Chapter 2:
The Climate and Air Quality of Dutchess County

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INTRODUCTION TO CLIMATE

Climate is the synthesis of long-term weather patterns in a given area. Temperature, wind, humidity, precipitation, and other climatic factors continually shape our lives and the environment. Climatic factors also continually shape land and water resources and their uses. Climate is distinguished from weather because weather is the general condition of the atmosphere regarding these same factors but at a particular time and place.

Dutchess County is located in the northern portion of the temperate climate zone, as shown below in Figure 1. Specifically, its climate is humid continental, which is characterized by strong seasonal contrasts and highly variable weather. Major storm systems which move through the continental United States or up the nearby Atlantic Coast have a significant impact on the weather, especially

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during the fall, winter, and spring months. These systems provide ample precipitation for the region, supplemented by tropical, maritime air masses during parts of the summer. Polar air masses from Canada move southeast into the area and strongly influence winters (New York State Climatologist).

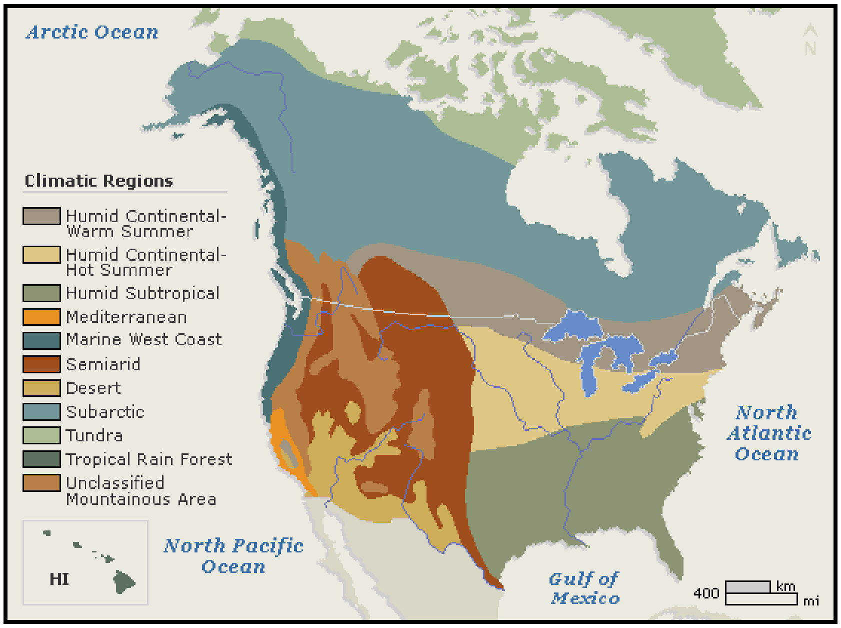

Figure 1: Climatic Regions of North America (Microsoft Encarta).

The relatively close proximity of Dutchess County to the Atlantic Ocean can have a moderating influence on the climate. The large-scale atmospheric circulation normally dominates the flow pattern near the surface. However, in the absence of a strong circulation, the Atlantic can have a considerable effect on the surface flow, leading to relatively milder winter days, and cooler days in the summer. Also, the area generally has a slightly longer freeze-free season than places at similar latitudes farther inland.

Moderate temperatures and sufficient precipitation make Dutchess County an excellent location for farming, while seasonal variations help to attract tourists and recreational users. The county's relatively warm summers and cold winters result in substantial heating and cooling costs for homes and businesses.

The National Climatic Data Center divides New York State into 10 climate divisions, shown below in Figure 2. Dutchess County is located in Region #5, the Hudson Valley (National Oceanic and

Atmospheric Administration (NOAA, *New York*). These climate regions are used for various research purposes, including estimations of energy use, drought monitoring, studies of the variability of local weather, and analysis of long-term climate change.

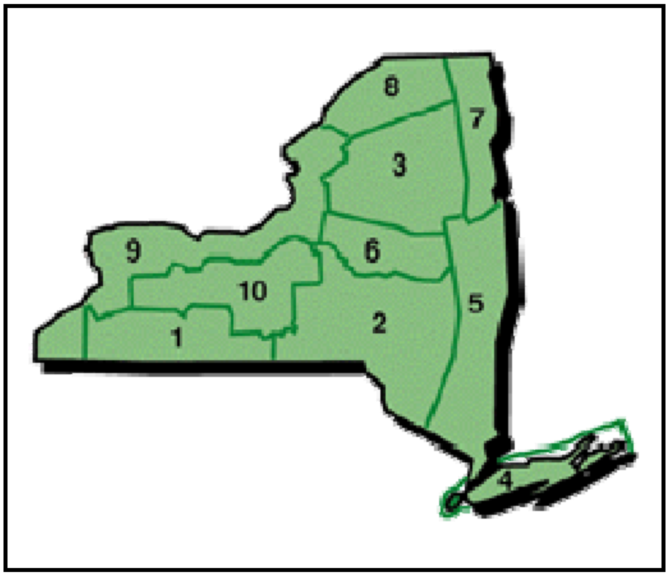

Figure 2: Climate Divisions of New York State (NOAA, *New York*).

TEMPERATURE

Temperature is a measure of the internal energy that a substance contains (NOAA, *NWS Glossary*). The county's mean annual temperatures for the meteorological winter (December, January, and February), and meteorological summer (June, July, and August) are 27.3 and 69.5 degrees Fahrenheit, respectively. The highest and lowest temperatures ever reported at Poughkeepsie were 107 degrees in July 1966, and 21 degrees below zero in February 1897. The mean annual temperature of Poughkeepsie (48.8 degrees) and six major cities within 150 miles of Dutchess County is shown below (Figure 3), based on 30 year data from 1971-2000 (Northeast Regional Climate Center [NRCC]).

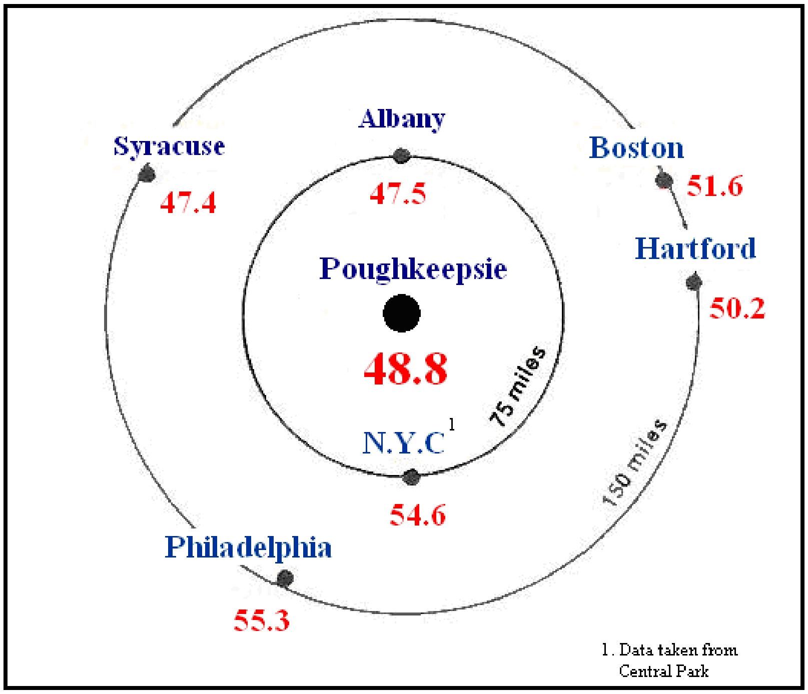

Figure 3: Mean Annual Temperature of Poughkeepsie and Nearby Cities (NRCC, *CLIMOD System*).

Temperatures at any one place in Dutchess County normally exceed 90 degrees Fahrenheit between 5 and 15 times during the summer. Air temperature reaching triple digits is uncommon, occurring in Poughkeepsie roughly once every five years (NRCC, *CLIMOD System*). However, hot temperatures combined with high summer humidity can lead to a much hotter-feeling day. The combination of the dew point temperature (the amount of moisture in the air) and air temperature which shows how hot it actually feels is known as the heat index (NOAA, *NWS Glossary*). Nearly every summer in the county features one or more hot spells with high temperatures and high humidity leading to extremely uncomfortable conditions. On average, temperatures fall below zero 5 to 10 times during the winter, primarily in January or February. During milder winters, temperatures may not drop into negative territory.

Figure 4 below shows the mean monthly temperatures in Dutchess County. The numbers are based on the average of data collected at the three principal reporting stations in the county; Glenham, Millbrook, and Poughkeepsie/ Dutchess County Airport. The monthly temperature at each individual station, as well as the coordinates and elevation of all stations in Dutchess County, can be found later in this chapter.

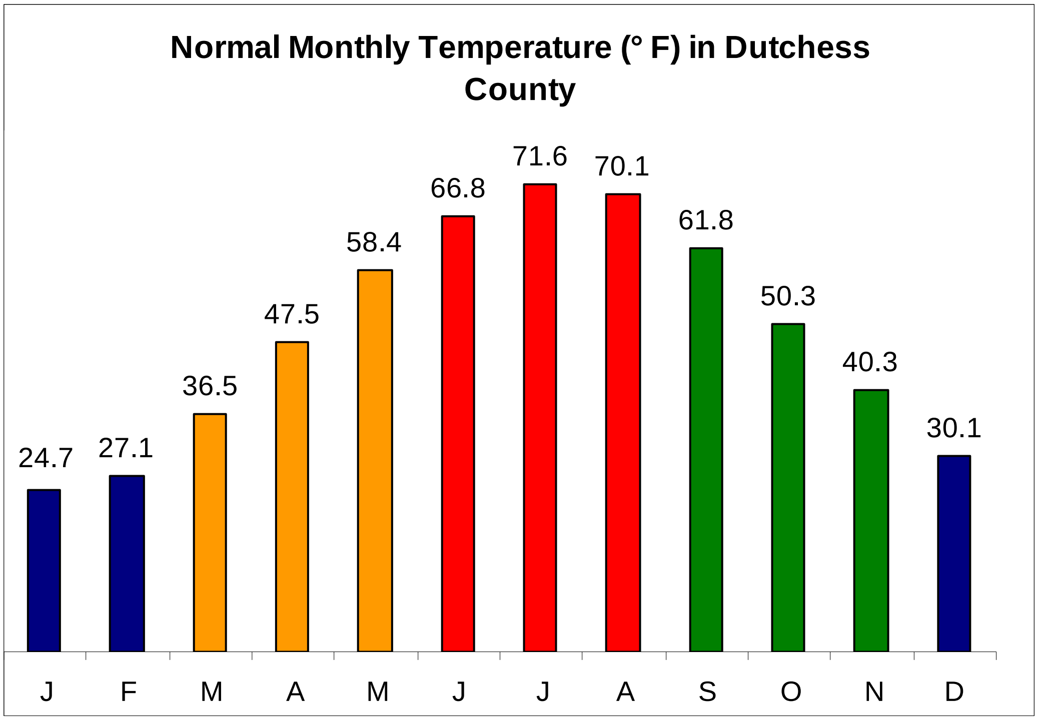

Figure 4: Normal Monthly Temperature in Dutchess County, 1971-2000 (NRCC, *CLIMOD System*).

