



# Climate Change And Delaware

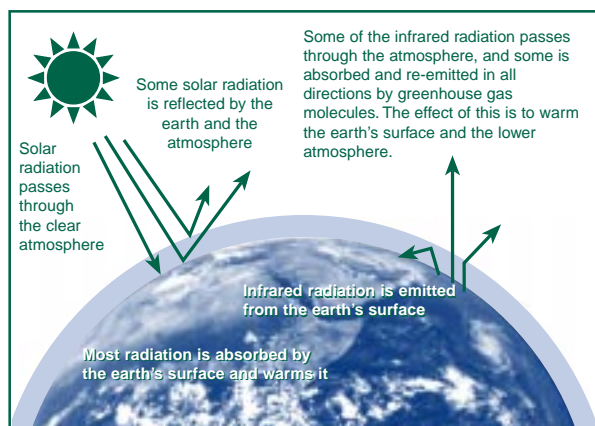
The earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases — primarily carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons. The heat-trapping property of these greenhouse gases is undisputed. Although there is uncertainty about exactly how and when the earth's climate will respond to enhanced concentrations of greenhouse gases, observations indicate that detectable changes are under way. There most likely will be increases in temperature and changes in precipitation, soil moisture, and sea level, which could have adverse effects on many ecological systems, as well as on human health and the economy.

## The Climate System

Energy from the sun drives the earth's weather and climate. Atmospheric greenhouse gases (water vapor, carbon dioxide, and other gases) trap some of the energy from the sun, creating a natural "greenhouse effect." Without this effect, temperatures would be much lower than they are now, and life as known today would not be possible. Instead, thanks to greenhouse gases, the earth's average temperature is a more hospitable 60°F. However, problems arise when the greenhouse effect is *enhanced* by human-generated emissions of greenhouse gases.

Global warming would do more than add a few degrees to today's average temperatures. Cold spells still would occur in winter, but heat waves would be more common. Some places would be drier, others wetter. Perhaps more important, more precipitation may come in short, intense bursts (e.g., more than 2 inches of rain in a day), which could lead to more flooding. Sea levels would be higher than they would have been without global warming, although the actual changes may vary from place to place because coastal lands are themselves sinking or rising.

## The Greenhouse Effect



Source: U.S. Department of State (1992)

## Emissions Of Greenhouse Gases

Since the beginning of the industrial revolution, human activities have been adding measurably to natural background levels of greenhouse gases. The burning of fossil fuels — coal, oil, and natural gas — for energy is the primary source of emissions. Energy burned to run cars and trucks, heat homes and businesses, and power factories is responsible for about 80% of global carbon dioxide emissions, about 25% of U.S. methane emissions, and about 20% of global nitrous oxide emissions. Increased agriculture and deforestation, landfills, and industrial production and mining also contribute a significant share of emissions. In 1994, the United States emitted about one-fifth of total global greenhouse gases.

## Concentrations Of Greenhouse Gases

Since the pre-industrial era, atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%. These increases have enhanced the heat-trapping capability of the earth's atmosphere. Sulfate aerosols, common air pollutants, cool the atmosphere by reflecting incoming solar radiation. However, sulfates are short-lived and vary regionally.

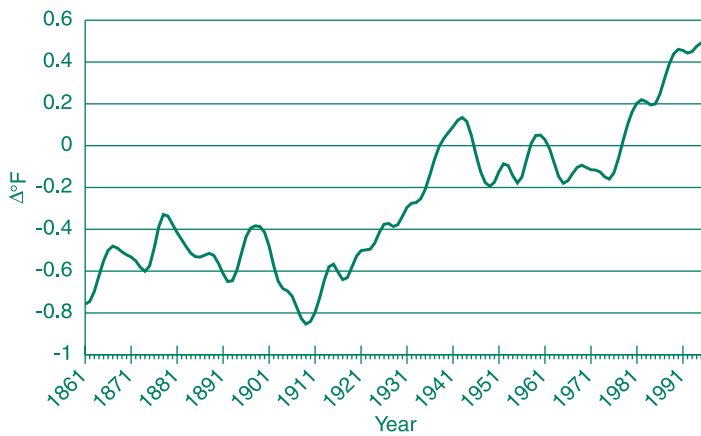
Although many greenhouse gases already are present in the atmosphere, oceans, and vegetation, their concentrations in the future will depend in part on present and future emissions. Estimating future emissions is difficult, because they will depend on demographic, economic, technological, policy, and institutional developments. Several emissions scenarios have been developed based on differing projections of these underlying factors. For example, by 2100, in the absence of emissions control policies, carbon dioxide concentrations are projected to be 30-150% higher than today's levels.

