



State of the Climate: New Jersey provides an overview of recent climate events and trends, their impacts, and their implications for the future of New Jersey. The changes that we are experiencing in New Jersey will be examined in the context of human-induced climate change, an important driver of recent and future climate trends.

Because the climate of any locality is influenced by global patterns and trends, the report begins with a discussion of the state of the climate on a global scale. This is followed by an analysis of local climate trends and recent extreme or unusual events and their impacts. Hurricane Sandy is the most noteworthy of these events, with estimated damages of approximately \$50 billion in the region. The implications of future climate change for high-impact events such as Sandy will also be discussed. Much of the concern about future climate change involves its consequences for people, ecosystems, and the natural and built environments. Sidebars in this report discuss selected impacts of climate change on New Jersey's residents and resources.

References and links are provided to direct the reader toward further information about global and local climate trends.



In New Jersey, transportation is the leading cause of greenhouse gas emissions.

GLOBAL CLIMATE

Greenhouse Gases:

Gases present in the atmosphere that have the ability to absorb and emit infrared radiation are called greenhouse gases. Greenhouse gases keep the earth's surface warmer than it would be otherwise by making it harder for the heat energy the earth receives from the sun to escape to outer space. Human activities have raised the concentrations of some of these gases well beyond natural levels. The primary greenhouse gas that humans contribute is carbon dioxide (CO₂), which enters the atmosphere through the burning of fossil fuels and deforestation. Other important greenhouse gases emitted by human activity are nitrous oxide, methane, and chlorofluorocarbons (CFCs).

Measurements of atmospheric concentrations of greenhouse gases are made by the National Oceanic and Atmospheric Administration's (NOAA) Earth System Research Laboratory esrl.noaa.gov/gmd. The atmospheric concentration of CO₂, the greenhouse gas with the largest effect on climate, has been measured continuously since 1958 at Mauna Loa in Hawaii. These measurements show increases in concentrations of CO₂ each year with an acceleration in growth rate over the course of the time series (Figure 1). At the time of this writing, 12-month average concentrations of CO₂ reached a value of 397 parts per million

(ppm), having increased from 315 ppm when direct measurements began in 1958. To put that value in perspective, the analysis of the composition of ancient air bubbles preserved in ice cores indicates that CO₂ concentrations in the 18th century prior to industrialization were between 270 and 280 ppm. Longer ice core records indicate that current CO₂ concentrations are the highest in the past 800,000 years.

Global Temperature:

Global average temperature analyses indicate that 2012 was the eighth or ninth warmest year based on records dating back to the late 19th century. The exact ranking varies slightly depending on which of the four major global temperature compilations is used. In all four compilations, 2012 was 0.25-0.3 °F above the average for the period 1981-2010 (16). Global temperatures have risen approximately 1.5 °F since the late 19th century. In its 2013 report, the Intergovernmental Panel on Climate Change (IPCC) concluded that it is extremely likely (i.e., greater than a 95% probability) that more than half of the warming in the second half of the 20th and early 21st centuries was caused by increasing greenhouse gas concentrations (3). This long-term trend is expected to continue or accelerate throughout the coming decades as greenhouse gas concentrations are projected to increase. Year-to-year variations in global temperature that occur within the long-term warming

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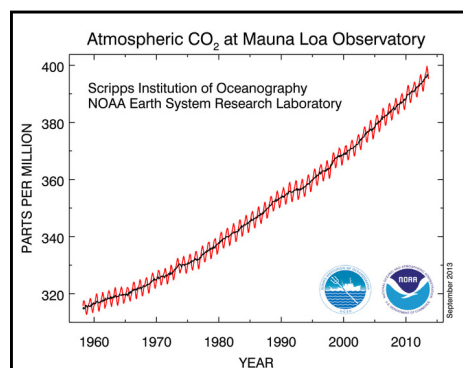


FIGURE 1

Atmospheric carbon dioxide concentrations measured at Mauna Loa. Red: monthly values; Black: 12-month running average.
[NOAA Earth System Research Laboratory]

Long-term monitoring: Sampling for larval fish in Great Bay, New Jersey

trend are primarily a result of natural climate variability. The most influential source of such variability is the El Niño Southern Oscillation (ENSO) phenomenon, which relates to the temperature of the tropical Pacific Ocean. ENSO can be in a warm phase ("El Niño"), a cold phase ("La Niña") or neutral. Warm events are associated with warmer global temperatures and cold events with colder global temperatures due to the breadth of global ocean area that ENSO affects. After beginning 2012 in its cold phase, ENSO transitioned to an incipient warm phase in the middle of the year before returning to a relatively neutral state. Consistent with these variations, global temperature in 2012 was slightly higher than in 2011, when La Niña conditions prevailed, but not as warm as 2010 when ENSO was in its warm phase.

