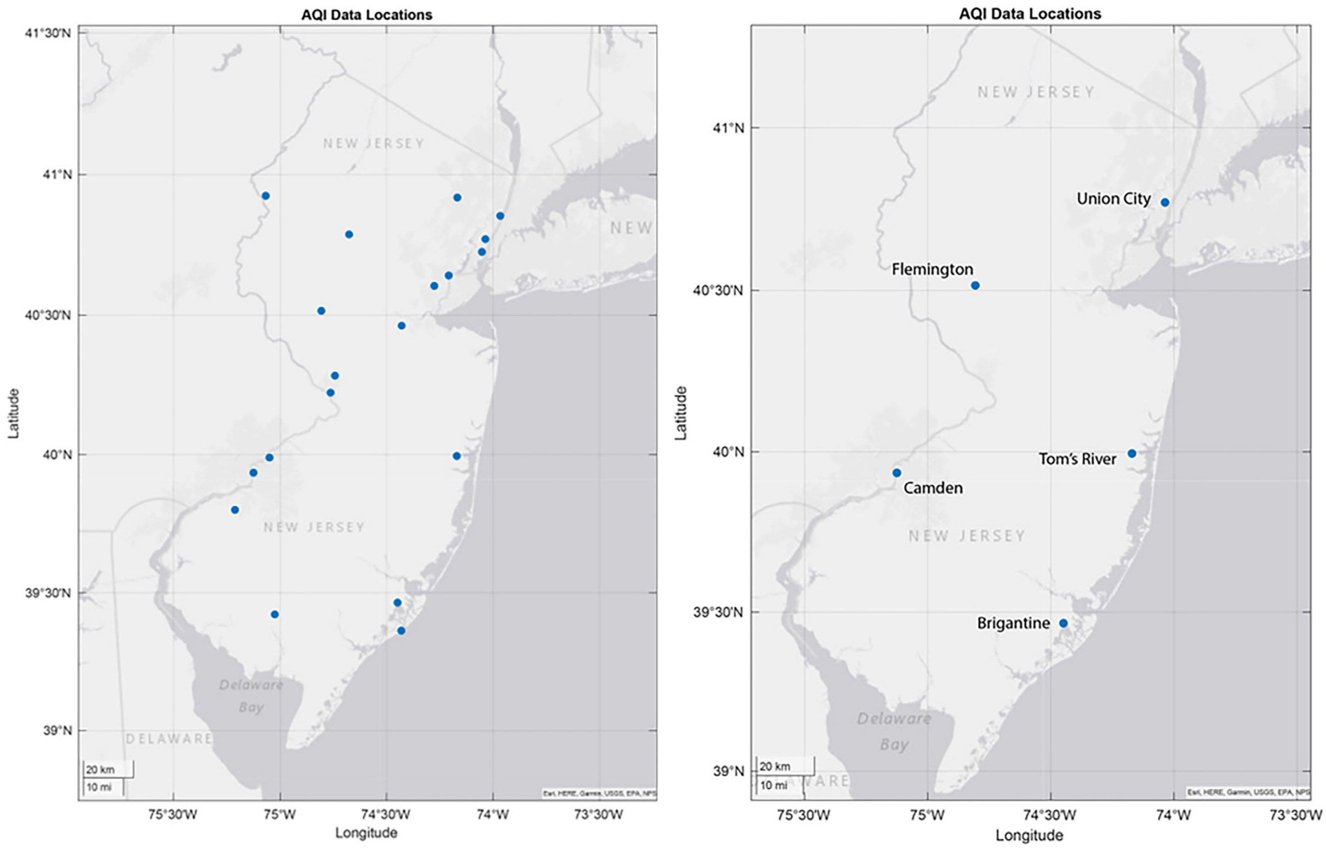


Figure 10. Location of U.S. Environmental Protection Agency air quality stations in New Jersey. The subset of PM2.5 air quality sensors in New Jersey used to analyze regional differences in air quality throughout the month of June 2023. Continuous data from sites in the Right Panel are used in the analysis presented in Figure 11 to present a regional description of air quality changes throughout June 2023. Note the northwest portion of the state is not represented due to a lack of continuous PM2.5 data. While many sensors tracked multiple air pollutants, only PM2.5 was analyzed as a direct consequence of wildfire smoke.

