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Weather and Climate

INTRODUCTION

Weather and climate are topics that stir the interests of most North Carolinians, particularly those who have outdoor interests or those who have lived through tornadoes, hurricanes, blizzards, and floods. The earth's atmosphere is constantly in a state of change—warm air interacting with cold air, storms moving across the continents, mountain barriers forcing air to rise and descend. All of these complex processes occur in the atmosphere and cause variations of temperature, humidity, cloudiness, precipitation, pressure, winds, and storms, and together they form weather. Therefore, weather can be defined as the atmospheric conditions in a specific place at a specific time.

Even though the weather varies from day to day, month to month, and even year to year, it is possible to discuss the composite of day-to-day weather conditions over the long term. Such average conditions are known as climate. An accurate description of an area's climate requires at least thirty years of weather records, and preferably more. Climate must not be viewed as a static element. Although it is difficult to ascertain if annual variations in weather are indications of a changing climate, deviations from observed climatic conditions over longer periods of time, such as decades or centuries, can be the result of a changing climate. In the last 500 years, the earth has witnessed significant variations in climate, North Carolina included. The Little Ice Age, extremely well documented in Europe, was a prolonged period of colder temperatures on a global scale that spanned three centuries from 1550 to 1850 (Barry 1992; Grove 1998).

Weather is short-term atmospheric conditions in a specific place, whereas climate is the long-term averages of these atmospheric conditions. As the saying goes, "climate is what you expect; weather is what you get" (McKnight 1996). The cold and snowy climate of the state's northern mountains may bring skiers in hopes of great skiing, but the warm, rainy weather on a particular winter day most likely will cause them to leave.

CONTROLS AND INFLUENCES OF WEATHER AND CLIMATE

Weather and climate are products of a combination of factors that are divided and discussed in the following manner: 1) controls, 2) synoptic (sub-continental) influences, and 3) local and regional influences. Each of these is fundamental in determining specific weather and climate characteristics for a particular region.

Controls of Weather and Climate

Many factors control weather and climate processes in North Carolina. The most important of these controls are latitude, elevation, the distribution of land and water, and topographic barriers. Depending on the specifics of location, all of these controls have varying degrees of influence on the weather and the climate.

Latitude (degrees north or south of the equator) is the main factor in determining the amount and intensity of incoming solar radiation, or insolation. Those areas that receive the sun's noontime rays at the greatest angle are exposed to the most concentrated insolation and therefore experience higher temperatures (Figure 1.4). Highest insolation intensity occurs over the tropics, while it is lowest in the polar regions.

Solar insolation has important implications for explaining seasonal weather and climate variations. As the earth revolves around the sun, the sun's vertical rays migrate north and south of the equator and seasons occur. In December and January, the sun's vertical rays are in the Southern Hemisphere. So, maximum insolation intensity and maximum heating are found in areas south of the equator. Simultaneously, the sun's rays strike North Carolina at comparatively low angles, providing considerably less heat energy and lower temperatures. In June and July, the sun's vertical rays are now in the Northern Hemisphere and North Carolina receives more intense insolation and more daylight, leading to higher temperatures. In Raleigh, for example, the noon solar elevation is 78° on June 21, whereas it is only 31° on December 21 (Figure 2.1).

Since the tropics receive higher levels and intensities of insolation than the polar regions on an annual basis, a latitudinal energy imbalance develops. Thus, weather is essentially an attempt to redistribute the latitudinal imbalances of heat energy—both horizontally and vertically—in the atmosphere.

Elevation is a second fundamental control on weather and climate. As a general rule, temperatures decrease 6.4°C per 1,000 meters (3.5°F per 1,000 feet) increase in elevation, whereas precipitation, relative humidity, cloud cover, and wind speed typically increase with elevation. Therefore, all other factors being equal, temperatures on the highest peaks of the Smoky, Balsam, and Black mountains of western North Carolina can be expected to be around 11.7°C (21°F) colder than places just above sea level at the same latitude. The higher elevations of the mountains also receive greater amounts of rain and snow, experience higher relative humidity, and have greater cloud cover and wind speed.

Large bodies of water, such as the Atlantic Ocean, have a very important influence on weather and climate patterns. Water both heats up and cools down much more slowly than land, leading to a general moderating influence on the local and regional climate known as the maritime effect. Therefore, temperatures in the Tidewater and Coastal Plain regions, particularly within a few miles of the coast and on the Outer Banks, are generally warmer than readings in interior locations during the winter and slightly cooler during the summer. The maritime effect helps to explain why the average January temperature is 2.6°C (36.7°F) in Greensboro, whereas it is a much warmer 7.0°C (44.6°F) at Cape Hatteras. The Atlantic Ocean is also an important source of moisture. This is demonstrated with the higher average annual precipitation along the Coastal Plain and Tidewater regions, as compared with Piedmont locations.

Topographic barriers, in this case the southern Appalachians, constitute a final major influence on weather and climate in North Carolina. These highest mountain ranges east of the Mississippi River, modify and change weather systems and air masses as they move from west to east across North America, leading to differences in the weather and climate in locations such as Chattanooga, Tennessee, and Charlotte. The southern Appalachians often serve as a hedge against cold, Canadian air masses that routinely invade the eastern United States. Consequently, temperatures east of the mountains can be slightly milder in winter than one would otherwise expect. In addition, the mountains force air to rise, resulting in orographic lifting and increased precipitation totals over the higher elevations (Box 2A).

Synoptic Influences

Weather and climate are not only products of the physical landscape of a given area (its latitude, elevation, and relative location in relation to bodies of water and topographic barriers), but also ultimately of atmospheric processes. The controls discussed in the preceding section affect the atmospheric processes, but they do not produce them. It is the clash of different air masses and the work of upper-level rivers of air, known as jet streams, that conspire to produce most of the weather systems affecting North Carolina. Therefore, it is important to introduce some of the sub-continental, or synoptic, influences: air masses and source regions, types of precipitation mechanisms, and the location of the polar front jet stream.