Arctic and Antarctic Sea Ice:

Arctic sea ice extent has declined over the period of modern satellite observations, which dates back to 1979. Each year the areal extent of Arctic sea ice reaches a maximum in March and a minimum in September. In September 2012, Arctic sea ice reached its lowest extent during the satellite record, covering an area of about 1.3 million square miles (sq. mi.) on the 16th. This broke the previous record of just over 1.6 million sq. mi. set in 2007 and was almost 50% lower than the average minimum sea ice extent for the period 1979-2000 (10). Sea ice recovered somewhat in 2013, with a minimum extent of 2.0 million sq. mi. on September 13. This was the sixth lowest on record and well below the 1979-2000 average nsidc.org/arcticseaicenews.



Impacts on Coastal Fisheries

Scientists are unraveling relationships between climate change, water temperature, and distribution, behavior and survival of fish in Northeastern coastal systems. Rutgers faculty research shows hundreds of coastal marine fish and invertebrates are shifting their distributions as temperature changes (12). Waters off the Northeastern U.S. have been warming at close to twice the global rate in recent years; many Mid-Atlantic species have been shifting into the Gulf of Maine. Particularly vulnerable are marine species that spawn either at sea or in fresh water but rely on estuaries for juvenile growth (2). Overwintering survival of juvenile Atlantic croaker, a fish species common to New Jersey waters, has been linked to warmer winters (6). Water temperature data from the late 1980s to early 2000s, collected at Rutgers University Marine Field Station, demonstrate milder winter temperatures in recent years while in this same period larvae of multiple fish species of southern origin became more abundant and those of northern species declined in richness and abundance. Not clear is whether these will be permanent shifts in faunal composition, as the number of southern juveniles did not follow the same pattern. Reduced abundance

of juveniles may result from their inability to successfully overwinter on the East Coast due to low temperature, predation, or food scarcity in their first winter. Rutgers Professor Kenneth Able suggests Atlantic croaker population dynamics in which winter temperature, influenced by climate forcing, controls recruitment to the fishery and subsequent population fluctuations, may be applicable to these other fish species. Graduate student, Jamie Caridad, studies climate change implications of larval fish ingress into Great and Barnegat bays to identify trends in species composition and abundance and shifts in community assemblages. Professor Able notes there are additional complex habitat responses including increased precipitation resulting in runoff and chemical changes in the estuary, variation in larval supply that could result from rising sea level and inability of marshes to naturally migrate inland (1). These factors will continue to have implications for fisheries management. Impacts are already being observed in many important fisheries for New Jersey and the region, landings from the summer flounder fishery have shifted northward as temperatures have warmed, complicating attempts to allocate fishery quota among Mid-Atlantic States (11).



Climate change in polar regions has been especially dramatic.

Many meteorological factors influence the year-to-year fluctuations in Arctic sea ice extent (such as wind direction and strength); however the overall trend in the annual mean Arctic sea ice extent has been downward, with a rate of 185,000 sq. mi. per decade during the period 1979-2012 (3). The thickness and age of Arctic sea ice has also been changing with an increasing tendency towards young and thin ice. Older ice (i.e., four years old or greater) has decreased from 26% of the ice in 1988 to 7% in 2012 (10). In the Antarctic, sea ice extent has been above average, with record high values in the past two years. The upward trend in annual mean Antarctic sea ice extent has been 64,000 sq. mi. per decade, which is only about one-third as large as the Arctic trend (3).

