Climate Change in New Jersey: Temperature, Precipitation, Extreme Events, and Sea-Level Rise

Background

There is good evidence that as a result of increasing atmospheric carbon dioxide (CO_2) and other climate pollutants from human activities, as well as natural climate variability, the Earth's surface has warmed by about 1.8 degrees Fahrenheit (°F; 1 degree Celsius (°C)) from 1901 to 2016.[1] These increased temperatures have contributed to an overall increase in precipitation, intensity of weather events, and rise in sea level.[1] Continued greenhouse gas emissions at or above current rates are expected to cause further warming and induce many changes in the global climate system during the 21st century that will very likely be larger than those observed during the 20th century.[1]

Regional assessments predict that the Northeastern United States, including New Jersey, will be especially vulnerable to the impacts of climate change and the potential ecological, economic, and public health impacts to New Jersey could be devastating.[2] The U.S. National Climate Assessment reports that temperatures in the Northeast region increased by almost 2°F (0.16°F per decade) while precipitation increased by over 10% or 5 inches (roughly 0.4 inches per decade) between 1895 and 2011.[3] From 1911 to 2019, sea level rose approximately 17.6 inches in New Jersey, compared to a 7.6-inch rise in the global mean sea level.[4] Extreme precipitation has increased more in the Northeast than in any other region in the U.S.[3] From 1958 to 2010, the region received more than a 70% increase in the amount of precipitation falling in very heavy events, which are defined as the heaviest 1% of all daily events.[3] In terms of projected climate change for the mid-century, much of the southern portion of the region (including Maryland, Delaware, New Jersey and West Virginia) will experience more days per year with temperatures above 90°F compared to the end of the last century.[3]

Regional impacts are unlikely to be completely avoided, despite the implementation of measures to further curb future emissions, due to the momentum generated by past/current activities.[2] In January 2016, the NJDEP Science Advisory Board's (SAB) Climate and Atmospheric Sciences Standing Committee responded to a series of questions pertaining to which aspects of climate change are considered inevitable and how New Jersey can best adapt.[5] Among the concerns presented by this Committee, sea level rise and the resultant impacts on coastal flooding and erosion were considered among the most significant outcomes of climate change that will require adaptation. In a subsequent May 2020 report, the same Committee responded to questions relating climate to drought, streamflow, and flooding as influenced by weather patterns and expected climate change.[6] Of note, there is a reported potential for increased annual streamflow in the Delaware River Basin and an increased supply of water to reservoirs earlier in the year.[7] The Committee also presented the trend of increasing extreme precipitation events and the need to incorporate this into hydrologic infrastructure planning.[8]

It is anticipated that the frequency and/or intensity of precipitation events will increase or show more variable distribution (temporally and spatially) due to climate change (e.g., increasing precipitation in certain seasons, droughts in other seasons, more extreme occurrences of both, etc.). For example, precipitation (as rain, rather than snow) and runoff are likely to increase in the Northeast in both the winter and spring.[2] In such areas where total precipitation is expected to increase the most, there would also be the largest increase in heavy precipitation events.[2] Observations indicate a transition to more rain and less snow, as well as snow pack reductions in the Northeast since 1970.[2] Peak streamflow in the Northeast now begins 7 to 14 days earlier than in the past.[2] Earlier runoff in the absence of increased precipitation produces extended low flow periods in summer, higher water temperatures, and reduced soil moisture in the summer and fall, which due to less water availability stress human and environmental systems.[2] According to data provided by the state climatologist, New Jersey is getting wetter.[9] Annual precipitation averaged over the last 10 year average (2010-2019) increased 7.9% over the long-term average (1895-2019).[8]

Despite a trend toward more precipitation since 1970, the Northeast is experiencing longer periods without rainfall during longer growing seasons.[2] The result is a drier growing season, especially during the summer months, when temperatures and evapotranspiration are highest. This summer drying tendency is exacerbated by reduced recharge from spring snowmelt. New Jersey has a comprehensive drought monitoring system, which allows assessment of drought conditions on a regular basis.[10] Since 2000 in New Jersey, a notable drought episode occurred in 2001-2002, with drought watches declared for short periods of time in 2005, 2006, 2010, and 2015.[11] New Jersey again experienced drought conditions from 2016 through 2017 for the northeastern, northwestern, and central drinking water supply regions in NJ.[10] It is anticipated that droughts lasting up to six months, may increase in frequency in the Northeast under a low emissions scenario and will increase under a high emissions scenario.[2]