Air mass characteristics are very important in determining what the weather conditions for a particular day may be, or in describing the winter climate of the mountains. Thermal and moisture properties of an individual air mass are directly related to its source area. An air mass that originates over warm

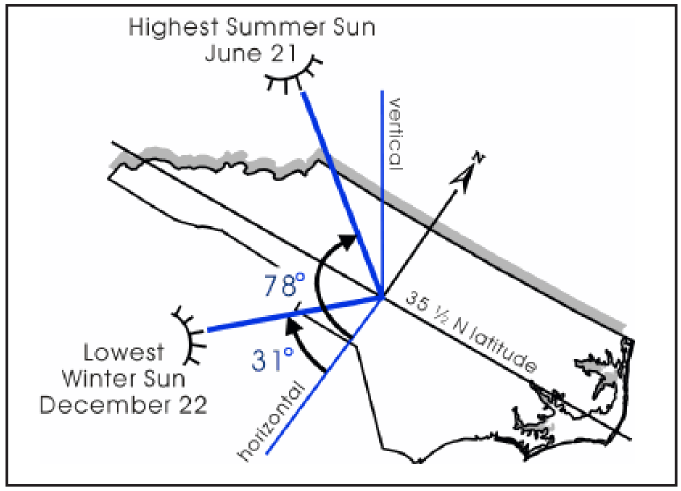


Figure 2.1: Noon Sun Angles.

ocean waters will display warm temperatures and high moisture content, whereas an air mass originating in the Klondike region of Canada will be cold and dry. Based on these thermal and moisture characteristics, it is possible to identify four different types of air masses that affect us in North Carolina (Figure 1.2). Maritime tropical (mT) air masses originate over the warm waters of the Gulf of Mexico and Atlantic Ocean. Maritime polar (mP) air masses that sometimes affect our state have their source over the Labrador Current, just off the Newfoundland and Nova Scotia coast. Continental tropical (cT) air masses form mainly in the summer months over the southwestern United States and occasionally influence our weather. The continental polar (cP) air masses are those that bring the cool, refreshing air during the summer months, or the bone-chilling cold of January. They generally originate in interior sections of northern Canada, far from moisture sources (Ahrens 1991).

Maritime tropical (mT) and continental polar (cP) air masses are the dominant players in our weather and climate. In the summer months, maritime tropical (mT) air is in firm control, allowing hot and humid conditions to prevail. As we move to the fall and winter, however, continental polar (cP) air masses tend to be more dominant. During the winter and spring months, in particular, when the thermal contrast of air masses is greatest, strong jet streams develop and spawn powerful winter storms with very pronounced divisions between cold and warm air masses.

The type of air mass or the interaction of different air masses directly influences precipitation. Maritime tropical (mT) air masses, dominating our summer weather and climate, favor convectional precipitation, and are synonymous with scattered afternoon and evening thunderstorms. As the land heats during the daytime hours, temperatures rise, creating great thermal contrasts in the lowest levels of the atmosphere. Convection allows the hot air to rise, causing condensation and cloud formation. The end result is the formation of towering cumulonimbus clouds, or thunderheads, and the potential for brief, hard rainshowers and possibly hail.

In fall, winter, and spring, however, precipitation mechanisms are a bit more complex. Most of our precipitation during this period comes from cyclonic and frontal activity, in direct association with the jet stream and contrasting air masses. Mid-latitude wave cyclones, or areas of low pressure—also referred to as storms, develop along these jet streams and their counter-clockwise circulation helps to draw warm air to the north on the storm's southeastern edge and cold air to the south on the western side (Figure 2.2). As these warm and cold fronts interact with dissimilar air masses, air is forced to rise, clouds form, and precipitation results (Figure 2.3). Often, a strong cold front trailing behind a well-developed mid-latitude wave cyclone will sweep across the state, bringing with it a strong line of thunderstorms as the warmer, less dense air ahead of the front is forced to rise by the colder, denser air behind the front (Photo 2.1). Warm fronts also cause air to rise and produce precipitation, although precipitation is usually less intense, yet of longer duration, than with a cold front (Photo 2.2) (Ahrens 1992).

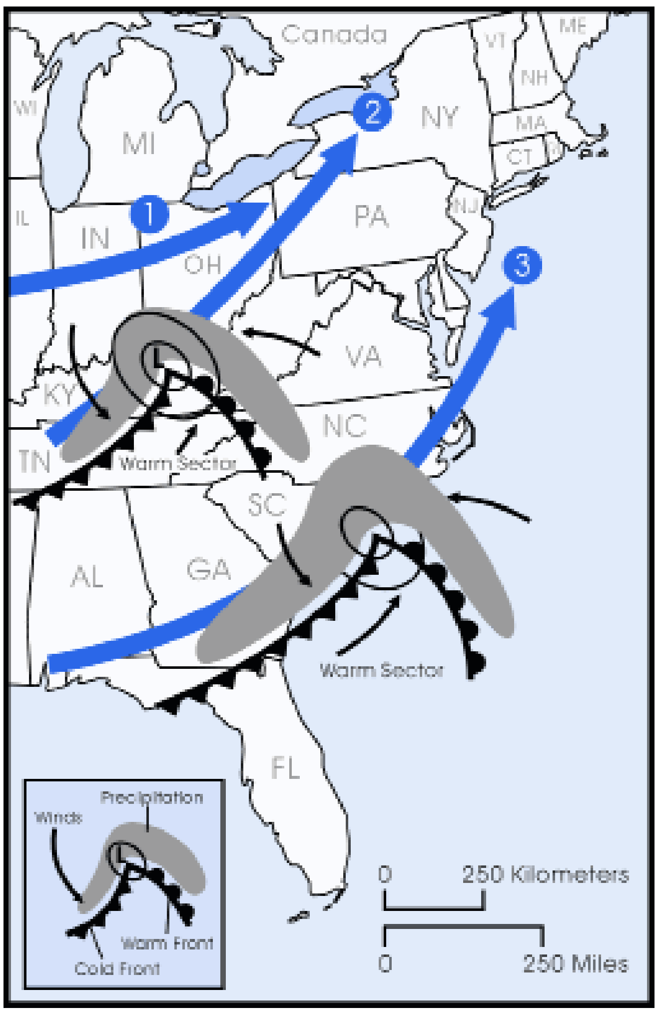


Figure 2.2: Mature Mid-latitude Wave Cyclone and Associated Storm Tracks.
Source: Modified from Meteorology Today, 1991 and Sierra Club Guide, 1980.