It is important to note that the graph above does not take into account the many, varied local micro-climates across the county. Areas along and just east of the Hudson River, including Red Hook, Rhinebeck, Hyde Park, Poughkeepsie, and Beacon, are generally milder than the rest of the county. Cooler temperatures prevail in higher elevations across the eastern and especially northeastern sections of Dutchess County. Finally, sheltered valleys such as the Harlem Valley also experience cooler conditions, especially at night.

Degree Days are a measure that gauges building energy use for heating or cooling. Days with the average temperature above 65 are known as cooling degree days, while days with the average temperature below 65 are known as heating degree days. The number of heating degree days is the most important statistic for Dutchess County since temperatures average below 65 degrees in all months except June, July, and August and space heating is normally required at temperatures below this level. A day with an average temperature of 65 degrees or more is said to have zero heating degree days, while a day with an average temperature of 50 degrees has 15 heating degree days (65-50=15 degrees). As the number of heating degree days increases, so does the use of energy to heat homes and businesses (NOAA, *Climate Prediction Center*). Figure 5 below shows average monthly heating degree days in Poughkeepsie.

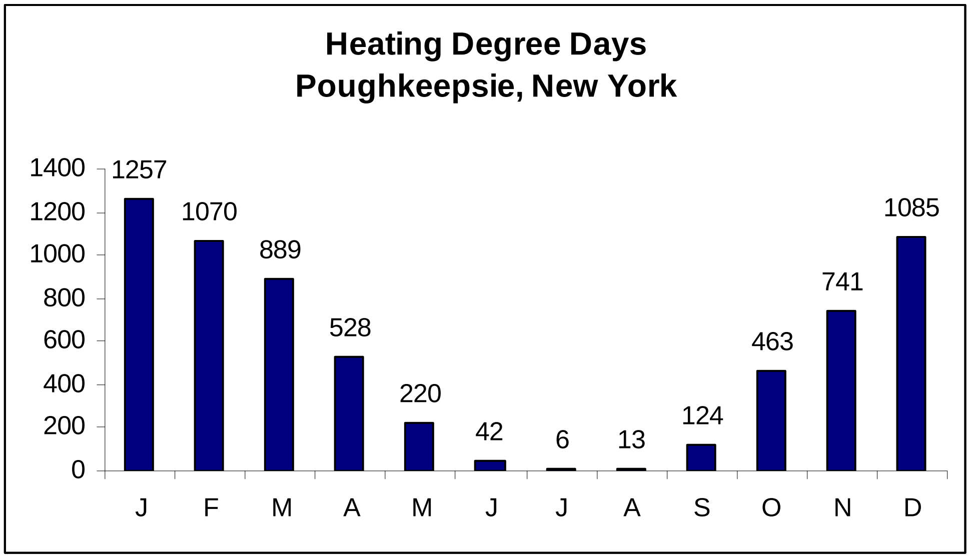

Figure 5: Heating degree days in Poughkeepsie, 1971-2000 (NRCC, *CLIMOD System*).

Poughkeepsie has an annual average of 6,438 heating degree days. The number varies with mean temperature across the county; for example, Glenham averages 5,813 heating degree days, while Millbrook averages 7,074. There is an average of 550 cooling degree days annually in Poughkeepsie. This number ranges from 312 cooling degree days in Millbrook to 790 in Glenham. With the advent of climate change, the number of degree days each year has changed due to warming temperatures. The number cooling degrees has gradually increased during the past 60 years, including a record 1,049 in Poughkeepsie during 2005. Similarly, the number of heating degree days has decreased over the same period. In 2006, there was a record low of just 5,406 heating degree days in Poughkeepsie (NRCC, *CLIMOD System*).

Another type of degree day is the Growing Degree Day. Growing Degree Days relate plant development and insect emergence to environmental air temperature to indicate which plants may be grown in a particular area (Cornell University). For example, most varieties of peas need 1200 to 1800 growing degree days (based on a 40-degree threshold) to reach maturity, so they can usually be grown only in areas that accumulate that many growing degree days or more. The most common threshold temperatures for measuring growing degree days are 40 degrees and 50 degrees. These are generally accepted as temperatures required for growing economically important plants. When using a 40-degree base, annual growing degree days range from roughly 4000 days in the eastern part of the county to 5000 near the Hudson River. When using the 50 degree base, the number of days varies between about 2000 in the east to almost 3000 near the Hudson (NRCC, *CLIMOD System*). Growing degree days in Dutchess County are shown in Figure 6 below.

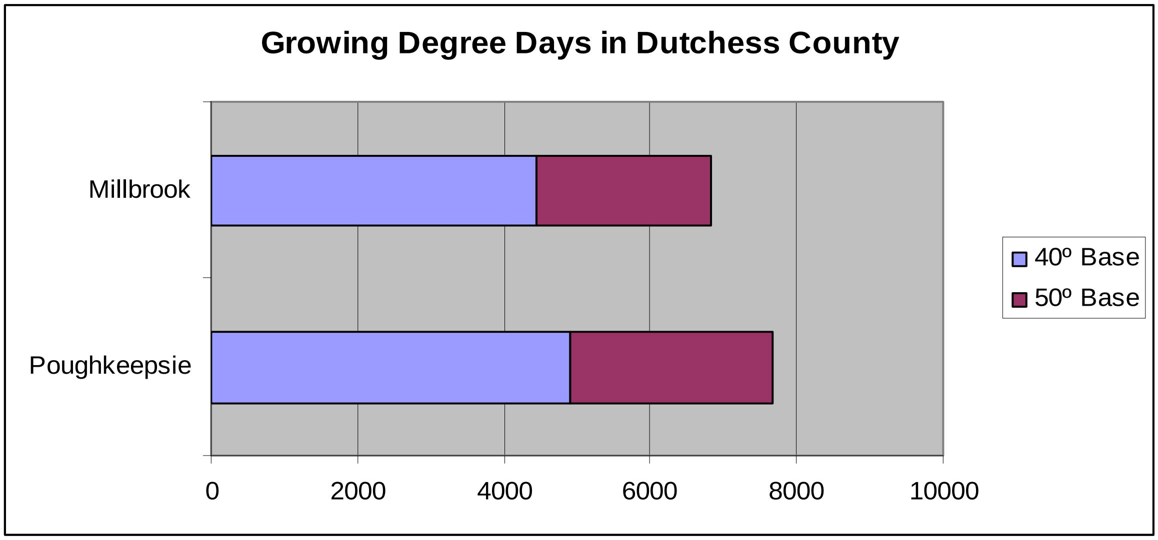

Figure 6: Growing Degree Days in Dutchess County, 1971-2000 (NRCC, *CLIMOD System*).

Information about growing degree days is useful to farmers, nurseries, research and extension specialists, and home gardeners. It is especially helpful in crop selection and in determining schedules for planting, pesticide application, and harvesting.

Figure 7: Image of agricultural fields in Dutchess County.

The growing season is primarily dictated by the period between the last spring frost and first fall frost. A **frost** occurs when surface temperatures fall to 32° Fahrenheit or below (NOAA, *NWS Glossary*). Knowing approximately when the first and last frost will happen and the normal length of the "frost free" season is critical for determining what types of crops are best suited for a particular area, and when they can be safely planted. Generally, the frost free season in the County lasts from early May through late September or early October. Table 1 below shows normal frost data for Dutchess County based on the 30 year period from 1971-2000.

Table 1: Frost Data in Dutchess County (NRCC, *CLIMOD System*).[2]

Station	Mean Date of Last Frost	Absolute Date of Last Frost	Absolute Date of First Frost	Mean Date of First Frost	Mean Number of Frost Free Days	Data Record Period
Poughkeepsie	May 3	May 28 (1949)	September 15 (1963)	October 9	159	1949-2007
Millbrook	May 9	June 11 (1980)	September 7 (1984)	September 30	142	1943-2001

PRECIPITATION

Precipitation is the process where water vapor condenses in the atmosphere to form water droplets that fall to the Earth as rain, snow, sleet, or hail (NOAA, *NWS Glossary*). Mean annual precipitation in Dutchess County ranges from 38 to 46 inches (Urban-Mead, 2006). During the May through September growing season, total precipitation averages between 18 and 22 inches, a sufficient amount to support the wide variety of vegetation found in the county (NRCC, *CLIMOD System*). One or more short periods of no rainfall occur during most summers. Figure 8 below shows mean annual precipitation for Dutchess County, as well as the locations of weather reporting stations in the county.

[2] Mean dates based on data from 1971-2000.

The significant differences in precipitation in parts of the county can primarily be attributed to the topographical profile of the region. The eastern half of Dutchess County receives the most rain due to its higher elevation on the uphill slopes of the Taconic Mountains. As the prevailing northerly and westerly winds reach this area, air is forced upward. As the air rises, it expands and cools. The cooler air can not hold as much moisture, so the relative humidity increases, leading to the formation of clouds and precipitation. During large storms, total rain or snow will often be greater in these areas due to this effect. The Hudson Highlands have a similar impact on the extreme southern portions of the county. The opposite effect causes lower precipitation in northwestern Dutchess County. As air is transported over the Catskill Mountains, it sinks on the down sloping side of the mountains. Sinking air warms and loses moisture which lowers relative humidity and leads to dry conditions. A rain or snow "shadow" can often be observed in these areas during major storms, resulting in considerably less precipitation.