Sea-level rise is documented throughout the world, and it is an indicator of the Earth's increasing temperature. Globally, sea level rise occurs due to two main reasons: ice melting on land (leading to increased water volume) and the expansion of the ocean as it warms. Locally, there are also influences on sea level that are not related to climate change including subsidence from natural sediment compaction, groundwater withdrawals, and isostatic rebound, the adjustment of land surface to the loss of ice sheets at the end of the last interglacial period.

Consistent with the observed trend, sea-level rise will lead to more frequent and extensive coastal flooding. By the end of the 21st century, several Northeastern U.S. states will have sizable portions of their projected populations at risk of adverse effects from sea-level rise.[12] One model estimates that by 2100 approximately 309,000 NJ residents could be impacted as a result of a 0.9 meter rise in sea level and over 827,000 residents impacted by a rise of 1.8 meters based on future population growth estimates.[12] These scenarios would place NJ with the fourth largest projected population in the country at risk of impacts from a 0.9 meter sea-level rise, and the fifth largest projected population at risk of impacts from a 1.8 meter sea-level rise.[12] Warming ocean waters also have the potential to strengthen storms, with more intense impacts likely to affect the Northeast than those seen during Superstorm Sandy in 2012.[13]

Other factors can also influence regional and local temperature and climate besides greenhouse gas emissions. One significant factor is increasing urbanization. The large expanses of asphalt and concrete associated with urban and suburban sprawl, and the resultant loss of forests, fields, and other open space, are exacerbating a warming effect. This effect is especially pronounced in densely populated urban areas, which can exhibit what is called the heat island effect.[14]

As illustrated in the figures and table below, long-term data for New Jersey document an increase in average temperature, precipitation, and sea level that are consistent with observed and predicted global trends.

Status and Trends

Temperature

The Office of the New Jersey State Climatologist at Rutgers University has gathered and quality-checked statewide temperature and precipitation records back to 1895. These data show a statistically significant rise in average statewide temperature over the last 125 years (Kendall Tau = 0.502; $p<0.05$). The departure from normal has also significantly increased over the period indicating that average annual temperatures are consistently greater than the longer-term average. The State mean annual temperature from 1895 to 2019 is shown in Figure 1.

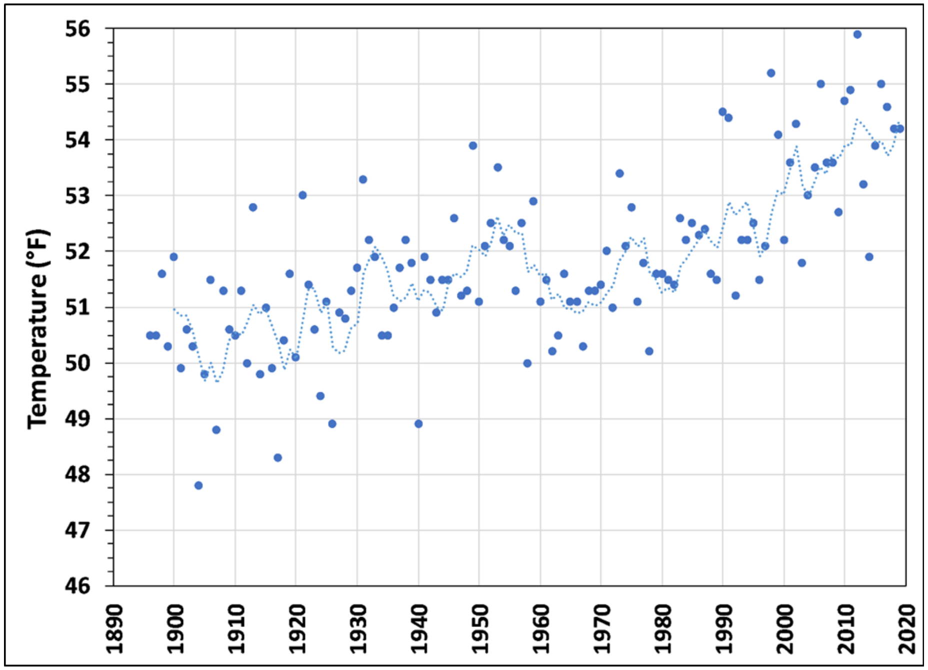


Figure 1: New Jersey 12-Month Average Air Temperature from 1895 to 2019. Points represent the average annual temperature and the dashed line represents a five-year average of those points. Data from the Office of the New Jersey State Climatologist 2020.[13]