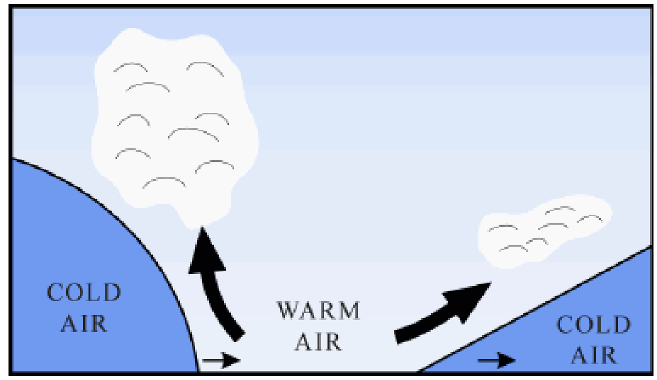


Figure 2.3: Frontal Lifting.

The type of precipitation, intensity, winds, and many other factors are directly related to the path, or track, of the mid-latitude wave cyclones (Figure 2.2). In the winter months, storm tracks generally fall into three categories across the eastern United States. First there are the storm tracks that follow a general west-east route, but well to our north (1). When these dominate, North Carolina can expect generally mild conditions, due to the dominant south and southwesterly flow south and east of the storm track. A second major storm track moves from the lower Mississippi Valley northeastward, paralleling the Appalachian Mountains to the west (2). Since North Carolina, particularly its western sections, is closer to the storm track, precipitation is of longer duration and greater, although temperatures remain relatively mild due to the warm sector on the eastern side of the storm. The third major storm track comes out of the Gulf of Mexico and follows the eastern seaboard, often directly over the warm waters of the Gulf Stream (3). It is this storm track that brings the most intense winter weather. As these storms (known as nor'easters as they move into the northeastern United States) pass through North Carolina, the majority of the state is in the western—or cold—section of the storm, producing heavy snowfalls in the mountains and occasionally in Piedmont and Coastal locations as well (Zishka 1980). The great Blizzard of March 1993 was of this type; it brought up to 1.3 meters (4 feet) of snow to the North Carolina mountains.

In mountain locations, orographic lifting helps to enhance precipitation throughout the year (Figure 2.4). As air is forced up

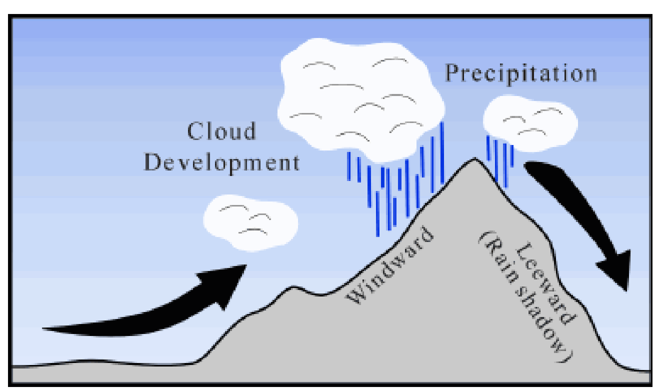


Figure 2.4: Orographic Lifting.

and over mountains, it cools, and as air cools the amount of water vapor (moisture) it can hold decreases. Clouds and precipitation often form as the water vapor condenses while the air is rising up the mountain slopes (Photo 2.3). Orographic lifting, therefore, is very effective in squeezing moisture out of the atmosphere and is an important lifting mechanism for precipitation formation in the western part of the state. Box 2B further details orographic lifting and the associated variability of precipitation totals in the mountains.

The location of the polar front jet stream is a fundamental influence on weather and climate in the mid-latitudes. This middle and upper level zone of high winds is the result of contrasting air masses; consequently, areas south of the polar front jet stream can usually expect much milder conditions than those areas to the north, or on the other side. Strongest in winter, the polar front jet stream varies widely, sometimes carving out pronounced ridges and troughs in the long-wave pattern, known as a meridional flow, or maintaining a rather uneventful zonal flow. The coldest temperatures of the year almost always coincide with a deep trough in the polar front jet stream, which allows cold continental polar air to dominate our weather. In this particular instance, we are north of the polar front jet stream. Conversely, our warmest weather in the winter is usually associated with a pronounced ridge in the upper level pattern, at which time we find ourselves south of the polar front jet stream.

Local and Regional Influences

In addition to the synoptic influences on our weather and climate, there are numerous regional and even local influences. Local residents and even the occasional tourist recognize that a nice breeze usually develops on hot summer afternoons along the coast, or that the valley bottoms are the coldest places on clear, calm nights. Urban heat islands, valley and mountain breezes, and rainshadow effects are also direct influences. Such regional and localized phenomena help give North Carolina's weather and climate a special flavor. This makes the job of weather forecasting in North Carolina a challenge.

A sea breeze developing in the afternoon hours along the coast brings a welcome relief to the searing summer heat. Although actual temperatures may only be slightly cooler than farther inland, the apparent temperature is much cooler, as the differential heating of land and water fuels a strong sea breeze, blowing from sea to land. On hot summer afternoons, air temperatures on land can be as much as 9°C (25°F) greater than air temperatures directly over the sea just a few miles offshore. Warm air over the land rises, creating a localized area of low pressure at the surface (Figure 2.5). A localized area of high pressure immediately develops over the relatively cool water and a pressure gradient, the fundamental force behind wind, is established. As the sea breeze kicks in, a return flow develops in the upper levels, completing the cycle. In the early morning hours, just the opposite occurs. Temperatures on land are cooler than the nearby ocean and a land breeze develops (McKnight 1996).