Additionally, northwest New Jersey is not well represented in the Figure 11 (next page) analysis due to a lack of air quality stations and continuous AQI data in that region. The second wildfire smoke event occurred between June 28 and July 1 with a peak average PM2.5 AQI around 150. Note that this analysis only considers AQI calculated using PM2.5, with the assumption that the large changes in PM2.5 can be attributed to the influx of wildfire smoke. Other pollutants, such as ozone, were not analyzed as a cursory overview did not show a noticeable trend with the wildfire smoke episodes in New Jersey.

Regional Analysis

As seen in Figure 11, the five stations (Figure 10) observed had a higher AQI around June 7th and June 29th. During the June 7th episode, Flemington had the worst air quality while Union City had the lowest AQI, the latter indicating better air quality than the other stations but still considered unhealthy. On June 29th, Camden experienced the highest AQI while coastal Brigantine had the lowest. However, Union City and Flemington had a comparably delayed response whereby their worst air quality for this event was on June 30th, at near "unhealthy" levels compared to other locations. Overall, the Canadian wildfire smoke affected most regions in New Jesey similarly, causing broadly "unhealthy" to "very unhealthy" air quality around June 7th and "unhealthy for sensitive groups" (e.g., residents with asthma) to "unhealthy" around June 29th. Another day to note, on June 2nd, the Brigantine station registered a higher AQI than the rest of the sites due to smoke from the Allen Road wildfire in Bass River Township that burned 5,474 acres, [67,68] leading to locally degraded air quality.

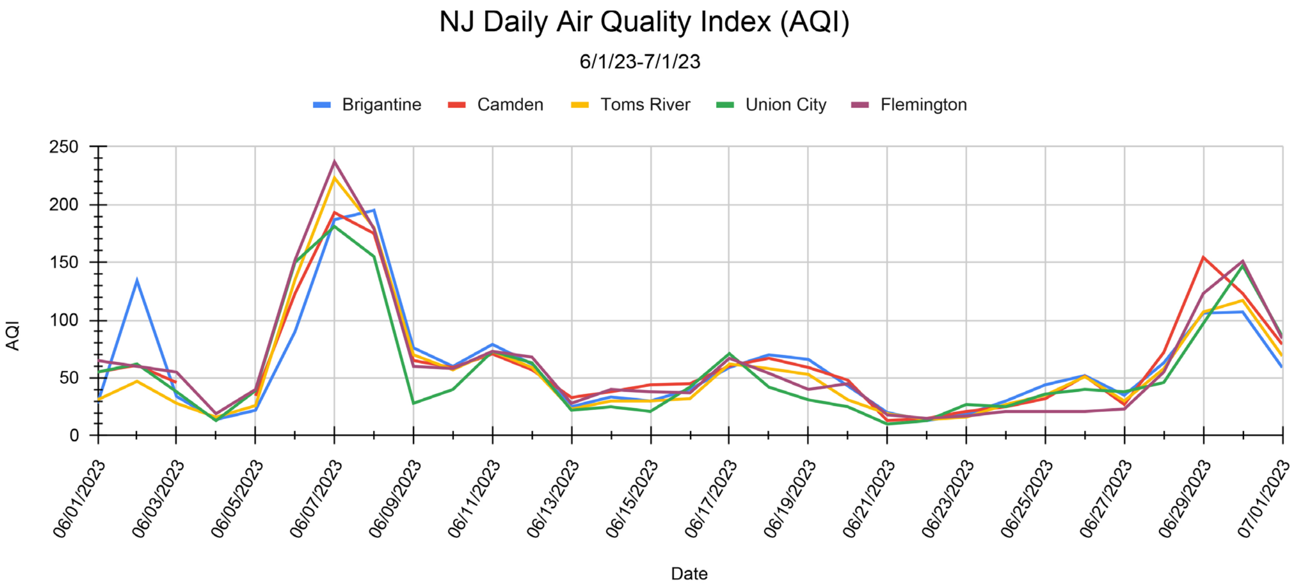


Figure 11. The Air Quality Index (AQI) for five New Jersey EPA stations corresponding to the subset in Figure 10 from June 1, 2023 to July 1, 2023.