Sea ice is highly reflective, causing it to have a cooling effect on the planet. The melting of sea ice will expose less-reflective ocean waters that can absorb more solar energy and store it as heat rather than reflect the energy directly back to space. As a result, this will lead to further warming, allowing the decline in sea ice extent to have significant impacts on the climate of the entire planet.

snow cover extent averaged 9.5 million sq. mi. in 2012, which is below the 43-year average and the 12th least extensive snow cover on record. Annual mean snow cover has declined since observations began in the late 1960s, but the decrease has been especially rapid in the spring and summer months. Every month from April through August 2012 reported snow cover that was among the four lowest values for that calendar month, with June and July reporting all-time low values.

NEW JERSEY CLIMATE

The Office of the New Jersey State Climatologist njclimate.org, located at Rutgers University, serves as the State's primary resource for statewide weather and climate data. New Jersey climate data are also archived at NOAA's National Climatic Data Center ncdc.noaa.gov.

Temperature:

The statewide average temperature in 2012 was the highest in 118 years of records. The 56.0 °F average for 2012 is 2.8 °F above the 1981-2010 mean. Nine of the ten warmest calendar years on record have occurred since 1990 and the five warmest years have occurred since 1998, consistent with the long-term upward trend of 2.2 °F per century (Figure 2). Abnormal warmth was common through much of the year, with only one month (November) recording temperatures below the 1981-2010 average. The year

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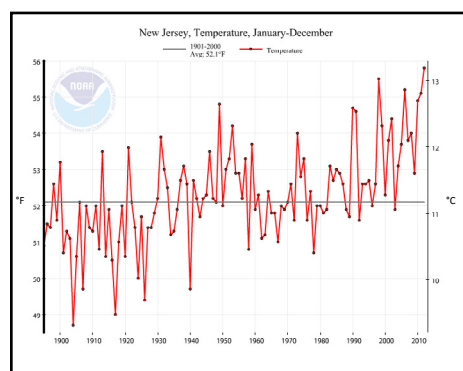


FIGURE 2

New Jersey statewide annual average temperature.
[NOAA National Climatic Data Center]

Northern Hemisphere Snow Cover:

Data compiled at the Rutgers University Global Snow Lab climate.rutgers.edu/snowcover indicates that annual average



Ragweed's season is getting longer and its allergen content increasing with increased emissions of CO₂.

2012 featured the warmest spring (March, April and May) on record and the sixth-warmest summer (June, July and August) on record. Unusual summertime warmth has been noteworthy in recent years, with six of the ten warmest summers on record occurring since 2005. So far in 2013, temperatures have been slightly above the 1981-2010 average, but not as warm as 2012.

The past 25 years have been characterized by many more unusually warm months in New Jersey than unusually cold months. If unusually warm and cold months are defined as the five warmest and coldest, respectively, for each calendar month, the period from 1988-2012 included 32 unusually warm months and only 5 unusually cold months. The disparity has been even greater since 2000, as unusually warm months have outnumbered unusually cold months by 25 to 2. The trend toward higher temperatures is expected to continue in the decades to come as greenhouse gas concentrations continue to increase. Rising temperatures are expected to occur in all seasons, but the trend is likely to be more noticeable in summer when year-to-year variability is smaller. One study has projected that by the middle of the 21st century approximately 70% of summers in this region will be warmer than what would now qualify as the warmest summer on record and that the frequency will rise to 90% by the end of the century (4).

Precipitation:

After the wettest year on record in 2011, precipitation during 2012 was slightly below normal, averaging

Impacts on Public Health

Climate change can have multiple public health impacts ranging from imminent danger and long-term stress from flooding to decreased lung or heart function from increases in particulate matter, to respiratory effects from increases in ozone, carbon dioxide and temperature. Climate change has caused an earlier onset of the spring pollen season in the United States, including birch and oak pollen and increases in ragweed season (2, 17, 19). Rising temperatures and carbon dioxide concentrations also increase pollen production, while the allergen content of ragweed increases with increased concentrations of carbon dioxide (15, 13). An earlier pollen season that is lasting longer in higher latitudes like New Jersey, is putting more people at risk of allergies, including asthma; while allergic reactions to pollen may become more severe as allergen content of pollen increases with increasing CO₂ concentrations. These risks are particularly significant for vulnerable populations such as children, where in New Jersey pollen increases children's asthma hospital admissions (7).