## Current Climatic Changes

Global mean surface temperatures have increased 0.6-1.2°F between 1890 and 1996. The 9 warmest years in this century all have occurred in the last 14 years.

Several pieces of additional evidence consistent with warming, such as a decrease in Northern Hemisphere snow cover, a decrease in Arctic Sea ice, and continued melting of alpine glaciers, have been corroborated. Globally, sea levels have risen 4-10 inches over the past century, and precipitation over land has increased slightly. The frequency of extreme rainfall events also has increased throughout much of the United States.

## Global Temperature Changes (1861–1996)



Source: IPCC (1995), updated

A new international scientific assessment by the Intergovernmental Panel on Climate Change recently concluded that *“the balance of evidence suggests a discernible human influence on global climate.”*

## Future Climatic Changes

For a given concentration of greenhouse gases, the resulting increase in the atmosphere’s heat-trapping ability can be predicted with precision, but the resulting impact on climate is more uncertain. The climate system is complex and dynamic, with constant interaction between the atmosphere, land, ice, and oceans. Further, humans have never experienced such a rapid rise in greenhouse gases. In effect, a large and uncontrolled planet-wide experiment is being conducted.

General circulation models are complex computer simulations that describe the circulation of air and ocean currents and how energy is transported within the climate system. While uncertainties remain, these models are a powerful tool for studying climate. Scientists are reasonably confident about the ability of models to characterize future climate at continental scales.

Recent model calculations suggest that the global surface temperature could increase an average of 1.6-6.3°F by 2100, with significant regional variation. These temperature changes would be far greater than recent natural fluctuations, and they would occur significantly faster than any known changes in the last 10,000 years. The United States is projected to warm more than the global average, especially as fewer sulfate aerosols are produced.

The models suggest that the rate of evaporation will increase as the climate warms, which will increase average global precipitation. They also suggest increased frequency of intense rainfall as well as a marked decrease in soil moisture over some mid-continental regions during the summer. Sea level is projected to increase by 6-38 inches by 2100.

Calculations of regional climate change are much less reliable than global ones, and it is unclear whether regional climate will become more variable. The frequency and intensity of some extreme weather of critical importance to ecological systems

(droughts, floods, frosts, cloudiness, the frequency of hot or cold spells, and the intensity of associated fire and pest outbreaks) could increase.

## Local Climate Changes

Over the last century, the average temperature in Dover, Delaware, has increased 1.7°F, and precipitation has increased by up to 10% in some parts of the state.