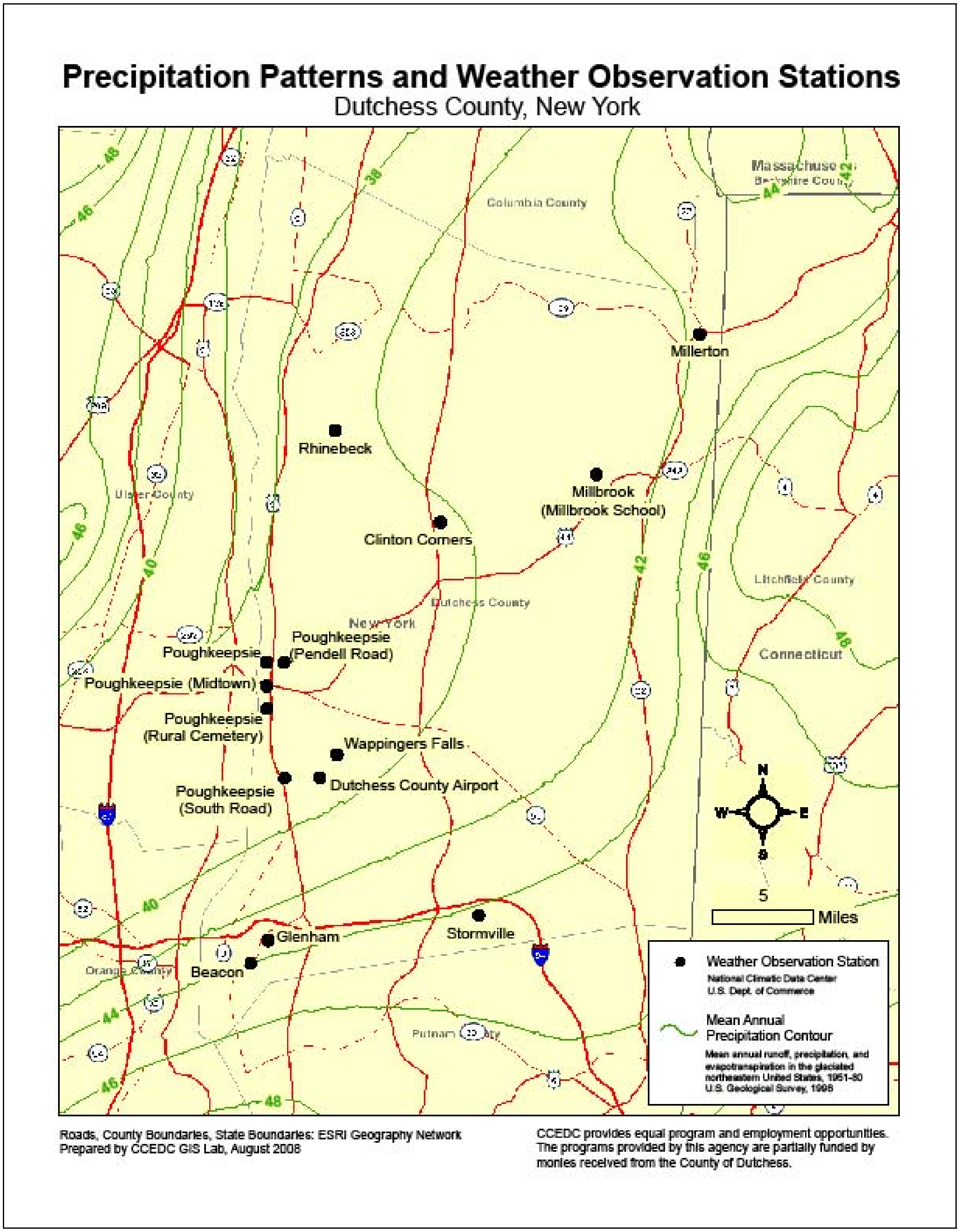

Figure 8: Mean Annual Precipitation in Dutchess County.

A bar graph showing the mean monthly precipitation (rain and melted snow) in Dutchess County can be found in Figure 9 below. The numbers are based on the average of data collected at the three official reporting stations in the county; Glenham, Millbrook, and Poughkeepsie/ Dutchess County Airport (NRCC, *CLIMOD System*).

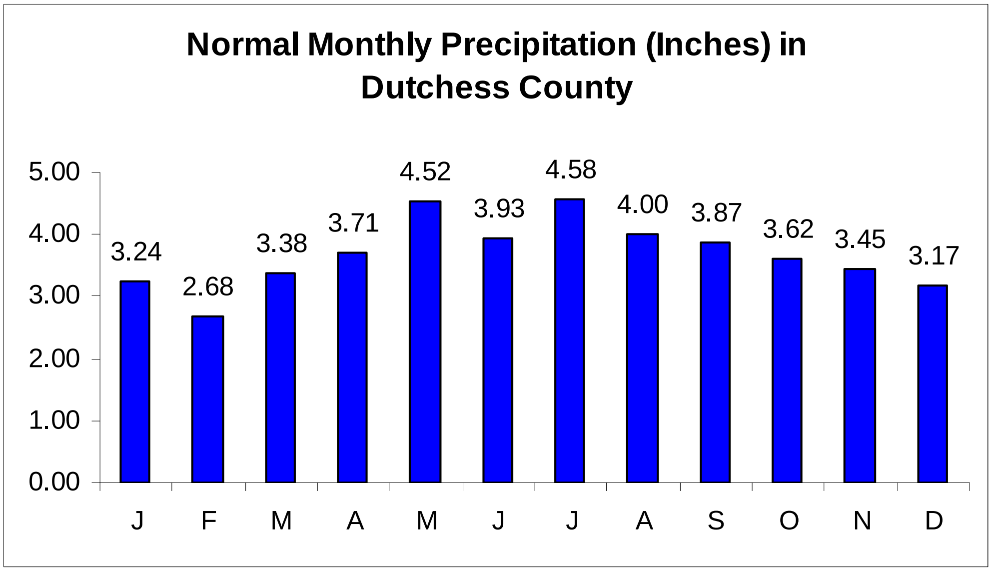

Figure 9: Normal Monthly Precipitation in Dutchess County, 1971-2000 (NRCC, *CLIMOD System*).

Much of the precipitation in the Northeast comes from the Gulf of Mexico and the Atlantic Ocean, and is transported by major atmospheric storm systems. These systems develop less frequently during the summer, but local convective activity in the form of thunderstorms produces significant amounts of summer rain. Local topographic variations also influence precipitation.

The following graph (Figure 10) traces the pattern of annual precipitation in Poughkeepsie from 1931-2000. The graph clearly shows the extended drought which affected the area during the early and middle 1960's. In fact, the Hudson Valley experienced drought conditions every single month from June 1962 through February 1967. The worst conditions occurred between July 1964 and February 1966, as every month during that period was spent in extreme drought environments (NOAA, *Historic Palmer*). In fact, 1964 was by far the driest year of this 62-year period, with only 24.52 inches of precipitation. Furthermore, the next two years were the third and fifth driest years during this time. The drought is the only one during the time period shown to persist through several consecutive growing seasons and reach severe levels before a return to normal precipitation

(NRCC, *CLIMOD System*). The red line on the graph is a best fit line of the yearly precipitation data. It shows there has been a gradual increase in annual precipitation to about 43.8 inches of rain per year (NRCC, *CLIMOD System*).

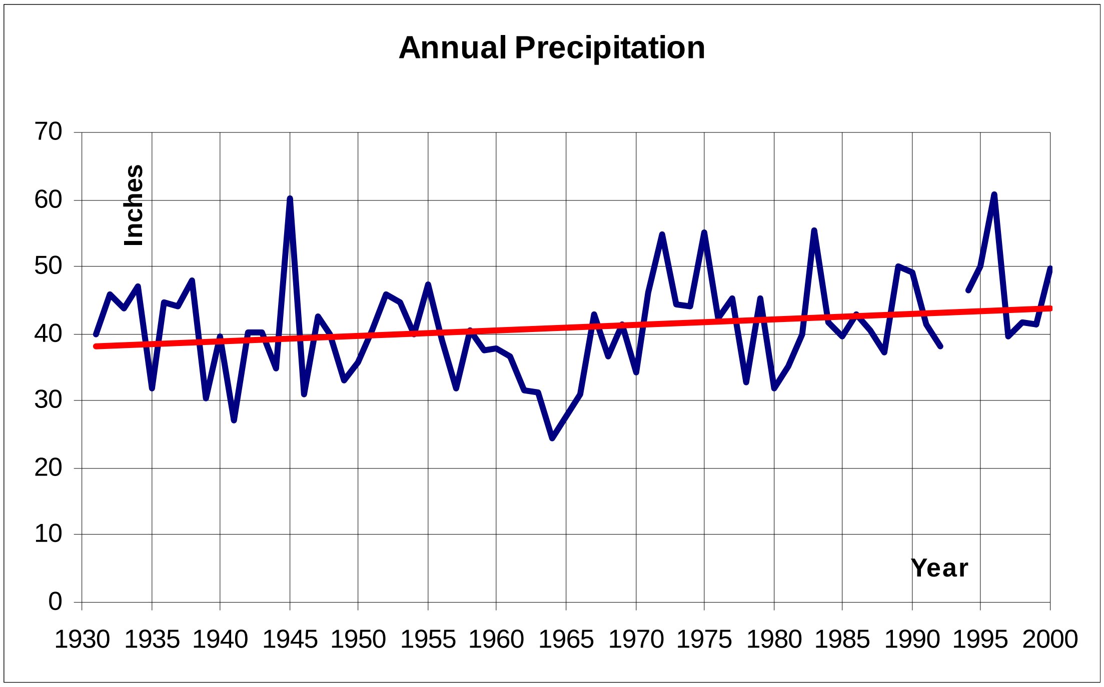

Figure 10: Annual Precipitation in Dutchess County (NRCC, *CLIMOD System*).[3]

Snow is precipitation in the form of ice crystals, formed from water vapor as it freezes in the air (NOAA, *NWS Glossary*). Dutchess County receives a moderate amount of snowfall, with roughly 30 to 50 inches throughout the county. Higher elevations in the northeast section of the county may receive 60 inches of snow in a given year. Storms bringing at least six inches of snow to the region are frequent and normally occur at least once in most winters (NRCC, *CLIMOD System*). Mean monthly snowfall for Poughkeepsie and Millbrook can be found in Figure 11 below.

[3] Note: 1931-52 data collected in Poughkeepsie, 1953-2000 at the Dutchess County Airport.

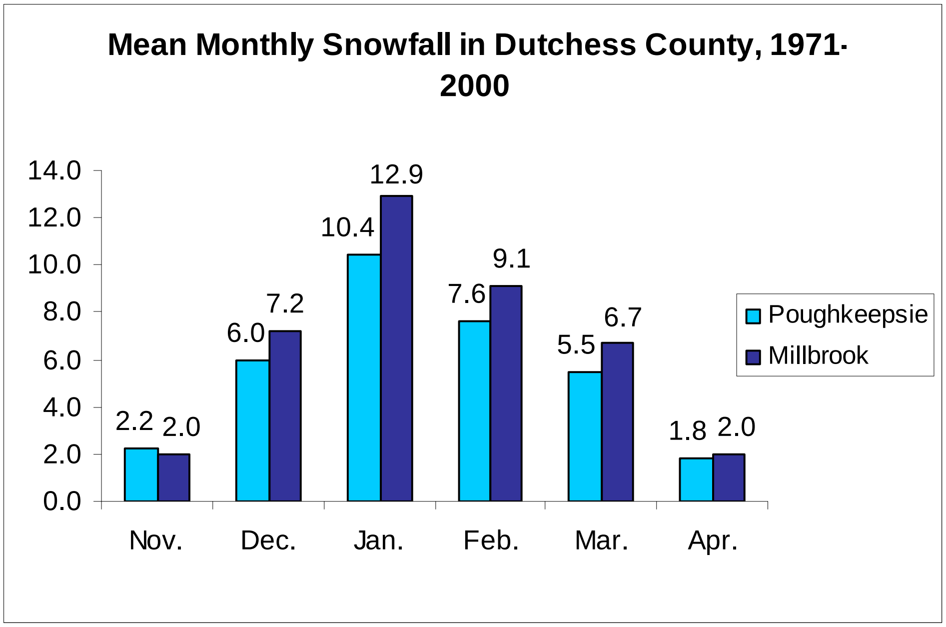

Figure 11: Mean Monthly Snowfall in Dutchess County, 1971-2000 (NRCC, *CLIMOD System*).