Rutgers University scientists from the

Environmental and Occupational Health Sciences Institute and the Center for Environmental Prediction, have been developing a model to predict pollen emissions, distribution, dispersion and human exposures in a changing climate. Estimates from worldwide birch pollen data predict expected increases in annual pollen production and peak pollen values ranging from 1.3 to 8.0 and 1.1 to 7.3 times higher, respectively, under various emissions scenarios for the years 2020 to 2100 compared to 2000, with the onset and peak date of pollen season advancing two to four weeks earlier (17).

Rutgers Professor Annmarie Carlton has shown a direct relationship between high energy demand days, typically a consequence of high stagnation periods, and increases in both particulate matter and ozone. Expected increases in energy use will undoubtedly result in both increased volatile organic carbons and nitrogen oxides which form ozone and particulate matter. Citing studies demonstrating the link between excess mortality and increases in fine particulates Professor Carlton notes, "Ozone can make you sick, but particulates can kill you."



Heavy precipitation events have increased dramatically in the past two decades.

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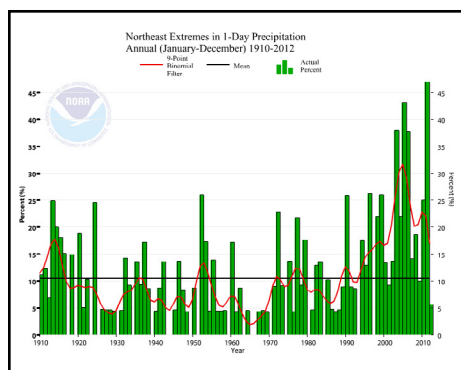


FIGURE 3

Frequency of heavy precipitation events in the northeastern United States.
[NOAA National Climatic Data Center]

43.21" statewide. This was 3.73" below average and ranks as the 8th driest calendar year of the past thirty. But 2012 was only the 47th driest for the entire 118-year period of record, demonstrating how much wetter New Jersey has been in recent decades than earlier in the 20th century. The central coastal area was wettest in 2012, with several stations in Ocean and Burlington Counties receiving more than 53". Western areas of central and southern New Jersey from Mercer to Salem Counties were driest in 2012, with a number of annual totals below 40". On a statewide basis, dry conditions prevailed from January through April followed by a return to near average rainfall from May through September. The end of 2012 was a study in contrasts, with above normal precipitation in October and December bracketing a dry November. So far in 2013, the state experienced its wettest June on record and its second wettest summer following closely on the heels of the wettest summer on record in 2011.

Over the longer term, there has been an upward trend in annual precipitation in New Jersey. Since 1895, annual precipitation has increased at a rate of 4.1 inches (or about 9%) per century. It is important to note, however, that the decade-to-decade variability in annual precipitation is quite large and can overwhelm any long-term trends. Precipitation was well below average during the

drought of the early 1960s, but much wetter conditions prevailed during the 1970s. The last decade has also been unusually wet. The heaviest precipitation amount for six of the twelve calendar months (March, April, June, August, October and December) has occurred since 2003, with August 2011 weighing in as the all-time wettest month since statewide records began in 1895.

Increases in the amount of precipitation falling in heavy precipitation events have been noted throughout the northeastern United States. An index of this quantity is depicted in Figure 3. Heavy precipitation events have increased dramatically in the past two decades, occurring more than twice as often in recent years than during the past century. There is reason to expect that this trend may continue, as the IPCC projects that "(e)xtrême precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases." (3)

Sea Level Rise:

Global sea level rose at an average rate of 0.6 inches per decade during the 20th century, driven primarily by two processes: the thermal expansion of a warming ocean, which makes the same amount of water take up more space, and melting glaciers and ice sheets, which add water to the

FIGURE 5
Satellite image of Hurricane Sandy on
October 28, 2012. [NASA]



ocean. The rate of global sea level rise has increased in recent decades, with an average rate of 1.2 inches per decade since the early 1990s (3). Rates of sea level rise vary globally and sea levels along the New Jersey shore have risen faster than the global average. At Atlantic City, where records extend back to 1912, sea level has risen by an average rate of 1.5 inches per decade over the period of record (Figure 4). The rate of sea level rise is greater along the New Jersey coastal plain because the land is subsiding at the same time that water levels are rising.