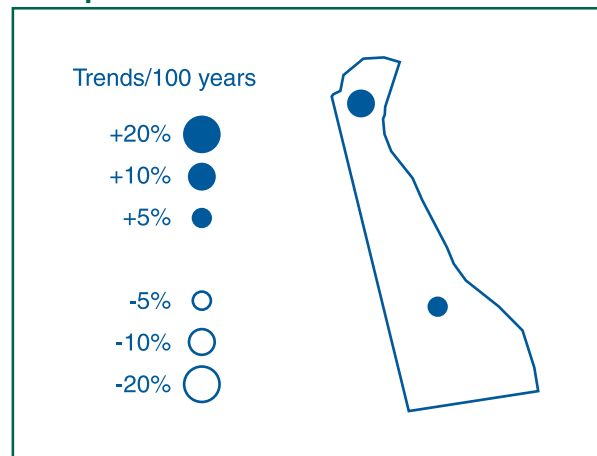
Over the next century, climate in Delaware may change even more. For example, based on projections made by the Intergovernmental Panel on Climate Change and results from the United Kingdom Hadley Centre’s climate model (HadCM2), a model that accounts for both greenhouse gases and aerosols, by 2100 temperatures in Delaware could increase by about 3°F (with a range of 1-7°F) in spring and about 4°F (with a range or 2-9°F) in the other seasons. Precipitation is estimated to increase 15-40% in all seasons, probably slightly less in spring and fall, and slightly more in winter. Other climate models may show different results. The amount of precipitation on extreme wet or snowy days is likely to increase. The frequency of extreme hot days in summer would increase because of the general warming trend. Although it is not clear how severe storms such as hurricanes would change, an increase in the frequency and intensity of summer thunderstorms is possible.

## Climate Change Impacts

Global climate change poses risks to human health and to terrestrial and aquatic ecosystems. Important economic resources such as agriculture, forestry, fisheries, and water resources also may be affected. Warmer temperatures, more severe droughts and floods, and sea level rise could have a wide range of impacts. All these stresses can add to existing stresses on resources caused by other influences such as population growth, land-use changes, and pollution.

Similar temperature changes have occurred in the past, but the previous changes took place over centuries or millennia instead

## Precipitation Trends From 1900 To Present



Source: Karl et al. (1996)

of decades. The ability of some plants and animals to migrate and adapt appears to be much slower than the predicted rate of climate change.

## Human Health

Climate change could increase concentrations of ground-level ozone. For example, high temperatures, strong sunlight, and stable air masses tend to increase urban ozone levels. Air pollution also is made worse by increases in natural hydrocarbon emissions during hot weather. If a warmed climate causes increased use of air conditioners, air pollutant emissions from power plants also will increase.

A 4°F warming in New York City, with no other change in weather or emissions, could increase concentrations of ozone, a major component of smog, by 4%. Similar increases could occur in Delaware. Currently, ground-level ozone concentrations exceed national ozone health standards throughout the state. Wilmington and the northern part of Delaware are classified as “severe” nonattainment areas for ozone. Ground-level ozone has been shown to aggravate respiratory illnesses such as asthma, reduce existing lung function, and induce respiratory inflammation. In addition, ambient ozone reduces crop yields and impairs ecosystem health.

Warming and other climate changes may expand the habitat and infectivity of disease-carrying insects, thus increasing the potential for transmission of diseases such as malaria and dengue (“break bone”) fever. Mosquitos flourish in some areas around Delaware. Some can carry malaria, while others can carry Eastern equine encephalitis, which can be lethal or cause neurological damage. Incidents of Lyme disease, which is carried by ticks, already occurs in Delaware. If conditions become warmer and wetter, mosquito and tick populations could increase, thereby increasing the risk of transmission of these diseases.

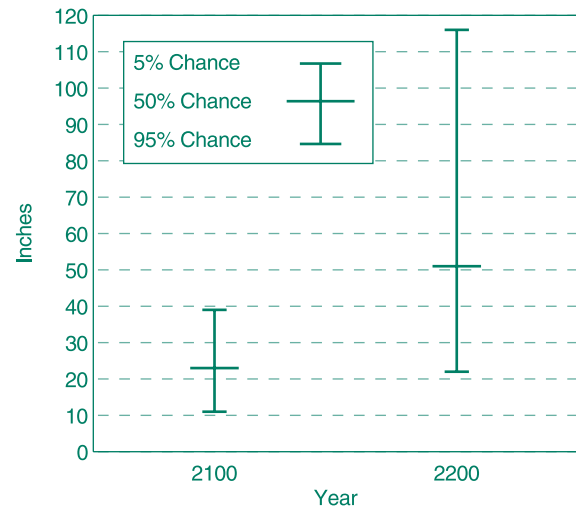
In addition, warmer seas could contribute to the increased intensity, duration, and extent of harmful algal blooms. These blooms damage habitat and shellfish nurseries, can be toxic to humans, and can carry bacteria like those causing cholera. Brown algal tides and toxic algal blooms already are prevalent in the Atlantic. Warmer ocean waters could increase their occurrence and persistence.