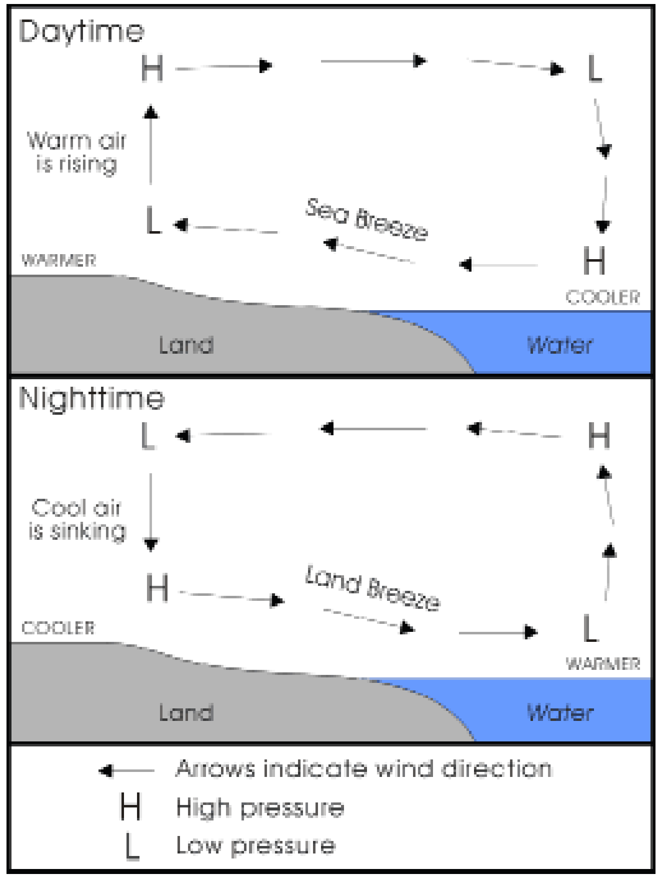


Figure 2.5: Sea Breeze Phenomenon.

Due to the topographic irregularities in the mountains, complex variations in temperature and precipitation occur over very short distances. Yet, some aspects of these mountain conditions are quite common and can be predicted with reasonable certainty. The formation of valley and mountain breezes is a general characteristic common to all mountain areas around the world. As Figure 2.6 illustrates, daytime heating causes the rising of air up the mountain slopes, leading to the formation of a valley breeze. At night, this process reverses, and the colder, denser air from the peaks and ridges begins to slide down the slopes and drains to the lowest level in the landscape (Figure 2.7). Thus a mountain breeze is air moving from the mountaintop to the valley bottom. During periods of clear, stable weather, cold air drainage helps to produce relatively consistent breezes on the slopes of a mountain, with a result of much colder temperatures at the bottom of the valley, as opposed to several hundred feet up the slope. These higher slope thermal belts are where those crops sensitive to late or early-season freezing temperatures, such as apples, are found. Temperature inversions are synonymous with these events, indicating that temperatures are warming with an increase in elevation, rather than cooling—as normally would be expected (Barry 1992). Topographic enclosures in close proximity to high mountains, such as the Banner Elk area of Avery County, or the Oconoluftee area of Swain County, demonstrate impressive cold air drainage throughout the year and consistently register the coldest minimum temperatures in the state.

Orographic lifting helps to produce complex variations in precipitation over short distances in mountain environments. As air rises over a mountain barrier, it cools and condenses, forming clouds and quite often precipitation. This side is referred to as the windward side. As long as air keeps rising over the topographic barrier, the lifting mechanism is present and precipitation is often the result, depending on water vapor content and temperature. However, once the air has reached the peak or ridge, it begins to descend—warming and drying out along the way. Consequently, this leeward side is much drier and warmer than the windward side. Most high peaks and mountain ranges, including our mountains, have pronounced rainshadows on their leeward sides. Box 2B highlights these precipitation variations across the southern mountains.

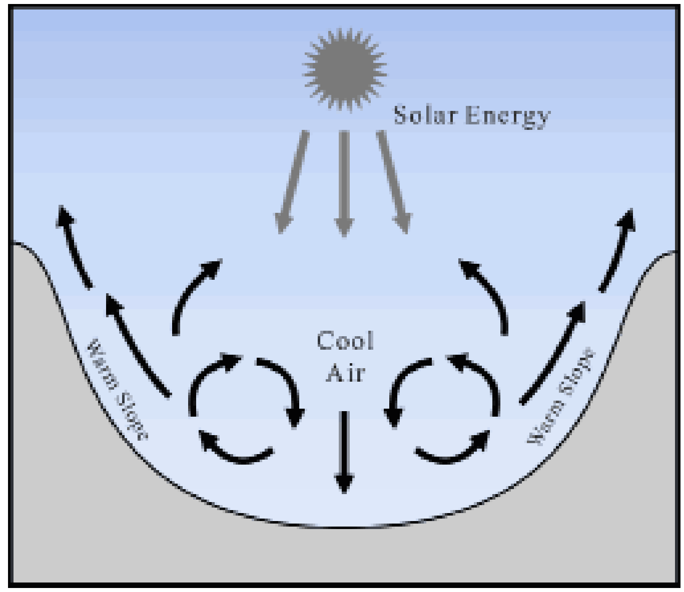


Figure 2.6: Valley Breezes.
Source: Sierra Club Guide, 1980.

ELEMENTS OF NORTH CAROLINA'S CLIMATE

Temperature, precipitation, wind, sunshine, and relative humidity are all important elements defining our state's climate. Among these, temperature and precipitation are perhaps the most obvious and easiest to observe, but the other, more subtle elements are important and have significant influences on our daily lives.

Temperature

Temperature varies considerably across the state, depending on location, elevation, time of day, and season. Even though average temperatures follow a fairly predictable pattern during the course of the year, reaching maximum readings in the summer months and minimum readings in the winter months, summer frosts and snowfalls have been observed in the mountains and coastal locations have baked even in the middle of winter. Nonetheless, average annual temperature is a very useful descriptor and highlights important variation within North Carolina. Average annual temperature readings range from a low of 5° Celsius (40° Fahrenheit) in many higher elevation areas of the mountains to around 16° Celsius (60° Fahrenheit) in coastal locations (Figure 2.8). January is generally the coldest month of the year, with average temperatures for the month again showing great variability—ranging from -4° Celsius (20° Fahrenheit) on the highest peaks to the 7° Celsius (40° Fahrenheit) in some coastal locations (Figure 2.9). Temperatures are a bit more uniform, particularly across the eastern third of the state, during July, the warmest month of the year. The higher elevation areas of the mountains remain much cooler than the rest of the state, with average temperatures close to 15.5°Celsius (60°Fahrenheit). Most of the Piedmont, Coastal Plain, and Tidewater, however, have average temperatures between 24° Celsius (75°Fahrenheit) and 27° Celsius (80° Fahrenheit) (Figure 2.10).