Jersey City (Shutterstock, 2019)

One important aspect of temperature is the effect it has on heating and cooling needs, which can be expressed by translating temperature into heating degree days or cooling degree days. Heating degree days are a measure of how much (in degrees) and for how long (in days) the outside air temperature was below 65°F, thereby requiring heating. Heating degree days are calculated by multiplying the number of degrees that each day's average temperature is below 65°F by the number of days when the temperature is below 65°F. Cooling degree days are the number of degrees that each day's average temperature is above 65°F, multiplied by the number of days above 65°F. More heating and cooling degree days generally translate to more energy expenditure for heating and cooling, respectively. However, other factors, such as the amount of insulation, the amount of space that is heated or cooled, and the efficiency of the heating or cooling equipment also play a role in heating and cooling energy requirements.

Yearly total heating and cooling degree days were calculated based on yearly average temperatures for each month for the years between 1895 and 2019, as provided by the State Climatologist (see Figures 2 and 3, respectively). The long-term trend indicates that temperatures have shifted such that relatively fewer days are spent on heating (i.e., warmer temperatures) and relatively more days are spent on cooling (i.e., warmer temperatures). Statistical analysis using Kendall Tau Rank Correlation shows both data sets have significant trends, positive in the case of the cooling degree days (Kendal tau = 0.415, $p < 0.0001$), and negative for the heating degree days (Kendal tau = -0.422, $p < 0.0001$), indicating that both the winters and summers have become warmer in New Jersey during this period.

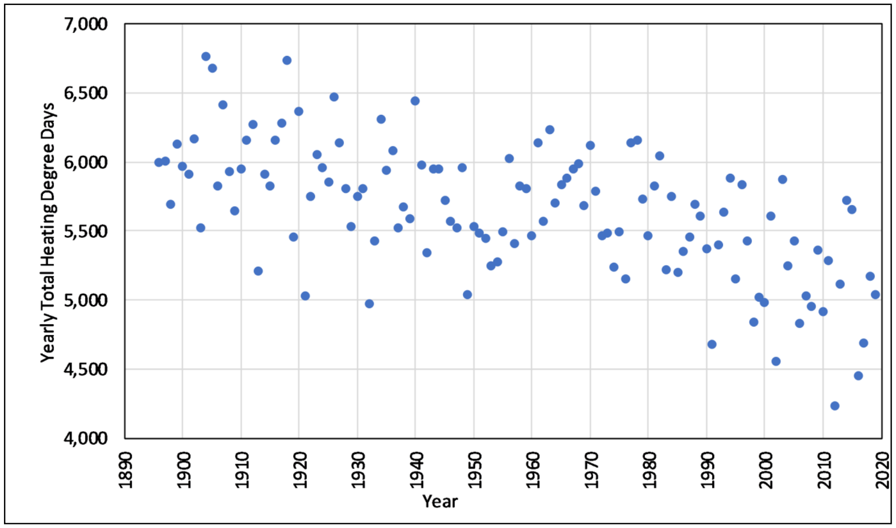


Figure 2: Yearly total heating degree days, NJ; computed from statewide monthly average temperatures below 65°F (1895-2019).[13]