Relative humidity is the ratio of the amount of moisture present in the atmosphere to the amount of moisture that the air can hold at any given temperature (expressed as a percent) (NOAA, *NWS Glossary*). Mean annual relative humidity in Dutchess County is between 66-75% (NOAA, *Mean Relative Humidity*).

BAROMETRIC PRESSURE

Pressure is the exertion of force upon a surface by a fluid in contact with it. Atmospheric pressure refers to the pressure the atmosphere exerts (NOAA, *NWS Glossary*). Surface barometric pressure measurements are usually converted to mean sea level pressure, which standardizes the observation so that pressure can be measured on the same scale regardless of altitude. This conversion is done to make pressure readings a useful weather and climate tool. Otherwise, barometric pressure readings at a high elevation location such as Denver, Colorado would always be lower than the readings at locations near or at sea level. The mean annual pressure in Dutchess County is about 1017 millibars, or 30.04 inches of mercury (NOAA, *Annual Mean Sea Level Pressure*). The lowest pressure in the county normally occurs during violent weather such as severe thunderstorms and coastal storms. The highest pressure is observed when large high pressure areas move over the region. Differences in pressure cause winds in the atmosphere and the sharper the change in pressure is over a given distance, the higher the winds will be.

WIND

Wind is the horizontal motion of air past a given point. It is caused by differences in air pressure and can also be affected by heating differences of the air as well as the physical profile of the Earth's surface (NOAA, *NWS Glossary*). Northerly and westerly winds dominate Dutchess County at an average annual velocity of 5.4 miles per hour (MPH). Winds are usually strongest during the winter and early spring, averaging 6-7 MPH. During the summer months, winds are weaker, on the order of 4-4.5 MPH, and have more of a southerly component (NRCC, *Wind Summary for Dutchess County*). The wind rose diagram below shows the average wind speed and direction at the Poughkeepsie/Dutchess County Airport during the ten-year period from 1997-2007. The numbers around the circle indicate the wind direction (0= North, 90= East, 180= South, and 270= West), while the colored bars indicate the percentage the winds occurred at a certain speed. Under normal atmospheric conditions, winds are strongest during the day, and weaken as the sun sets and daytime heating is lost. Severe winds are rare in Dutchess County. Most high wind events are caused by localized, quick-moving severe thunderstorms. Longer, more widespread wind events occur occasionally and are due to larger mid-latitude cyclones such as nor'easters.

The strongest and most frequent winds generally come from the west because Dutchess County is located in the westerly wind belt which can be found at the middle latitudes of the Earth. The westerlies are just one of the components of global circulation patterns.

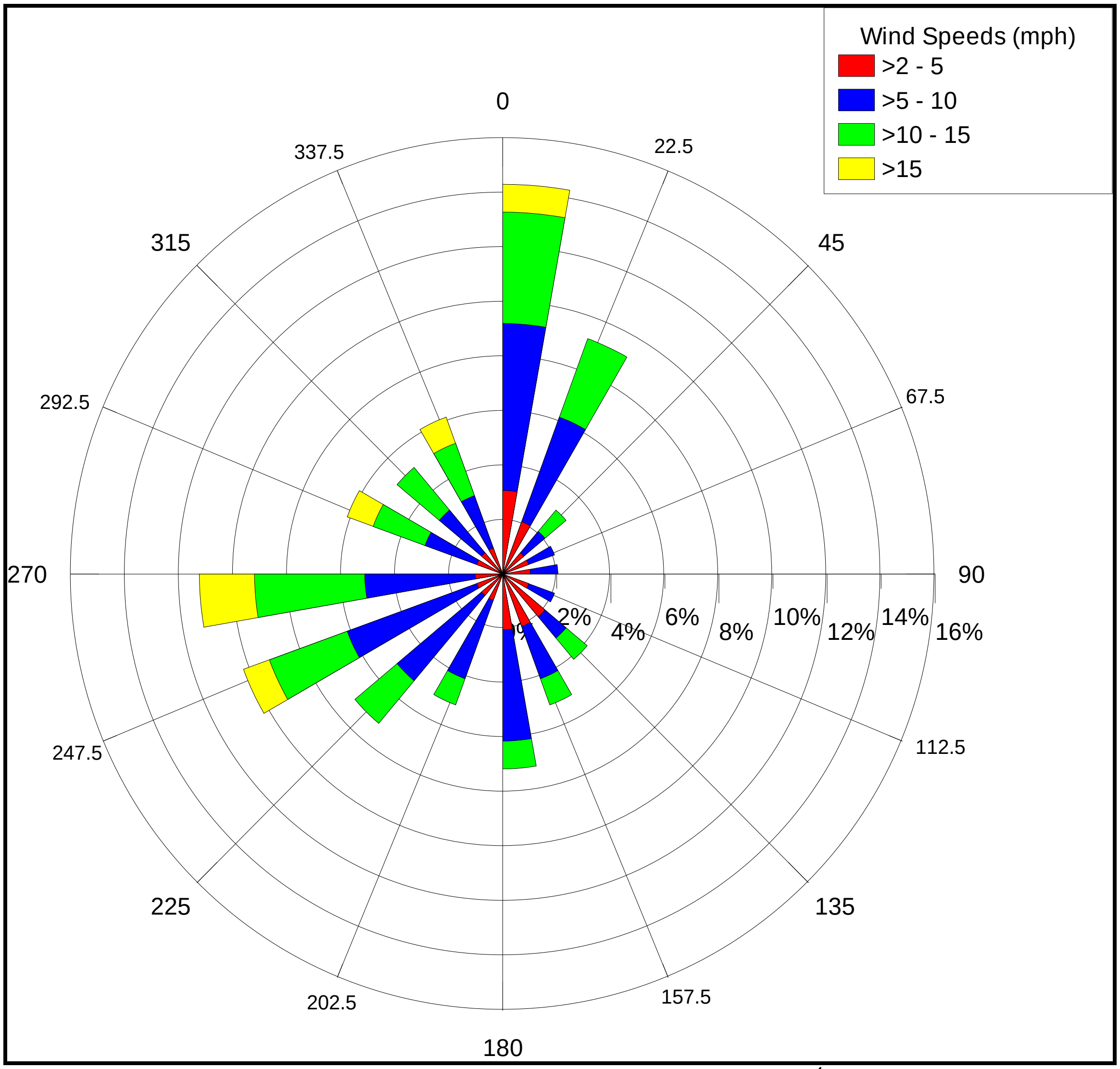

Figure 12: Wind Rose for Poughkeepsie, New York, 1997-2007.[4]

SUN CLOUD COVER

The ratio of actual bright sunshine to the total possible amount of sunshine in a location is known as **percentage of possible sunshine** (NRCC, *Percent of Possible Sunshine*). In New York State, this value ranges from 46% in Syracuse to 58% in New York City. The location of Dutchess County between New York City and Albany (53%) means that the area receives some of the highest amounts of sunshine in the state. Sunshine is at a maximum during July, August, and September, with clouds

[4] Poughkeepsie FAA Airport, latitude 41.63 degrees, longitude -73.88 degrees, elevation 155 feet.

most prevalent in January and March (NOAA, *Percentage of Possible Sunshine*). The graph below shows the percentage of possible sunshine as measured at Poughkeepsie/Dutchess County Airport during the ten-year period of 1997-2007.

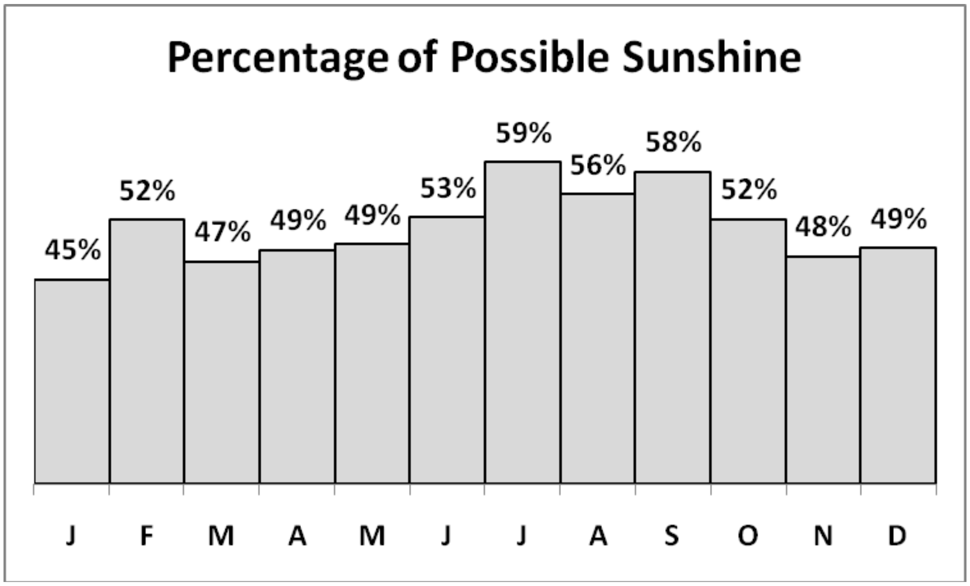

Figure 13: The percentage of possible sunshine by month at Poughkeepsie, New York, 1997-2007.[5]

SEVERE WEATHER

Thunderstorms, tornadoes, winter storms, hurricanes, floods, and droughts have all impacted Dutchess County. Many of these storms have left behind considerable damage and in a few cases proven fatal. The NOAA Storm Prediction Center in Norman, Oklahoma monitors severe weather and issues real-time watches, forecasts and discussions.

Thunderstorms are relatively common in Dutchess County, primarily during the fall, spring and summer. Thunderstorms can be accompanied by frequent lightning, hail, torrential rains, violent winds, and tornadoes. The time of greatest occurrence for **severe thunderstorms** is during the late spring and summer. The National Weather Service defines a thunderstorm as severe if it produces at

[5] Poughkeepsie FAA Airport, latitude 41.63 degrees, longitude -73.88 degrees, elevation 155 feet.

least one of the following: 1) Winds of at least 58 miles per hour, 2) Hail at least ¾" in diameter, or 3) a tornado. The National Weather Service issues a **severe thunderstorm warning** if severe thunderstorms are imminent or occurring. Additionally, a **severe thunderstorm watch** is issued when severe weather is possible but not yet occurring (The Weather Channel). Between 1955 and 2007 there were 71 large hail (at least ¾" diameter) events in Dutchess County, or about 1-2 per year (NOAA, *NCDC Storm Events*). Thunderstorms are also capable of producing urban and small stream flooding, uprooting trees, widespread power outages, and damage to structures.