The mountains have the greatest variation in temperature. Figure 2.11 highlights these variations by providing a more detailed view of the average July temperatures across the western part of the state. In spite of these complex variations, clear patterns do exist. Average temperature in the mountains is basically

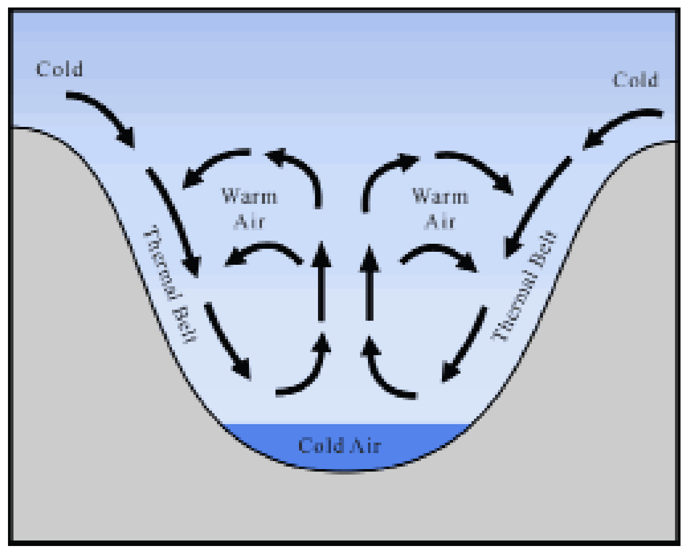


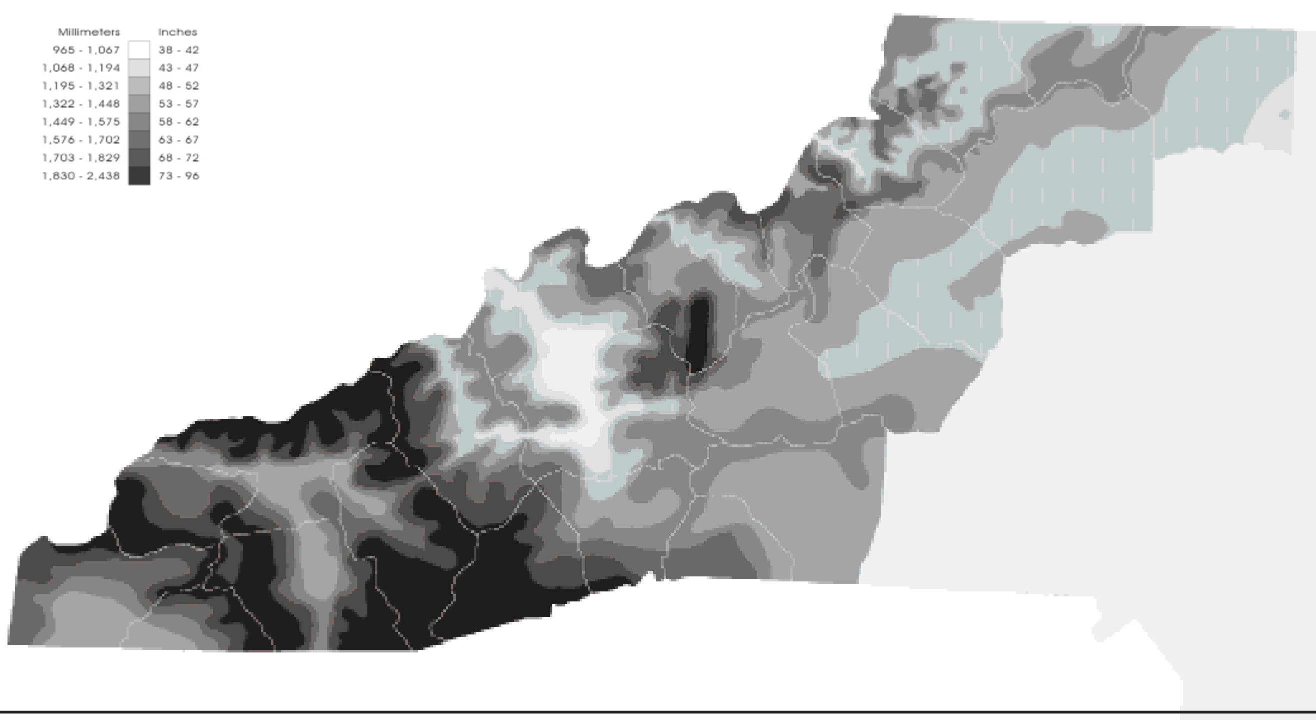
Figure 2.7: Mountain Breezes and Cold Air Drainage.
Source: Sierra Club Guide, 1980.

a product of elevation. Therefore, the highest elevations of the Great Smoky Mountains, Balsam Mountains, Pisgah Range, Black Mountains, Roan Mountain area, Grandfather Mountain area, and the Snake Mountain area experience the coolest temperatures. Conversely, the lowest elevations, the river basins of the Hiwassee, Little Tennessee, Pigeon, French Broad, Toe, and the Watauga—in addition to the Foothills counties—experience the warmest readings.

Box 2A: Orographic Lifting and Rainshadow Effects.