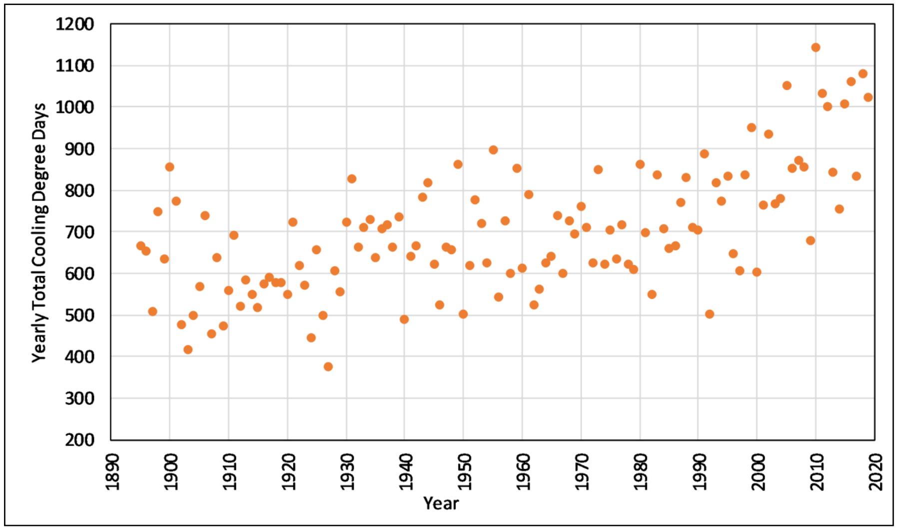


Figure 3: Yearly total cooling degree days, NJ; computed from statewide monthly average temperatures above 65°F (1895-2019).[13]

Precipitation

Total annual precipitation data are also available from the State Climatologist (see Figure 4).[7] Analysis of the data shows a statistically weak increase in total annual precipitation since 1895 (Kendall Tau = 0.092; p=0.13). However, five-year and ten-year averages of annual precipitation evaluated over the same 125-year period show strong statistical increases (Kendall Tau = 0.206; p<0.05, and Kendall Tau = 0.303, p<0.05, respectively). These period averages account for the interannual variability found in precipitation patterns.

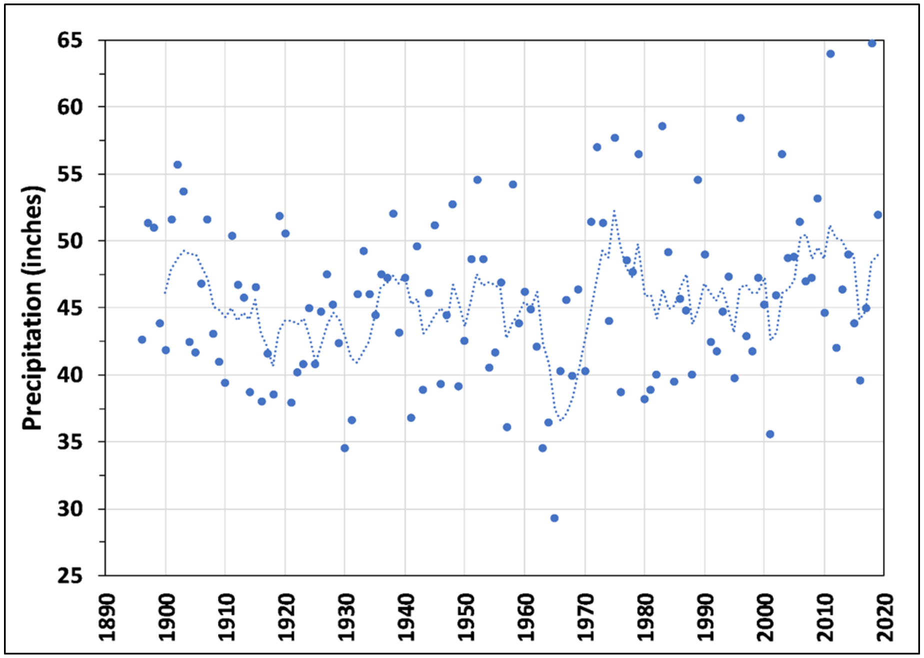


Figure 4: Statewide Annual Precipitation in Inches (1895 – 2019). Points represent the statewide annual precipitation and the dashed line represents a five-year average of the data based on year of interest and the previous four years. Data acquired from the Office of the New Jersey State Climatologist 2020.[7]

On average, New Jersey receives 46 inches of precipitation annually.[7] There is a north to south gradient for precipitation where the north to central portion of the state averages 49 inches of precipitation annually while the coastal and southern regions average 44 and 45 inches, respectively.[7] New Jersey is becoming wetter in recent decades. In the northern part of New Jersey, the average precipitation increased over 5 inches from the 1895-1970 period to the 1971-2000 period.[7] In southern New Jersey, the average precipitation increased about 2 inches when comparing the same periods.[7] To date, 2018 was the wettest year on record with a total of approximately 65 inches of precipitation.[7]

Although increased precipitation is projected for New Jersey's future climate, there is considerable uncertainty with respect to the magnitude of change from the baseline, as well as the seasonality of the change, both of which remain active areas of research.