A recent study led by Rutgers scientists has projected future rates of sea level rise (9). The projections are expressed as a best estimate and a range to account for uncertainties in future rates of global ocean warming and melting rates for the large ice sheets covering Greenland and Antarctica. (All projections are relative to a 2000 baseline.) By 2030, sea level is projected to rise by 7 to 16 inches, with a best estimate of 10 inches. In 2050, the range is 13 to 28 inches with a best estimate of 18 inches, and by 2100 the range is 30 to 71 inches with a best estimate of 42 inches. Even if the most conservative of these projections materialize, the implications for coastal flooding will be substantial.

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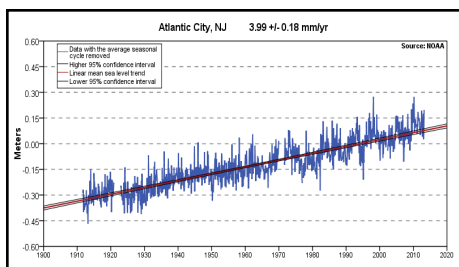


FIGURE 4

Sea level at Atlantic City.
[NOAA National Ocean Service]

Hurricane Sandy:

One of the most extreme meteorological events to affect New Jersey in many years was Hurricane Sandy in October 2012. Sandy was an unusual storm that began as a tropical depression in the Caribbean and developed into a major hurricane before making its first landfall on the south coast of Cuba. After crossing Cuba, Sandy moved into the Bahamas and began a course that took it northeastward, paralleling the coast of the southeastern United States about 350 miles offshore (Figure 5). Sandy began an abrupt left turn while east of Cape Hatteras, with its center driving directly into the southern New Jersey coast near Brigantine Island on the evening of October 29. The presence of a large loop in the jet stream and its accompanying pool of cold air facilitated Sandy's transition from a tropical system to a large and powerful hybrid storm. Sandy's winds were characteristic of a category 1 hurricane but expanded to cover an area that extended from Cape Cod to the southern New Jersey coast. Wind gusts reached or exceeded 90 miles per hour at locations in New Jersey and Long Island, with many stations reporting gusts at or above hurricane force.

The most destructive element of Sandy was the powerful storm surge that was produced by the large area of strong winds and unusual west-northwestward track of the storm.



Hurricane Sandy damage in Mantoloking near Rt 35 Nov. 2, 2012.

The greatest surge affected the areas to the right of storm track, including the central and northern New Jersey coast, Raritan Bay, New York Harbor and adjacent estuaries, and the coast of western Long Island. The storm surge reached 9-10 feet above normal high tide levels in many of these locations, causing extensive damage and loss of life. Numerous homes were destroyed or damaged, and a new inlet was temporarily opened across the Barnegat Peninsula in Mantoloking.

An important question for coastal planners and residents is whether climate change will increase the likelihood of events similar to Sandy. A determination of past changes in tropical cyclone activity in the North Atlantic is complicated by the changes in observing methods that have occurred as new technologies have been introduced. Recent studies find little evidence of an increase in the number of hurricanes and tropical storms in the North Atlantic during the past century, but there is evidence of an increase in the frequency and intensity of intense tropical cyclones during the period since 1970. Projecting future changes in tropical cyclone activity remains an area of active research. Recent studies suggest that the global frequency of tropical cyclones will either decrease or change little as a consequence of global warming. Their average intensity is likely to increase, in terms of

both maximum wind speed and rainfall, and the frequency of the most intense storms is expected to increase (8). Regional projections of tropical cyclone activity cannot be made with great confidence, however, making it difficult to quantify future changes in tropical cyclone risk in New Jersey.

Despite the uncertainties in future changes of tropical cyclone activity, there is high confidence that the impacts of future storms are likely to be more severe because of rising sea levels. Sea level rise will raise the baseline for flooding events, making severe coastal flooding events more frequent in the future. A recent NOAA study projects that the return period for coastal inundation equivalent to that from Sandy would decrease to less than 20 years by the end of the century if sea level rise in New Jersey is at the high end of the expected range (14).

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