A tornado is a rotating column of air with a circulation reaching the ground (NOAA, *NWS Glossary*). The intensity of Tornadoes is measured by the Fujita Scale, with an F0 being the weakest and F5 the strongest. An update to the old Fujita Scale, the Enhanced Fujita Scale, was implemented in 2007. Tornadoes are rare but not unheard in New York State. A total of 11 tornadoes have been reported in Dutchess County since 1950 (NOAA, *NCDC Storm Events*). All of the tornadoes have been either an F0 or Fl on the Fujita Scale, causing light to moderate damage with winds of up to 112 miles per hour (NOAA, *Storm Prediction Center*). The National Weather Service issues a **tornado warning** if Doppler radar indicates the presence of a tornado, or if a spotter has sighted one. Additionally, a **tornado watch** is issued if conditions are favorable for the development of tornadoes (Florida Division of Emergency Management).

A variety of winter storms can impact Dutchess County. Heavy snowstorms bringing several inches of snow are not uncommon. True blizzard conditions in the area are extremely rare since they require strong winds of at least 35 miles per hour and extreme blowing and drifting of the snow (NOAA, *NWS Glossary*). Storms occurring with mixed precipitation often wreak havoc on Dutchess County. Rain, snow, sleet, and freezing rain may all occur as part of the same storm system. **Freezing rain**, rain that freezes on contact with the ground (NOAA, *NWS Glossary*), is especially problematic, as it can lead to icy roads as well as downed trees and power lines which may cause widespread power outages. On average, Dutchess County receives 12-18 hours of freezing precipitation (rain and drizzle) per winter (Dirienzo, 2008).

Hurricanes are tropical cyclones with sustained winds of at least 74 miles per hour. **Tropical storms** are also tropical systems but weaker, with sustained winds between 39 and 73 miles per hour (NOAA, *National Hurricane Center*). Hurricanes, tropical storms, and their remnants occasionally impact Dutchess County. Several tropical storms and four hurricanes have made landfall in New York State since 1950 (NOAA, *Continental United States Hurricane Strikes*). Since Dutchess County is well north of the Atlantic Coast, the primary impacts from tropical cyclones are heavy rain and flooding. In 1999, Tropical Storm Floyd brought torrential rain to the county as it passed through Long Island and southeast New England. There were widespread reports of over 4.5 inches of rain, with 11.02 inches recorded in Stormville (NOAA, *Floyd Deluges Eastern New York*). The National Hurricane Center in Miami, Florida monitors tropical weather in the Atlantic and eastern Pacific Oceans and issue all pertinent watches, warnings and advisories.

Floods occur frequently in Dutchess County. Each major stream in Dutchess County has a significant number of flood prone areas. Certain areas are known for annual flooding. The probability of flooding is greatest from December to April. Runoff from melting snow and ice often causes minor spring floods. Ice flows and heavy rainfall sometimes aggravate spring runoff conditions, producing severe floods in low-lying areas.

Figure 14. Recent Flooding in Dover, NY, Dutchess County (Town of Dover).

Most major floods in Dutchess County are triggered by coastal storms. Some are caused by storms of tropical nature. Widespread flooding occurred in September 1938 due to the Great Hurricane of 1938, which made landfall in Long Island and Connecticut. In August 1955, Hurricane Diane passed just to the south of the region, leading to record flooding of the Tenmile River and Wappinger Creek.

Severe nor'easters may also produce floods in the County. In April 2007, an area of low pressure intensified rapidly as it moved from the southern Appalachians to the Long Island coast. The storm brought two days of heavy precipitation which brought about extensive flooding of small streams and creeks in the county. Record flooding occurred on the Wappinger Creek at Wappingers Falls, which crested at 15.06 feet, 7.06 feet above the flood stage of 8.0 feet. Moderate flooding also was recorded along the Tenmile River at Webatuck, which crested at 11.23 feet. The storm produced three to eight inches of liquid throughout the county, including 4.99 inches of rain in Poughkeepsie and 6.83 inches in Rhinebeck (NOAA, *Past Storm Events*).

Flash Flooding is a rapid water level rise in a stream or creek above a predetermined flood level (NOAA, *NWS Glossary*). Flash floods can occur anytime of year in Dutchess County. On average, there are about ten days a year when at least one inch of rain falls (NRCC, CLIMOD System). These days are most common between May and October, and the rain is usually courtesy of strong thunderstorms which can often lead to flash flooding. Rapid snowmelt in association with strong precipitation events may also lead to flash flooding during the late winter and early spring.

A **drought** is a deficiency in moisture that results in adverse effects on people, animals, or vegetation over a sizeable area (NOAA, *NWS Glossary*). The county's major drainage basins have sufficient capacity to sustain some flow even during severe droughts, such as the aforementioned drought from 1962-1967. For a period of 29 months between May 1964 and September 1966, the lowest Palmer Drought Severity Index (PDSI) value was -6.66 in November 1964. Serious droughts are rare; brief dry spells are far more common. Dry periods temporarily place crops under stress and often force restrictions in the recreational uses of forested lands because of fire hazards. Mandatory or volunteer water restrictions may also be put in place by local municipalities. Further information about droughts can be found on the Northeast Regional Climate Center's Northeast Drought Page.

AIR QUALITY & POLLUTION

The major air pollutants in Dutchess County are ground-level ozone, particulate matter and acid deposition. Because some of these pollutants are transported across state and county lines, the federal Clean Air Act was enacted to control these pollutants at the state and federal geographic scale. It's important to remember that some pollutants measured in Dutchess County are not emitted here. Likewise, some pollutants emitted in Dutchess County affect downwind areas outside of Dutchess County.

Overview of Clean Air Act

The principle statutory authority for controlling air pollution at the Federal and State level is contained in the Clean Air Act (CAA), which was enacted by Congress and signed into law in 1970. Although subsequently amended, the core provisions of the 1970 Clean Air Act are still in effect. In Section 109 of the law, the United States Environmental Protection Agency (EPA) is directed to establish National Ambient Air Quality Standards (NAAQS) for six specific criteria pollutants:

1. Carbon Monoxide
2. Lead
3. Nitrogen Dioxide (NOx)
4. Ozone (or smog)
5. Particulate Matter and
6. Sulfur Dioxide (SO_2)

For each of the six criteria pollutants, NAAQs are set by EPA at a level designed to protect public health with an adequate margin of safety (Brownell, 1993). One set of limits, the primary standard, protects health. Another set of limits, the secondary standard, is intended to prevent environmental and property damage (United States Environmental Protection Agency 1993).

Under section 110 of the Clean Air Act, each state is required to submit a "State Implementation Plan," commonly known as the "SIP" to the EPA, which details how the state will implement, maintain, and enforce the primary and secondary NAAQS in each air quality control region within the State (United States Code of Federal Regulations). As the regulatory authority for New York State, the NYS Department of Environmental Conservation (DEC), working with local authorities, drafts the SIPs for submission to the EPA to meet the requirements of the Clean Air Act in New York State.

Upon passage of the CAA Amendments of 1990, several changes were put in place, including new designation of areas of the country not meeting the NAAQS for each criteria pollutant, also known as Areas of Non-Attainment. Under the CAA, a geographic area that meets or does better than the primary standard is called an Attainment Area; areas that do not meet the primary standard are called Non-Attainment Areas (United States Environmental Protection Agency 1993). For areas that are in Non-Attainment for any one of the six NAAQS for criteria pollutants, Title 1 of the 1990 CAA Amendments imposes deadlines for meeting the NAAQS that vary with the severity of pollution problems, and requires states to submit revised SIPs – which require that the states make "measurable progress" in meeting the NAAQS.

Ozone

One of the most critical criteria pollutants, ground level ozone, is the main harmful component of smog. It is a highly reactive gas that consists of 3 oxygen atoms. Ozone is not emitted directly, but is formed through chemical reactions between precursor emissions of Volatile Organic Compounds (VOC) and Nitrogen Oxides (NOx) in the presence of sunlight. These reactions are stimulated by sunlight and high temperature, which is why peak ozone levels occur during summer and the warmest period of the day. The VOC and NOx precursors to ozone are produced by the combination of pollutants from many sources, including smokestacks, cars, paints and solvents. According to the EPA, when a car burns gasoline, releasing exhaust fumes, or a painter paints a house, smog-forming pollutants rise into the sky (United States Environmental Protection Agency 1993).

The initial NAAQS for ozone was a maximum 1-hour average not to exceed 0.12 parts per million (ppm) (United States Code of Federal Regulations 2006). In 1997, the EPA established a new NAAQS for ozone. To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm. In May 2008 that standard was lowered from 0.08 ppm to 0.075 ppm. Standards are periodically changed because the Clean Air Act requires the EPA to review and revise standards as new information develops about public health, safety and environmental and property effects of criteria pollutants.

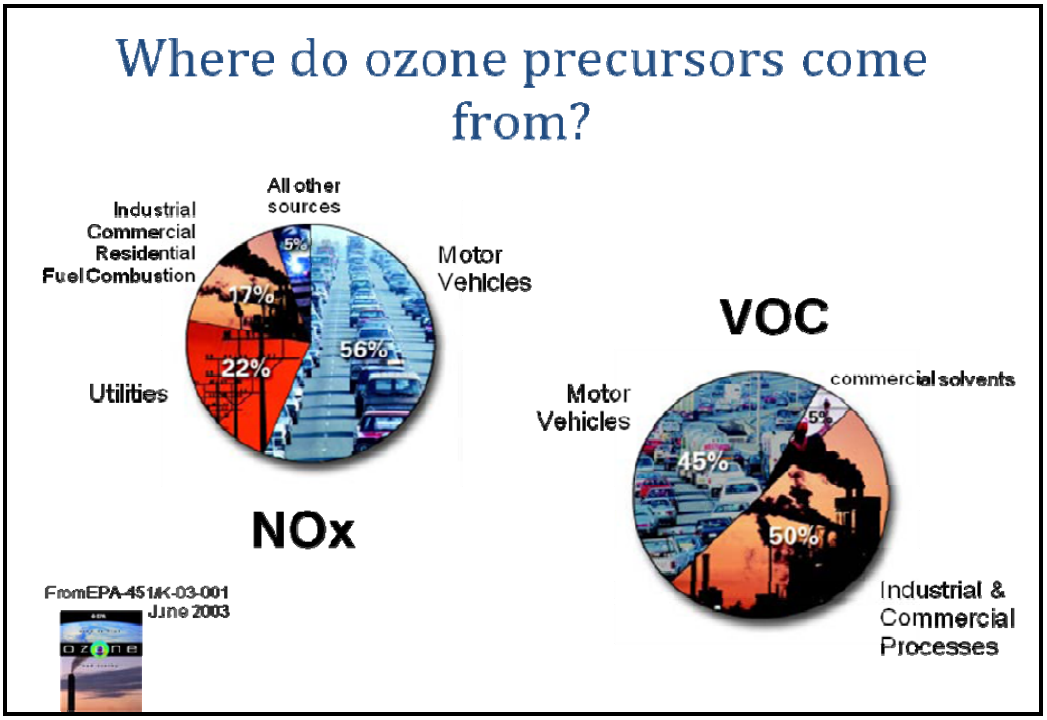

Figure 15: Sources of Ozone (USEPA, 2008).