Precipitation varies greatly across the mountains—even across relatively short distances. Steep and considerable rises in the land cause orographic lifting to occur throughout the year, greatly enhancing precipitation amounts across higher elevations and windward slopes. In addition, leeward slopes with their associated rainshadow effects help to explain why some places, most notably the Asheville Basin, are the driest in the state. Orographic lifting also contributes greatly to the high snowfall totals parts of the mountains observe, whereas snowshadow effects impact annual snowfall amounts as well. Average annual precipitation variation is perhaps best represented and understood through a journey beginning in Lake Toxaway, in Transylvania County, to downtown Asheville, in Buncombe County. Lake Toxaway, at 939 meters (3,080 feet) , is situated near the top of the southern margin of the Blue Ridge escarpment. As already moist air hits the abrupt escarpment, orographic lifting maximizes precipitation totals at 2,327 millimeters (91.6 inches). Rosman, at a lower elevation (671 m/2,200 ft) and ten kilometers (six miles) east of Lake Toxaway (as the crow flies), is still in a favorable position, along the southern margin of the Blue Ridge escarpment, for orographic lifting. Average annual precipitation of 2,080 mm (81.9 in) is predictably less than Lake Toxaway. Continuing to the northeast, we move farther away from the escarpment, but as of yet pass no significant mountain barrier, arriving in Brevard (657 m/2,155 ft) after thirteen kilometers (eight miles). Here the average annual precipitation is 1,704 mm (67.1 in). As we journey on toward the northeast and gradually curve around to the north-north east, we move farther away from the Blue Ridge escarpment and associated orographic lifting and begin to come under the influence of the rainshadow cast by the Pisgah Range, located just to the west-southwest. Here at the

Average Annual Precipitation



sheville Regional Airport (652 m/2,140 ft), average annual recipitation totals 1,209 mm (47.6 in), almost 508 mm (20 in) less than in Brevard, thirty-one kilometers (nineteen miles) away! Continuing north sixteen kilometers (ten miles) to downtown Asheville (683 m/2,242 ft), we actually gain some elevation but we enter a basin ringed with high mountains in all directions, except south. The rainshadow effect is dramatic here, as average annual precipitation has now dropped to 965 mm (38.0 in), less than half of the 2,327 mm (91.6 in) in Lake Toxaway, just sixty kilometers (thirty-seven miles) away. This journey from Lake Toxaway to Asheville is just one of a number that one can take to highlight the extreme variations in precipitation due to the elevation and orientation of the mountain ranges (Robinson et al. 1993).

Average annual snowfall amounts also vary considerably, depending on elevation, aspect, local relief, and regional topography. Temperature is undoubtedly the major control on snowfall, but orographic lifting is also critical in explaining the variation in snowfall amounts. Even though temperatures are cold enough for snowfall across much of the mountains quite often, it is only those favorable windward and higher elevation areas that are going to receive significant snowfall under certain circumstances. High pressure builds and provides a northwest wind with residual moisture from lake-effect snows of the Great Lakes or a backlash in association with a mid-latitude wave cyclone. Then the orographic processes serve to extract the remaining moisture. Under these circumstances, Clingman's Dome (in the Great Smoky Mountains) gets hammered with heavy snows, while Bryson City will have clear and dry conditions. North Carolina's northern mountains also tend to be affected by orographically-induced snowfall, more so than other mountain locations in the State.

As the examples in this box indicate, precipitation varies considerably on a spatial scale in the mountains. Higher elevations and more exposed windward areas exhibit the highest

Average Annual Snowfall

Photo Courtesy of Mike Mayfield

Photo 2.1: Cumulonimbus clouds, or Thunderheads, often form in conjuction with cold fronts pushing through an area or through convective acitivty. Storms generated by these formations are localized, can be very severe, and may even spawn tornadoes.

Photo Courtesy of Mike Mayfield

Photo 2.2: Warm fronts normally produce gentle rains with several overcast days, and the stratus clouds resemble a blanket coverage in the sky. Here stratocumulus clouds, as seen from above, give testimony to this type of cloud formation.

Photo 2.3: Cloud formations, often a result of orographic uplifting, are seen here during the winter in the Mountain Region. Rapid rises in elevation force moist air over the mountain top and cause the air to be cooled and reach its dew point.

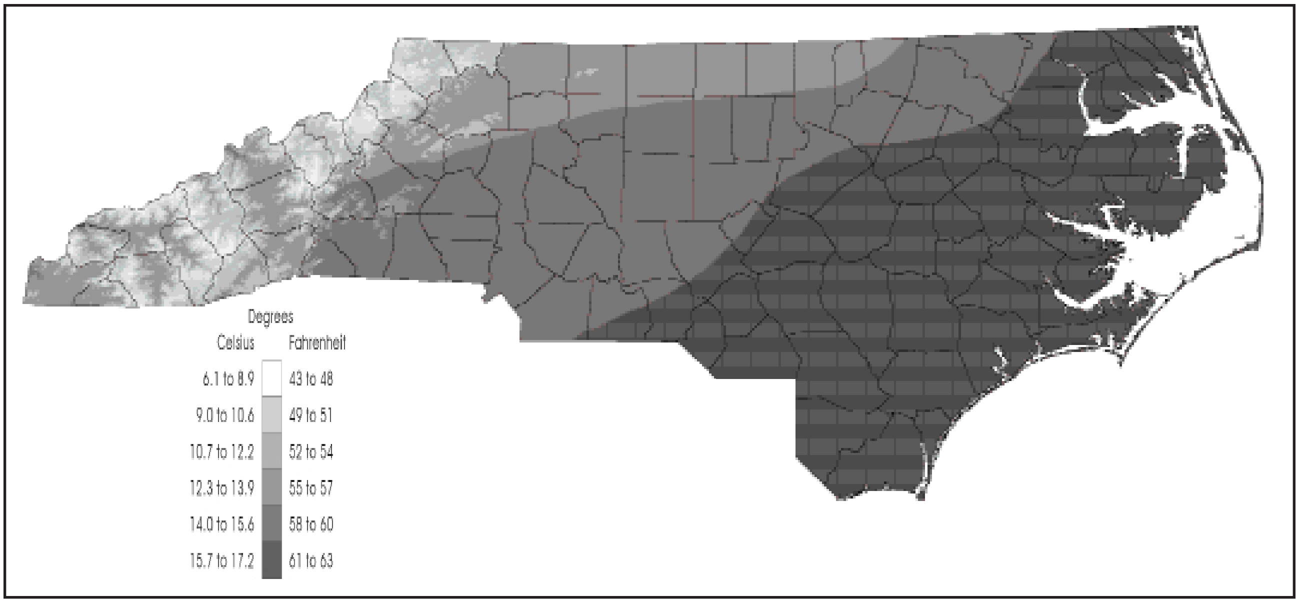


Figure 2.8: Average Annual Temperature.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