Extreme Events

A "Climate Extreme" is the occurrence of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of that variable.[16] Since 1998, the State has experienced a string of extreme events including Hurricane/Superstorm Sandy, which struck New Jersey in October 2012.[5] It is the most notable in a line of recent weather and climate extremes including:

- The ten warmest calendar years on record have occurred since 1990 while the ten coldest years all occurred before 1940.[15]
- Eight of the top ten warmest summers have occurred since 1999 based on the period of 1895 to the present, with 2016 being the fourth hottest summer on record.[17]
- The warmest year on record occurred in 2012 when the average annual temperature was 4.1°F (2.3°C) above the long-term average and 3.0°F (1.7°C) above the 30-year normal.[15]
- During the 12-month period from October 2015 to September 2016, New Jersey experienced the 9th driest March and its 8th driest August in the last twenty-nine years.[18]

- Four of the top ten snowiest Januarys since 1905 have occurred since 1996.[19]
- Major floods (those that have caused extensive inundation of structures and roads, significant evacuations of people, and/or transfer of property to higher elevations[20]) have occurred in New Jersey in recent years, including 2004, 2005, 2006, 2007, 2010, 2011, and 2016.[21]
- In the Northeast, 10-year 24-hour extreme precipitation events have increased by over 130 percent from 1950 to 2017.[22]

While increasing variability and extremes are expected in the future, the nature and magnitudes of the extremes still represent an area of great uncertainty.

Sea Level

Tide gauge data made available by the National Oceanic and Atmospheric Administration (NOAA) show that the sea level at the New Jersey coast sites of Atlantic City, Cape May, and Sandy Hook has risen at a rate of approximately 4 millimeters per year (mm/yr) (0.157 in/yr) since recording began in the early- (for Atlantic City and Sandy Hook) to mid-1900s (for Cape May). Research completed for the DEP shows that the pre-anthropogenic sea level rise in New Jersey was approximately 2 mm/yr (0.079 in/yr), due to geological factors.[24] This suggests that the anthropogenic contribution to the recent higher rate of rise is approximately 2 mm/yr (0.079 in/yr), approximately one-half of the total observed rate of rise, which is in line with recent estimates of the global rate. Some of the anthropogenic rise is due to land subsidence caused by groundwater withdrawal and past glacial retreat; with groundwater withdrawal suspected of being especially influential at the Atlantic City site.

Long-term (for years 2050 and 2100) projections of sea level rise for New Jersey from the New Jersey Climate Alliance's Science and Technical Advisory Panel (STAP), including estimates based on low, moderate, and high emissions for 2100, are shown in Table 1.[4] For the central estimates in the table, there is a 50% probability that New Jersey sea level rise will meet or exceed the given values. For the estimates in the likely range, there is a 66% probability that sea level rise will be between the values given in each range. The STAP report recommends that practitioners use a range of estimates due to the array of exposures and vulnerabilities within the state. The projections through 2050 are not separated into low, moderate, and high projections because differences in sea-level rise projections between emissions scenarios are minor in the first half of the century. Estimates presented are based on methodologies from Kopp et al. (2019).[4]

Table 1. Sea-level Rise Projections (feet above year 2000 average sea level) for New Jersey From 2030 to 2150 Under Low, Moderate, and High Emissions Scenarios. The likely range represents the range of levels between which there is 66% chance that sea-level rise will occur. Table modified from Kopp et al. 2019.