Ozone in Dutchess County

The United States EPA and New York State DEC maintain a network of air quality monitoring for the United States and New York State, respectively. According to EPA, the EPA's ambient air quality monitoring program is carried out by State and local agencies (United States Environmental Protection Agency 2006). The New York State DEC measures air pollutants at more than 80 sites across the state, using continuous and/or manual instrumentation, as part of the federally-mandated National Air Monitoring Stations Network (NYS DEC). Continuous air quality monitoring of DEC's Region 3 - the Hudson Valley - occurs at several sites, including White Plains in Westchester County, Mt. Ninham in Putnam County, Valley Central in Orange County, and Belleayre Mt. in Ulster County. The only monitoring station in Dutchess County is site #132801, which is maintained at the Cary Institute of Ecosystem Studies in Millbrook, NY. The DEC's Division of Air Resources maintains accurate hourly, daily, monthly and yearly air quality data and forecasting, and information is available from the NYS DEC website. According to the DEC, in 2007, compliance with the existing NAAQS for ozone was met at the Millbrook station in Dutchess County (see Table 2).

Table 2. Comparison between NYS Ambient Air Quality and Ambient Air Quality Standards for Calendar Year 2007 for Ozone for NYSDEC Region 3 (NYS DEC, 2007)[6]

Station	2007 One Hour Averages					4th Highest Daily Maximum 8-Hour Average –Not to exceed an avg. of 0.08 ppm during the last 3 years*			
	Number of Observations > 0.12 ppm	Highest Values, ppm							
		1st	2nd	3rd	4th	2005	2006	2007	Avg.
White Plains	3	0.138+	0.127+	0.126+	0.121	0.095	0.083	0.095	0.091+
Valley Central	2	0.145+	0.131+	0.116	0.093	0.087	0.077	0.084	0.082
Millbrook	0	0.114	0.107	0.097	0.090	0.082	0.064	0.078	0.074
Mt. Ninham	1	0.126+	0.111	0.108	0.108	0.096	0.074	0.086	0.085+
Belleayre Mt.	0	0.088	0.084	0.083	0.082	0.080	0.077	0.073	0.076

Particulate Matter

Particulate Matter (PM) includes dust, dirt, soot, smoke and liquid droplets. It can be formed by condensation or transformation of gases. There are two size classifications for particulates: 10 microns (PM10), which are particles that are less than 10 microns and 2.5 microns (PM2.5), which are particles that are less than 2.5 microns. The PM2.5 size class causes decreased lung function that can have serious effects on individuals with asthma, bronchitis or other airway diseases. PM2.5 is most commonly the result of combustion, including fossil fuel burning, and transformation of gases such as sulfur dioxide, nitrogen oxides, and volatile organic compounds. The National Ambient Air Quality Standards (NAAQS) for PM2.5 include a 24-hour average and annual average, which are not to exceed 35 and 15 µg/m^3, respectively.

Particulate Matter in Dutchess County

PM2.5 is not currently monitored in Dutchess County. The closest monitoring sites are Newburgh and Albany. PM2.5 was monitored in Poughkeepsie between 1999 and 2002 and was compliant within NAAQS during that time. Although Dutchess County is currently within compliance for PM2.5, development and vehicular travel should be controlled to ensure that it remains in compliance.

[6] *NYS and Federal Ambient Air Quality Standard. + Denotes a contravention of Federal AAQS.

Air Quality Index

The Air Quality Index (AQI) is an index that illustrates the level of each of the criteria pollutants. For Dutchess County, AQI's for ozone and PM2.5 are forecast on a daily basis by the NYS DEC. The AQI was created as an easy way to correlate levels of different pollutants to one scale; the higher the AQI value, the greater the health concern. When levels of ozone and/or PM2.5 are forecast to exceed an AQI value of 100, an Air Quality Health Advisory is issued alerting sensitive groups to take the necessary precautions. AQI alerts are reported via media outlets and weather forecasting facilities. For real-time air quality data and forecasts for the Hudson Valley visit the NYS DEC Air Quality Forecast for New York State.

Acid Precipitation

Acid precipitation refers to rain, snow or ice that is more acidic than what is normal for a given area. In the northeastern United States, normal precipitation pH is about 5.2. The pH scale is a measure of acidity ranging from 0 to 14, with pH 7 being neutral, pH less than 7 is acidic, and pH greater than 7 is basic. The pH scale is logarithmic, which means that each pH unit is 10 times that of its neighbor. So a solution with pH 4 is 10 times more acidity than a solution with pH 5. The 1984-2007 average precipitation pH for Millbrook in Dutchess County is 4.31 (Cary Institute of Ecosystem Studies).

Acid precipitation most commonly forms from sulfur dioxide (SO_2) and oxides of nitrogen (NOx). Most SO_2 is emitted by coal burning power plants while NOx most commonly comes from car exhaust and other industrial processes as well as coal burning. In the atmosphere, the SO_2 and NOx transform to sulfate (SO_4^{2-}) and nitrate (NO_3^-) which combine with hydrogen ions (H^+) to form sulfuric acid (H_2SO_4) and nitric acid (HNO_3). Acid precipitation is more correctly called acid deposition. There are 2 forms of acid deposition: wet, which is deposition in the form of rain, snow or ice and dry deposition, which is deposition in the form of gases or particles. By far, most acid deposition falls as wet deposition. H_2SO_4 is the most important component of acid deposition although HNO_3 is also important. Because the prevailing wind direction for Dutchess County is southwest, as it is for most of the northeastern US, we are upwind of the midsection of the country where many coal burning power plants are. Our air and precipitation largely originates in areas with high emissions of the acid deposition precursor SO_2.

Acid deposition and other pollutants harm natural ecosystems and threaten biological diversity. Acid deposition acidifies soils, lakes and streams and enhances the process that makes toxic mercury (another pollutant emitted during the burning of coal) available to organisms. Acid deposition also enhances the mobilization of toxic aluminum from soils to tree roots, increases leaching of sulfate and nitrate to soils and surface waters and promotes the loss of important buffering nutrients from soils. In aquatic systems, aluminum can kill fish and other aquatic organisms, reducing fish species richness. The increased acidity in lakes and other surface waters can reduce ecosystem productivity. While existing acid precipitation regulations are necessary, they are insufficient to conserve natural ecosystems and their valuable services (Lovett and Tear, 2008).

Title IV of the 1990 Clean Air Act Amendments (CAAA) mandates requirements for the control of acid deposition. The CAAA set a goal of reducing annual SO_2 emissions by 10 million tons below 1980 levels. To achieve these reductions, the law required a two-phase tightening of the restrictions placed on the highest emitting fossil fuel-fired power plants. Phase I began in 1995 and Phase II began in the year 2000. The Act also called for a 2 million ton reduction in NOx emissions by the year 2000.

Acid Precipitation in Dutchess County

Figure 16 illustrates the decline in the acidity of precipitation at the Cary Institute of Ecosystem Studies in Dutchess County between 1984 and 2007. Notice, however, that the red line, which represents the acidity of normal precipitation, is still far below our rain's acidity today.

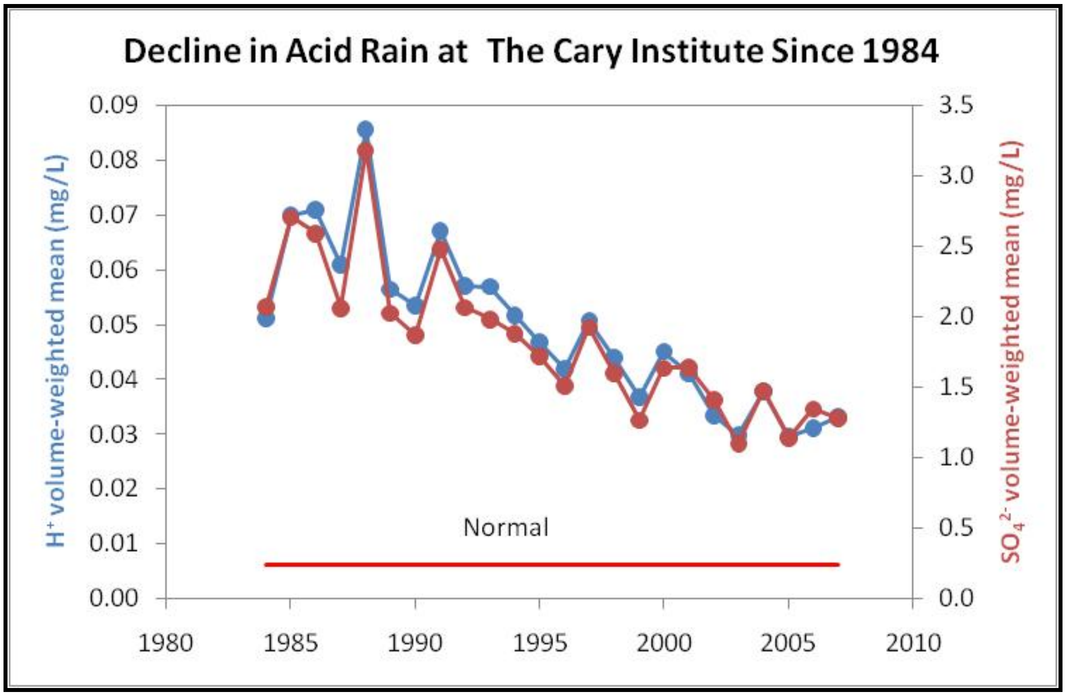

Figure 16: Acid Rain Measurements at the Cary Institute, 1984-2007.