## Coastal Areas

Sea level rise could lead to flooding of low-lying property, loss of coastal wetlands, erosion of beaches, saltwater contamination of drinking water, and decreased longevity of low-lying roads, causeways, and bridges. In addition, sea level rise could increase the vulnerability of coastal areas to storms and associated flooding.

The coast of Delaware is an important resource with 381 miles of shoreline. Delaware’s coastline includes barrier beaches, inland bays and productive estuaries, freshwater and salt marshes, tidal flats, and several islands that dot the coast. Delaware Bay is the chief spawning ground for the horseshoe crab and a nursery for many coastal fisheries.

## Future Sea Level Rise At Lewes



Source: EPA (1995)

At Lewes, Delaware, sea level already is rising by 12 inches per century, and it is likely to rise another 23 inches by 2100. Rising sea levels, combined with possible decreases in summer stream flows could increase the salinity of the Delaware River and Bay. A 20-inch rise in sea level could inundate about 50% of the wetlands in Delaware Bay.

As in many estuaries, the Delaware Inland Bays are already affected by shoreline erosion. Rising sea levels will further erode shores along the bay. Responses are likely to be increases in the use of traditional techniques to combat erosion, such as building bulkheads and revetments, which would threaten habitats of least tern and other species depending on estuarine beaches. Public access along the shore could also be diminished.

Other possible responses to sea level rise include allowing the sea to advance and adapting to it, and raising the land (e.g., by replenishing beach sand, elevating houses and infrastructure). Each of these responses will be costly, either in out-of-pocket costs or in lost land and structures. For example, the cumulative cost of sand replenishment to protect the coast of Delaware from a 20-inch sea level rise by 2100 is estimated at \$34-\$143 million.

## Water Resources

Water resources are affected by changes in precipitation as well as by temperature, humidity, wind, and sunshine. Changes in streamflow tend to magnify changes in precipitation. Water resources in drier climates tend to be more sensitive to climate changes. Because evaporation is likely to increase with warmer climate, it could result in lower river flow and lower lake levels, particularly in the summer. If streamflow and lake levels drop, groundwater also could be reduced. In addition, more intense precipitation could increase flooding.

Most of Delaware drains to either Delaware Bay or Chesapeake Bay. The state relies heavily on a relatively shallow groundwater system for industrial and municipal water supply. Climate change could increase summer evaporation and thus reduce summertime recharge of aquifers, although some of this loss could be offset by

increases in winter recharge if winter precipitation increases. Many of Delaware's aquifers are contaminated by industrial pollutants. Although the effects of climate change on the movement of pollutants are not well understood, changes in infiltration rates could affect the rate at which pollutants migrate throughout an aquifer. Increased precipitation could contribute to groundwater contamination by increasing the inflow of contaminants into the state's aquifers.

## Agriculture

The mix of crop and livestock production in a state is influenced by climatic conditions and water availability. As climate warms, production patterns could shift northward. Increases in climate variability could make adaptation by farmers more difficult. Warmer climates and less soil moisture due to increased evaporation may increase the need for irrigation. However, these same conditions could decrease water supplies, which also may be needed by natural ecosystems, urban populations, industry, and other sectors.

Understandably, most studies have not fully accounted for changes in climate variability, water availability, and imperfect responses by farmers to changing climate. Including these factors could change modeling results substantially. Analyses that assume changes in average climate and effective adaptation by farmers suggest that aggregate U.S. food production would not be harmed, although there may be significant regional changes.