Wildfire Effects on Human Health

The June 2023 Canadian wildfires affected more than 75 million people in the U.S., creating unhealthy and hazardous air quality. [69] The PM2.5 particles created by the wildfires were of primary concern to human health as they are more concentrated and more toxic to the lungs than ambient particulate matter. [70] These particles, which are less than ⅓ the diameter of an average human hair, can lodge deep inside the lungs, possibly triggering asthma attacks, heart attacks, strokes, and possible mortality. [71] According to Johnston et al. (2012), [62] 260,000–600,000 deaths worldwide are caused by landscape fire smoke annually. During the 19 days that the Canadian wildfire smoke covered part of the U.S., emergency department visits for asthma were 17% higher than expected across the U.S. [72]

Carbon monoxide (CO) exposure due to wildfires poses another risk to human health. While CO concentrations in wildfire smoke are not large enough to cause harm to the general public, firefighters and others near the fires can be at risk, resulting in dizziness, disorientation, headaches, and visual impairments.[73,74]

Black carbon (BC) is also emitted from wildfires. BC from wildfires, commonly known as soot, is an aerosol and component of PM2.5 formed by the incomplete combustion of wood. [75] BC in the troposphere, the bottom layer of the atmosphere containing Earth's surface, causes the air to warm and has a strong effect on climate warming. [76] Black carbon has been found to cause damages in vascular function, cardiovascular mortality, and premature death. [77,78]

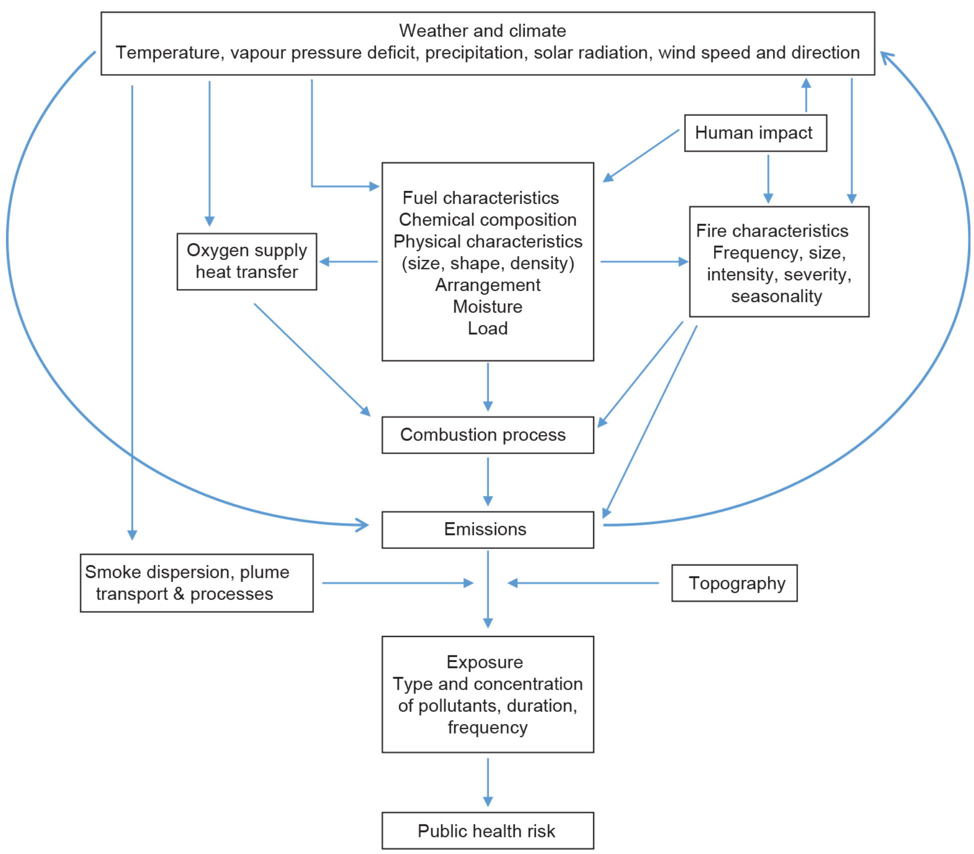
As climate change is likely to increase the intensity and frequency of wildfires, these risks to human health will likely also increase. [24]

Wildfires and Climate

About 85% of wildfires in the United States are caused by anthropogenic actions, including leaving campfires unattended, burning debris, improper disposal of cigarettes, incorrect use of equipment, and deliberate acts of arson.[80] In Canada, however, approximately half of wildfires are caused by lightning strikes, accounting for 90% of total area burned. [81] The other half is caused by human activity, but only accounts for 10% of burned area. [81] As mentioned previously, not only do wildfires produce particulate matter, but they also release CO_2 and other greenhouse gases such a methane and nitrous oxides. The Canadian wildfires that started in May emitted about 480 megatons of carbon. [82] These carbon emissions contribute to the greenhouse effect, increasing climate warming and, in turn, leading to stronger and more frequent wildfires in a feedback loop. [24,83] The loss of forestland also reduces potential future carbon sequestration, [84] further exacerbating greenhouse gas emissions and climate change.