	Chance SLR Exceeds	2030	2050	2070 Emissions			2100 Emissions			2150 Emissions		
				Low	Mod.	High	Low	Mod.	High	Low	Mod.	High
Low End	*> 95% chance*	*0.3*	*0.7*	*0.9*	*1.0*	*1.1*	*1.0*	*1.3*	*1.5*	*1.3*	*2.1*	*2.9*
Likely Range	*> 83% chance*	*0.5*	*0.9*	*1.3*	*1.4*	*1.5*	*1.7*	*2.0*	*2.3*	*2.4*	*3.1*	*3.8*
	~ 50 % chance	*0.8*	*1.4*	*1.9*	*2.2*	*2.4*	*2.8*	*3.3*	*3.9*	*4.2*	*5.2*	*6.2*
	< 17% chance	*1.1*	*2.1*	*2.7*	*3.1*	*3.5*	*3.9*	*5.1*	*6.3*	*6.3*	*8.3*	*10.3*
High End	*< 5% chance*	*1.3*	*2.6*	*3.2*	*3.8*	*4.4*	*5.0*	*6.9*	*8.8*	*8.0*	*13.8*	*19.6*

*2010 (2001-2019 average) Observed = 0.2 ft

Notes: All values are 19-year means and are measured with respect to a 1991-2009 baseline. Projections are 19-year averages based on Kopp et al. (2014), Rasmussen et al. (2018), and Bamber et al. (2019). Moderate (Mod.) emissions are interpolated between the high and low emissions scenarios. Rows correspond to different projection probabilities. For example, the 'Likely Range' rows correspond to at least a 2-in-3 (66-100% chance) chance of sea-level rise from the relevant projections considered, consistent with the terms used by the Intergovernmental Panel on Climate Change (Mastrandrea et al. 2010)*. Note alternative methods may yield higher or lower estimates of the chances of low-end and high-end outcomes.*

Rutgers University has developed an interactive online mapping tool called NJ Flood Mapper (https://www.njfloodmapper.org) to assist local communities in making decisions concerning flooding hazards and sea level rise.

According to the National Climate Assessment (2014) report, sea-level rise of two feet, without any changes in storms, would more than triple the frequency of dangerous coastal flooding throughout most of the Northeast.[2] New Jersey is already experiencing tidal flooding on sunny days, even in the absence of precipitation events. The occurrence of high tide flooding has increased in recent years.[4] In Atlantic City, New Jersey, the frequency of tidal flooding events has increased from an average of less than one event per year in the 1950s to an average of eight per year from 2007 to 2016.[4] Under a moderate emissions scenario, by the year 2100 it is extremely likely (>95% chance) that Atlantic City will experience high-tide flooding at least 95 days a year, and likely (50% chance) that Atlantic City will experience high-tide flooding 355 days per year.[4] In addition to flooding from rising sea levels, under a high emissions scenario modeling has predicted that the occurrence of tropical cyclones along the Mid-Atlantic coast will increase such that the historical 100-year flood level will occur as often as annually by 2100.[26]

Outlook and Implications

Rising temperatures are expected to have human health impacts, including increased heat stress,[1] increased levels of ground-level ozone,[27] accelerated secondary fine particle formation,[1] and facilitation of the northern spread of insects carrying arthropod-borne viruses, particularly due to increased temperatures in the winter season.[28]

Heat stress is of special concern for vulnerable urban populations. Climate models predict an increase in the number of days per year with temperatures above 90°F in the New York City metro area, with a potentially significant impact on human health due to heat stress.[29] By 2080, the number of days above 90°F are projected to range from 24 (10th percentile) to 75 (90th percentile) days compared to the 1971-2000 baseline of 10 days.[30] The frequency, duration, maximum temperature, and intensity of heat waves are also projected to increase through the 21st century.

Natural ecosystems in New Jersey would also be impacted by warmer temperatures and associated changes in the water cycle. These changes could lead to loss of critical habitat, further stresses on some already threatened and endangered species, impacts on water supply, agriculture, and fisheries, more intense rain events, more frequent periods of extended dryness, and continued increases in fires, pests, disease pathogens, and invasive weed species.[31,32]

Sea-level rise is a major concern for New Jersey. Sea level in the Northeastern region is projected to rise more than the global average.[26] The State is especially vulnerable to significant impacts due to geologic subsidence, the topography of its coastline, current coastal erosion, and a high density of coastal development.[33] A sea-level rise in line with median projections would threaten much of New Jersey's coastlines. By the year 2050, it is likely (>50% chance) that Atlantic City will experience high-tide flooding at least 120 days per year.[4] These effects will be magnified during storm events, increasing the severity of storm-related flooding and associated erosion in coastal and bay areas. Atlantic City is predicted to experience floods as severe as those that today happen only once a century, increasing to every year or two by the end of the century.[26,34] In addition, if measures showing a dramatic increased rate of melting of the Greenland ice sheet[35,36] are substantiated by further data, and if the melting continues at this rate or accelerates further, the rate of sea-level rise throughout the world will increase, and the severity and frequency of coastal flooding in New Jersey will be even greater.