CLIMATE CHANGE

Climate Change is a noticeable change in climatic factors (temperature, precipitation, etc.) over a period of many years. This change can be a result of natural conditions, human influences, or both (NOAA, *NWS Glossary*). Until recently, climate change occurred over long periods of time and has been driven by a variety of natural factors, including variations in solar intensity, changes in the Earth's angle of tilt and orbital shape, occurrence of volcanoes, and the presence of ice sheets. However, there is now strong evidence that the current climate change is occurring rapidly and is in fact being caused by human intervention (IPCC, 2007). The current atmospheric concentration of Carbon Dioxide is about 385 parts-per-million (ppm), the highest level in over 700,000 years. Most of this increase is due to the combustion of fossil fuels by humans (NOAA, *Carbon Dioxide, Methane Rise Sharply*). Natural carbon dioxide and other gases such as methane contribute to the **greenhouse effect**. This is necessary to keep the Earth at a reasonably mild temperature by allowing solar radiation to pass through unimpeded, and simultaneously absorbing outgoing radiation. However, this effect is enhanced as the concentration of these greenhouse gases is increased (Pidwirny 2006).

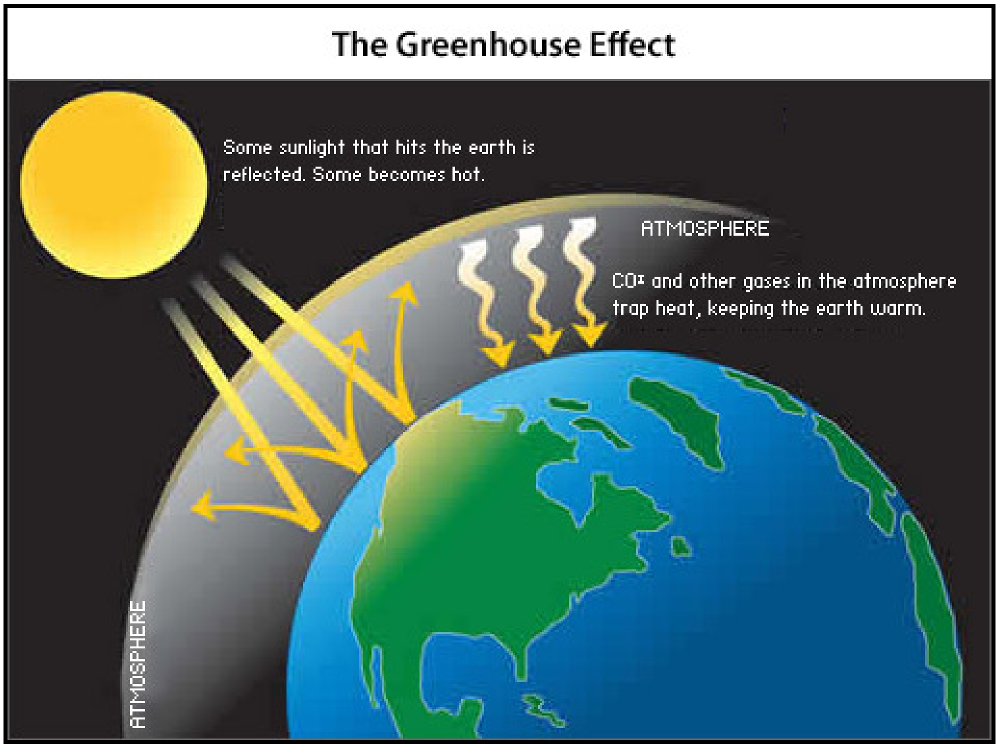

Figure 17: The Greenhouse Effect (eere.energy.gov, 2008).

Average global temperatures in the Northern Hemisphere have risen by over 1°F since 1850 due to the increase in these so-called greenhouse gases. Since 1970 alone, the northeastern United States has been warming by an average of nearly half a degree Fahrenheit per decade. Winter temperatures have been increasing the most, by 1.3°F per decade (Union of Concerned Scientists, 2006). This warming has already brought about numerous notable changes to the climate of Dutchess County and New York. Observed and projected changes of temperature and precipitation are detailed below. These future projections are taken from the Union of Concerned Scientists, Northeast Climate Impacts Assessment (NECIA) and their 2006 report, *Climate Change in the U.S. Northeast*. The future predictions are heavily dependent on society's greenhouse gas emissions. Since there is a lagged response of climate to an increase in greenhouse gases, changes over the next few decades will continue but will not be significantly affected by emissions over that period. However, by the middle of the century and beyond, there are substantial differences between possible changes under higher or lower emissions scenarios. For example, the estimated temperature change in the Northeast by 2100 is double under the higher-emissions scenario than if lower emissions occur (Union of Concerned Scientists, 2006).

Temperatures, Seasons and Climate Change

Dutchess County is already experiencing a rise in temperatures. The mean annual temperature in Poughkeepsie has generally increased during the past 55 years, as evidenced by the Figure 18 below. There has been an overall increase of about 1.1° F during this time period (NRCC, *CLIMOD System*).

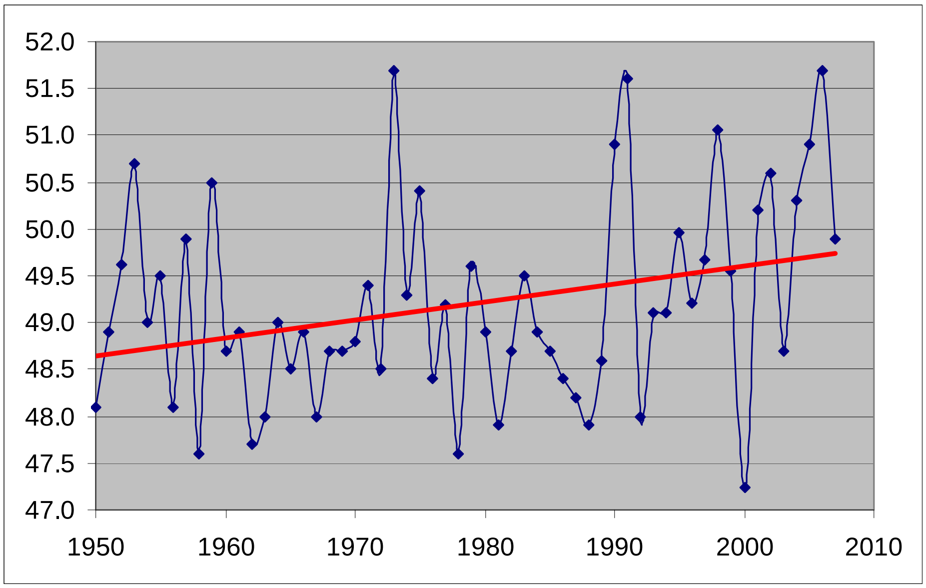

Figure 18: Mean Annual Temperature in Poughkeepsie, 1950-2007 (NRCC, *CLIMOD System*).

Mean temperatures are expected to rise an additional 2-3 degrees by 2039. By the close of the century mean temperatures are expected to be 8-10 degrees above previous levels under the higher emissions scenario and 4-6 degrees warmer under lower-emissions. Summers are projected to warm slightly more than winters, and the combination of warmer temperatures and high humidity may cause summer days to feel 12 to 14 degrees warmer than at the present, which is more comparable to the current climate of South Carolina (Union of Concerned Scientists, 2007).

The timing of the seasons will also be affected by climate change. The growing (frost free) season has increased by over 20 days in Dutchess County over the past 60 years, as shown in Figure 19 (NRCC, *CLIMOD System*). This trend is expected to continue and by the close of the century, the growing season may be 4-5 weeks longer than it is currently (Union of Concerned Scientists, 2006).

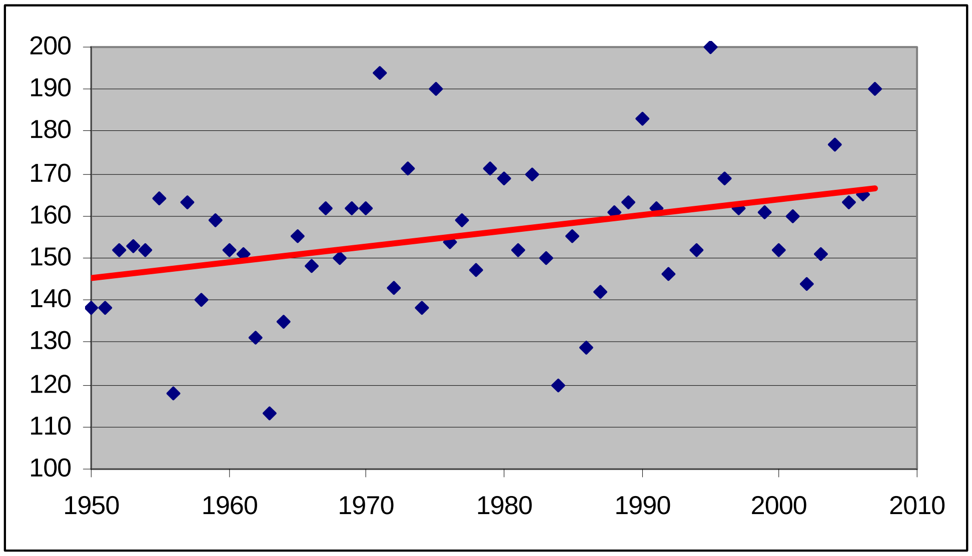

Figure 19: Frost Free Season in Poughkeepsie (number of days), 1950-2007 (NRCC, *CLIMOD System*).

Precipitation and climate change

There has been no discernable trend in annual precipitation in New York State over the past several decades. Precipitation is expected to gradually increase through 2100. The most striking trend is the observed and projected increase in frequency and intensity of extreme precipitation events, especially under the high emissions scenario. In Poughkeepsie, the average number of days per year with at least 2 inches of rain has increased from one to two and a half, as shown in Figure 20. In 2005, there were six of these events, a record during this period (NRCC, *CLIMOD System*). By the end of the century, there will be 1-2 more days of at least 2 inches of rain, and on average 12% more rain during these events (Union of Concerned Scientists, 2006).

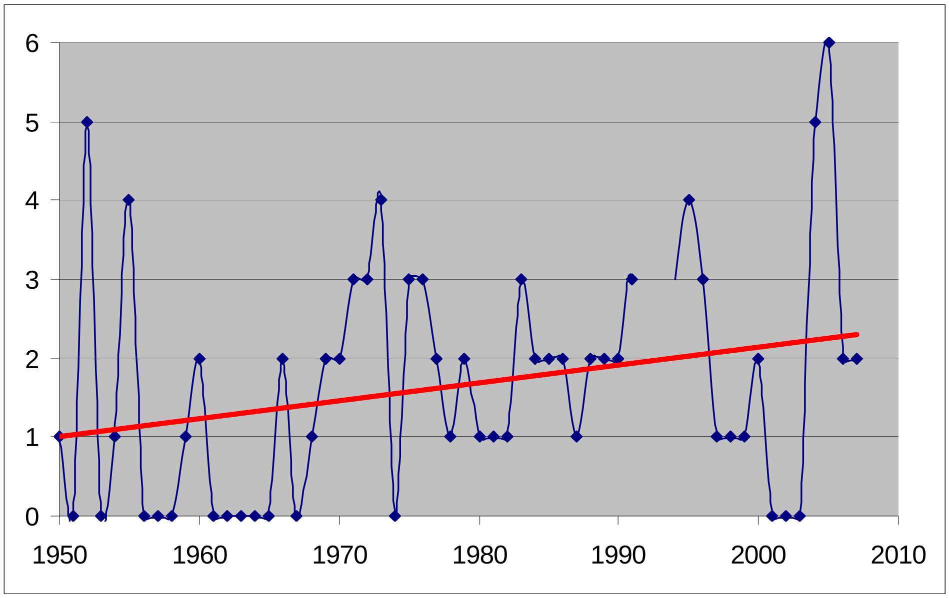

Figure 20: Extreme Precipitation Events in Poughkeepsie, 1950-2007 (NRCC, *CLIMOD System*).