After ignition, the extent of the fire depends on fuel availability and distribution, forest composition and structure, temperature, humidity, and wind speed. [85] Each of these factors are affected by climate change, causing widespread wildfire

Figure 12. Reproduced from Reisen et al. (2015). [79] Interaction of physical factors that influence wildfires, smoke production, and human exposure.



As climate change continues and temperatures increase, wildfires are expected to increase in size and frequency.

events to increase in intensity and frequency. [86] Changes in climate can affect aridity and heat, which can result in increased fire activity and burned area at the sub-annual scale. [87] Warmer temperatures cause greater water evaporation and transpiration from plants and soil, desiccating trees, bushes, and grass, turning dead leaves and branches into fuel. Following this process, 63% of the variability in the Canada-wide annual area burned from 1959 to 1999 was affected by summer available moisture. [88] As climate change continues and temperatures increase, wildfires will likely continue to increase in size and frequency, as they have in the past few decades,[86,89] resulting in continued hazardous air quality episodes globally and a loss of more forestland area. Projections of air pollution-related U.S. mortality by 2100 with very high warming of 9–14 °F by 2100 suggest an increase of 25,000 relative to 2000. [24] However, estimates in future mortality rates could underestimate the effects of a rapid increase in wildfire smoke and PM2.5 from a warmer climate. [24]

In addition to forests being burned, climate change reduces the resiliency of forested regions. Forest regeneration (regrowth and seeding after fires) following wildfires has greatly declined in the 21st century. [90] For example, at a number of sites in the Rocky Mountains, forest regeneration has decreased substantially following wildfires at the start of the 21st century compared to the end of the 20th century due to warmer and drier mean conditions. [90] A study conducted on post-fire forest regeneration in Quebec found that the regenerations of black spruce (the most common tree species in eastern Canada) is greatly hindered after severe wildfires (i.e., low tree density and limited seed production), especially when these fires reach the canopy and destroy seeds. [91] Extrapolating these results, it is likely that a potential increase in wildfire frequency and severity with climate change could further affect regeneration across a wider range of forests and tree species. However, wildfire impacts tend to differ based on severity, forest type and composition, forest age, and disturbance histories, which can affect future wildfire recovery efforts and may necessitate more localized study.

Around 40% of New Jersey land area is covered by forests [92] and experiences multiple wildfires each year. Unlike Canada, most (nearly 99%) of New Jersey's wildfires are due to anthropogenic causes.[68] 2023 was considered "an abnormally active fire year" by the NJDEP with wildfires burning over 18,000 acres. [93] With more people moving into rural areas due to New Jersey's high population density and housing pressure in urban areas, more human-caused wildfires are likely to occur. [94] In addition to the potential of more anthropogenic wildfires, severe weather and hot and/or dry conditions are increasing, putting more people at risk to wildfire exposure. [85,94]

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Appendix A

Table A1. Publicly Available Datasets used in this Report and the URLs for Access

Data Type	Organization	Data Source URL
Atmospheric Carbon Dioxide Concentrations Measured at Mauna Loa	NOAA Global Monitoring Laboratory	https://gml.noaa.gov/ccgg/trends/
Global Land-Ocean Temperature Index Anomalies	NASA's Goddard Institute for Space Studies; NASA Global Climate Change Vital Signs of the Planet	https://climate.nasa.gov/vital-signs/global-temperature/
New Jersey Climate Data	Office of the New Jersey State Climatologist	https://njclimate.org
Atlantic City Relative Sea Level Rise Trend	NOAA Tides and Currents	https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8534720
Projected Changes in Extreme 24h Rainfall Events	NJ Department of Environmental Protection; Northeast Regional Climate Center, Cornell University	https://www.nj.gov/dep/dsr/publications/projected-changes-rainfall-model.pdf
Parameter-elevation Regressions on Independent Slopes Model	Oregon State University	https://prism.oregonstate.edu
$PM_{2.5}$ Air Quality Index Map	U.S. EPA	https://www.airnow.gov/
Air Quality Data from Outdoor Monitors	U.S. EPA	https://www.epa.gov/outdoor-air-quality-data