A separate issue related to climate change that will impact the State is ocean acidification. The associated risks to NJ's waters and recommendations for mitigation have been explored by the DEP Science Advisory Board's Ocean Acidification Working Group.[37] Although the ocean can act as a buffer for some climate change impacts, higher levels of carbon dioxide in the atmosphere ultimately result in increased acidity of ocean waters.[38] In some sea areas of the world, there has been a 0.1 unit change in pH, which corresponds to a 30% increase in acidity over levels in the mid-eighteenth century.[39] If CO_2 emissions continue at current rates, ocean pH levels are projected to drop another 0.3 to 0.4 pH units by the end of the century to 7.8 or 7.7, resulting in the most acidic ocean conditions that have occurred in the last 20 million years.[40] Increased acidity is expected to challenge the ability of bivalves, lobsters, crabs, sea urchins, plankton, and coral reefs to form shell material.[41] More acidic conditions have also been observed to affect the success of hatching, larval development, organ development, immune response, acid-base regulation, metabolic processes, and olfaction (smell) in calcifying as well as non-calcifying species.[40]

Given the year to year variability (in the frequency and intensity) of nor'easters and hurricanes and their associated storm surges, tracking over long-time scales is necessary before a statistically significant trend can be documented. A shift away from the usual/familiar patterns of climate variability will be bringing changes in many aspects of climate. While it is quite difficult to attribute one particular extreme event, such as a severe hurricane, to human induced climate change rather than natural climate variability, the increased occurrence of such events may be attributed to changes in climate.

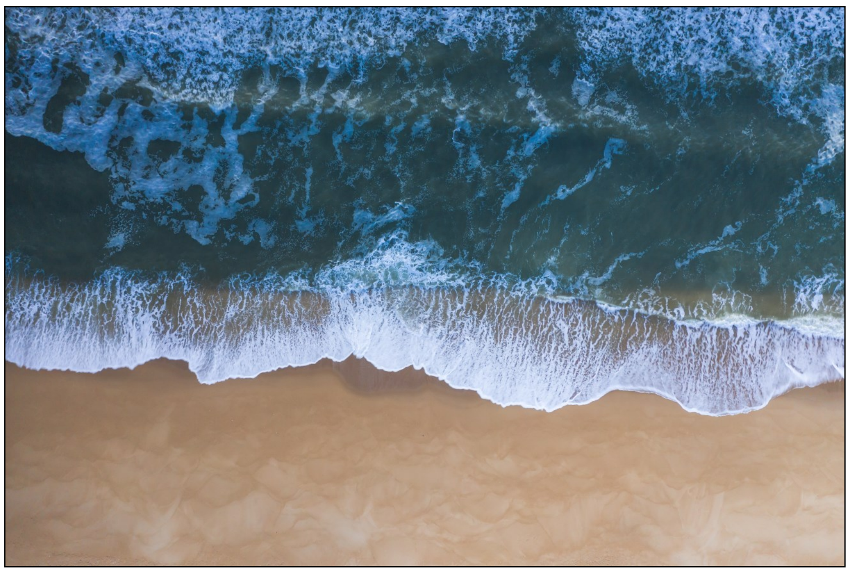
More Information

Additional information on climate change and NJ's response can be found at https://nj.gov/dep/climatechange/.

Indicators and impacts from the Coastal Management Program are available at https://www.nj.gov/dep/cmp/czm_hazards.html.

New Jersey temperature and other climate data are available from the New Jersey State Climatologist. See https://climate.rutgers.edu/stateclim/. In addition, the New Jersey Climate Alliance has compiled a variety of reports specific to the State of New Jersey. Visit https://njadapt.rutgers.edu/ for more information.

For additional information on greenhouse gases and initiatives that are being enacted at the state and federal levels to help mitigate their impacts and encourage renewable energies, see the reports, "Greenhouse Gas Emissions" and "Energy Use and Renewable Energy Sources" in this NJDEP Environmental Trends series.



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