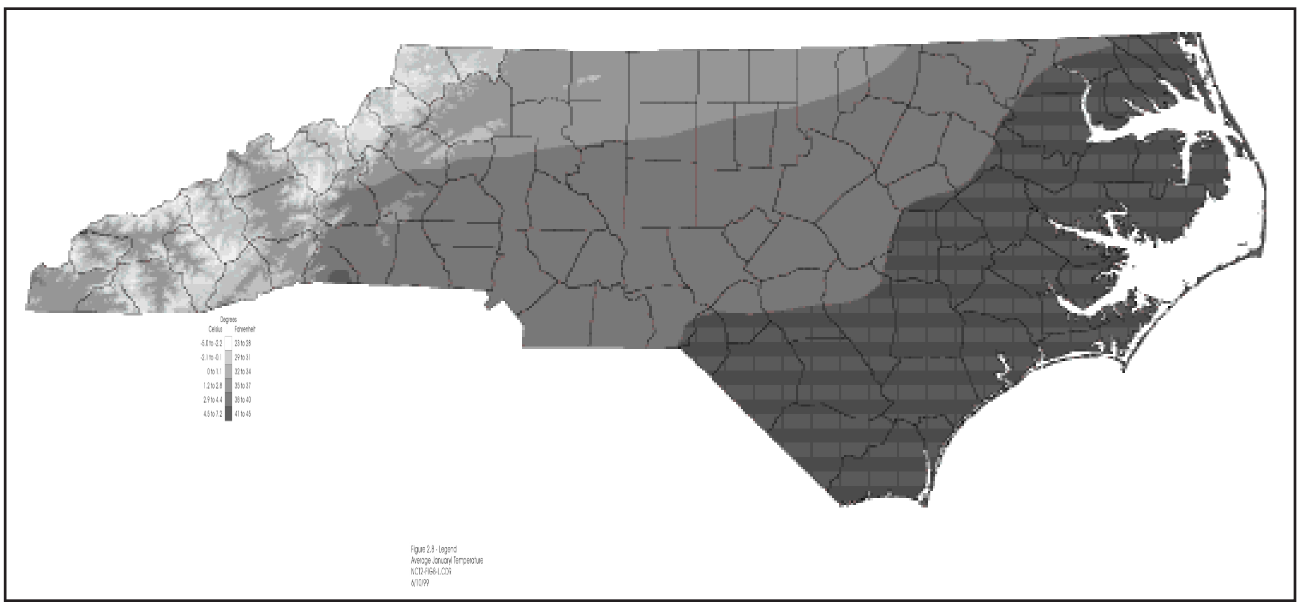


Figure 2.9: Average January Temperature.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

Precipitation

Average annual precipitation also varies considerably across the state, particularly across the mountains where orographic lifting and rainshadow effects predominate. Average annual totals range from 965 millimeters (38 inches) in parts of the Asheville Basin to in excess of 2,286 millimeters (90 inches) in parts of the southern mountains, although most of the state is in the 1,092 to 1,448 millimeters (43 to 57 inch) range (Figure 2.12). It is easy to note the influence of the Atlantic Ocean on average annual precipitation. The southeastern portions of North Carolina, in addition to the Outer Banks, average substantially greater amounts of precipitation than interior Coastal Plain and Piedmont locations. Here the mixing of different air masses and the greater relative impact of hurricanes provides the main rain-producing mechanisms.

Even though most of the state receives little, if any snow, during the winter months, higher elevations in the mountains can expect significant accumulations. Average annual snowfall amounts are primarily a product of elevation, although other factors such as surrounding topography, latitude, and storm tracks

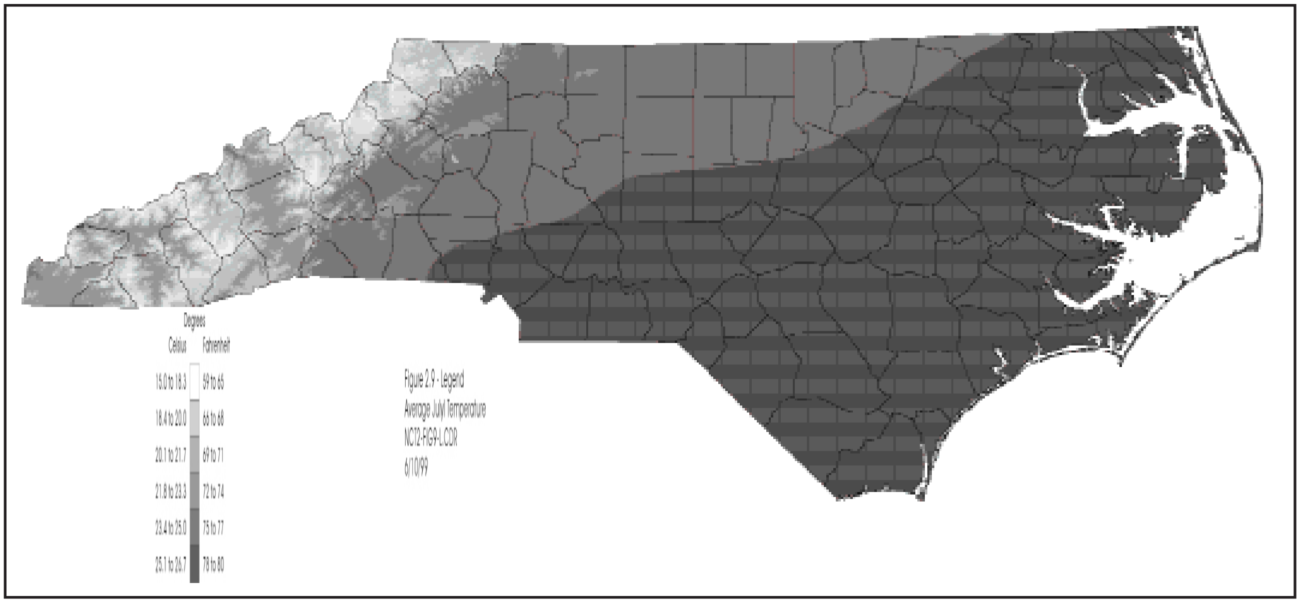


Figure 2.10: Average July Temperature.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