Snowfall and snow cover will be impacted considerably by climate change. The number of days with snow cover has already been decreasing across the Northeast. Throughout the rest this century, the number of days with snow cover is expected to continue diminishing, so that there will be 4-8 fewer snow-covered days per month during the winter. The overall snow season will also shorten, with snowfall arriving later and leaving earlier. As temperatures rise, the snow that does fall will become "slushier"- wetter, heavier, and denser. Furthermore, winter storms which once brought the area just snow will now be more likely to produce sleet, freezing rain, and rain with less, if any snowfall (Union of Concerned Scientists 2006).

CLIMATE DATA

The **National Climatic Data Center**, located in Asheville, North Carolina, is the world's largest active archive of weather data. The NCDC archives 99% of all NOAA data, adding 224 gigabytes of new data daily. The center's stated mission is "to provide access and stewardship to the Nation's resource of global climate and weather related data and information, and assess and monitor climate variation and change" (NOAA, Wha*t is NCDC?*).

The NCDC also manages six regional climate centers which disseminate climate data, research, and applications at a regional and local level. A map of the coverage areas of each regional climate center can be found below (Figure 21). The **NRCC**, located in the Department of Earth and Atmospheric Sciences at Cornell University, covers Dutchess County (NOAA, *Regional Climate Centers*).

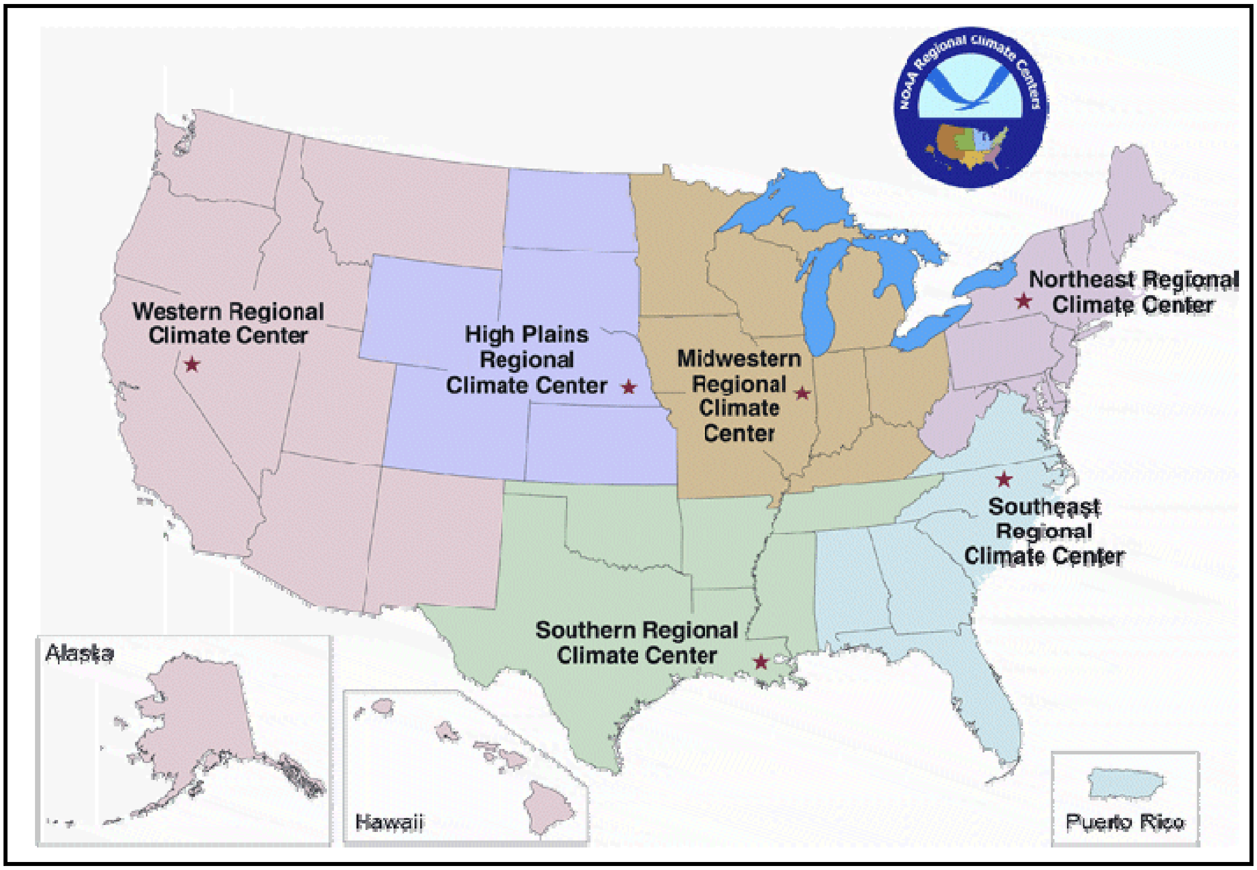

Figure 21: NOAA Regional Climate Centers (NOAA, *Regional Climate Centers*).

Finally, the NCDC and the regional climate centers support the American Association of State Climatologists, an organization composed of state climatologists and the directors of the six regional climate centers. The **New York State Climate Office** is co-located with the Northeast Regional Climate Center at Cornell University.

The National Weather Service's **Cooperative Observer Program** is a climate observing network of over 11,000 volunteers throughout the country. Data is used for NWS products and archived at the National Climatic Data Center (NOAA, *NWS Cooperative Observer Program*). There have been 15 cooperative reporting stations in Dutchess County at one time or another. 8 stations currently operate in the county and are listed in Table 3 below.

Table 3: Weather station locations in Dutchess County (NRCC, *CLIMOD System***).**[7]

Station	Latitude	Longitude	Elevation (ft.)	Years in Service
Beacon	41º 30' N	73º 57' W	322	1930-1935
Clinton Corners	41º 49' N	73º 46' W	280	1971- Present
Glenham	**41º 31' N**	**73º 56' W**	**275**	**1948-1996**
Millbrook (Millbrook School)	**41º 51' N**	**73º 37' W**	**820**	**1948- Present**
Millbrook (Institute of Ecosystem Studies)	*41º 47' N*	*73º 45' W*	*413*	*2004- Present*
Millerton	41º 57' N	73º 31' W	732	1948-1985
Poughkeepsie (South Road)	41º 38' N	73º 55' W	170	1993- Present
Poughkeepsie (Rural Cemetery)	41º 41' N	73º 56' W	102	1948-1974
Poughkeepsie	41º 43' N	73º 56' W	50	1962- Present
Poughkeepsie/ Dutchess County Airport	**41º 38' N**	**73º 53' W**	**166**	**1932- Present**
Poughkeepsie (Midtown)	41º 42' N	73º 56' W	10	1960-1974
Poughkeepsie (Pendell Road)	41º 43' N	73º 55' W	220	1965-1976
Rhinebeck	41º 53' N	73º 52' W	301	1989- Present
Stormville	41º 32' N	73º 44' W	915	1990- Present
Wappingers Falls	41º 39' N	73º 52' W	114	1948- Present

[7] Bold Stations denote NCDC principal reporting stations for 1971-2000 data period. *Italics* denote a member of the US Climate Reference Network.

Table 4: Mean temperatures and total precipitation in Dutchess County, 1971-2000 (NRCC, *CLIMOD System***).**

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp (°F)													
Glenham	26.6	29.2	38.5	49.5	60.7	69.5	74.3	72.7	64.7	53.0	42.9	32.2	51.2
Millbrook	22.9	25.2	34.7	45.5	56.1	64.1	68.7	67.0	58.8	47.9	37.7	28.1	46.4
Poughkeepsie	24.5	26.8	36.4	47.4	58.4	66.9	71.9	70.5	62.0	50.1	40.4	30.0	48.8
Total Precipitation (inches)													
Glenham	3.48	2.90	3.49	3.95	4.50	4.11	4.65	3.92	4.11	3.70	3.69	3.29	45.8
Millbrook	3.05	2.62	3.07	3.40	4.34	3.96	4.37	4.24	3.82	3.61	3.12	2.99	42.59
Poughkeepsie	3.19	2.53	3.59	3.79	4.73	3.73	4.72	3.83	3.69	3.56	3.53	3.23	44.12

POLICY CONSIDERATIONS

Climate, the synthesis of long term weather patterns, dictates many facets of life in Dutchess County. The county experiences a humid continental climate, with hot summers, cold winters, and generally sufficient precipitation. Severe weather such as thunderstorms, winter storms, and floods occasionally impact Dutchess County.

Climate change is already happening in Dutchess County. Changes such as milder temperatures, more extreme precipitation events, and a longer growing season have already been observed. In the future, there are expected to be additional, more extreme changes to the climate of the area if greenhouse gas emissions continue to increase.

Climate change will have far-reaching effects on many industries. Businesses have begun to adapt to climate change by improving efficiency, lowering greenhouse gas emissions, and implementing new technology. However, business leaders must also remember to take into account the future risks of climate change when planning and making decisions. Those involved in agriculture, insurance, transportation and many other sectors must be cognizant of the latest climate change information and future projections (Sussman and Freed).

RESOURCES FOR ADDITIONAL INFORMATION

- **Albany National Weather Service Forecast Offic**e: The office provides weather forecasts, observations, and climate data for Dutchess County and surrounding locations in Eastern New York and Western New England. See: http://www.erh.noaa.gov/er/aly/.
- **Cary Institute of Ecosystem Studies**: Provides real-time and summarized climate data from Millbrook, NY through the Cary IES Environmental Monitoring Program, at: http://ecostudies.org/emp_daily.html.
- **Jet Stream:** Many of the hyperlinks in this document link to **Jet Stream**, an online weather course for the general public from the National Weather Service. The homepage is: http://www.srh.noaa.gov/jetstream/index.htm.
- **National Climatic Data Center**: Provides climate data free of charge, at: http://www.ncdc.noaa.gov/oa/mpp/freedata.html.
- **Union of Concerned Scientists**: Provides reports and findings from the **Northeast Climate Impacts Assessment**. See: http://www.northeastclimateimpacts.org/.

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