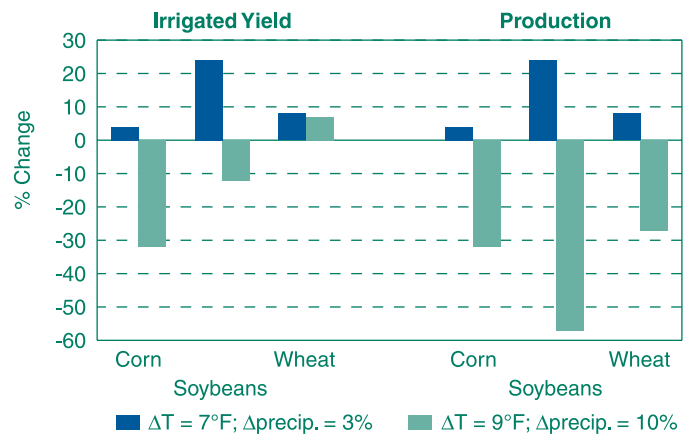
In Delaware, agriculture is a \$600 million annual industry, three-fourths of which comes from livestock, mainly broiler chickens. About 10% of the farm acreage is irrigated. The major crops in the state are corn, soybeans, and wheat. Grain yields could fall by as much as 32% or rise by as much as 24%, leading to changes in acres farmed and production. In Delaware, wheat yields could rise while production falls because of a decrease in wheat acres farmed.

## Forests

Trees and forests are adapted to specific climate conditions, and as climate warms, forests will change. These changes could include changes in species, geographic range, and health and productivity. If conditions also become drier, the current range of forests could be reduced and replaced by grasslands and pasture. Even a warmer and wetter climate could lead to changes; trees that are better adapted to warmer conditions, such as southern pines, would prevail. Under these conditions, forests could become more dense. These changes could occur during the lifetimes of today's children, particularly if change is accelerated by other stresses such as fire, pests, and diseases. Some of these stresses would themselves be worsened by a warmer and drier climate.

With changes in climate, the extent and density of forested areas in Delaware could change little or decline by as much as 10-20%. However, the types of trees dominating those forests are likely to change. Mixed forests, dominated by southern pines and oaks, would spread northward, replacing the predominantly hardwood

## Changes In Agricultural Yield And Production



Source: Mendelsohn and Neumann (in press); McCarl (personal communication)

forests currently found in the northern half of the state. Maritime forests, important for their recreational and aesthetic value and for their role in coastal hydrology, could be affected adversely by changes in the frequency of large storms associated with climate change (hurricanes in the late summer and fall, nor'easters in the winter and spring). Coastal estuaries are the breeding ground for important commercial fish and shellfish species, and changes in the hydrology of upland forests in Delaware and surrounding states could have profound effects on these sensitive coastal systems.

## Ecosystems

The most notable ecosystems of Delaware are the coastal estuaries, marshes, and barrier islands. Delaware's coastal waters are critical for many commercial species, game species such as deer, and migratory birds, including bobwhite quail. The Delaware estuary is an important habitat for migratory shorebirds, waterfowl, migratory songbirds, fish, and other coastal species such as horseshoe crabs. Approximately 35% of the Delaware estuary's rare species live in or depend on wetland habitats, and 70-90% of the state's commercial fish and shellfish species either live entirely in estuarine habitats or use them as nursery grounds. Delaware Bay has the second largest concentration of migratory shorebirds in the Western Hemisphere, with approximately 1.5 million shorebirds passing through the bay area each spring.

Small changes in sea level, freshwater inputs, and storm frequency, intensity, and character, driven by climate change, could affect these ecosystems substantially. The combination of human activities and sea level rise could result in a net loss of coastal wetlands and could increase the salinity of the waters of those that remain. The result could be a sharp loss in the diversity of these ecosystems and the species that depend on them, such as shorebirds.

*For further information about the potential impacts of climate change, contact the Climate and Policy Assessment Division (2174), U.S. EPA, 401 M Street SW, Washington, DC 20460.*