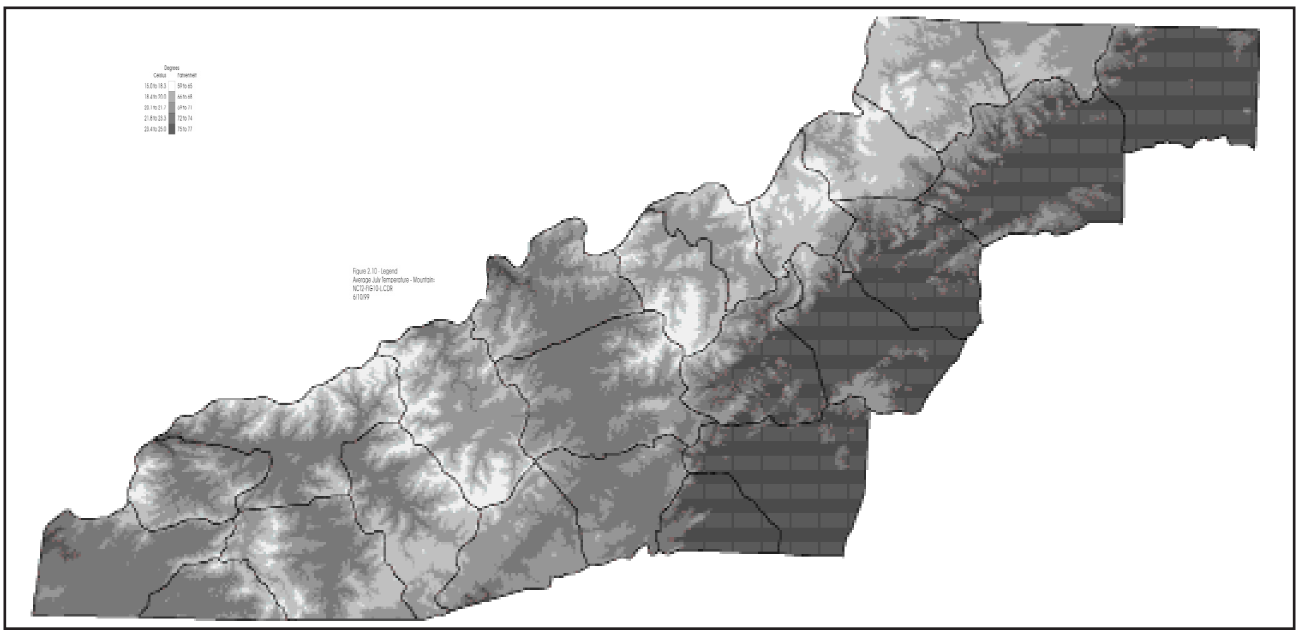


Figure 2.11: Average July Temperature in the Mountain Region.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

are very important. Snowfall totals range from 5 centimeters (2 in) across much of the Tidewater and Coastal Plain, to as much as 264 centimeters (104 in) on the summits of the highest peaks. Figure 2.13 clearly indicates that significant snowfall totals, greater than 28 centimeters (11 in), are confined to the mountains and extreme northwest Piedmont. This is not to say that Piedmont and coastal locations do not ever receive significant accumulations, but rather that heavy snowstorms are infrequent. Likewise, it is important to note that snowfall amounts are highly variable from year to year across the mountains, much more variable than the other elements of climate.

Wind

With the exception of where strong pressure gradients are created by intense storms, winds in North Carolina are generally light, with prevailing winds out of the west. Strong winds sometimes develop in association with enhanced sea and valley breezes in coastal and mountain locations, whereas the oc-

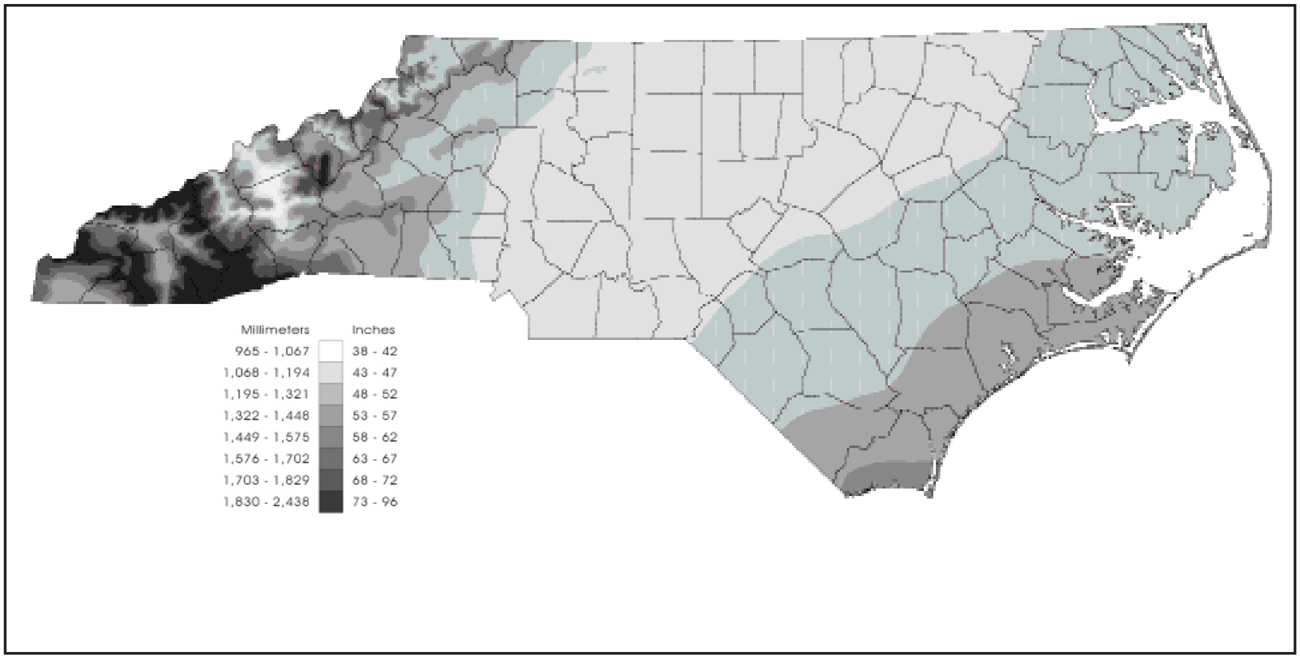


Figure 2.12: Average Annual Precipitation.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

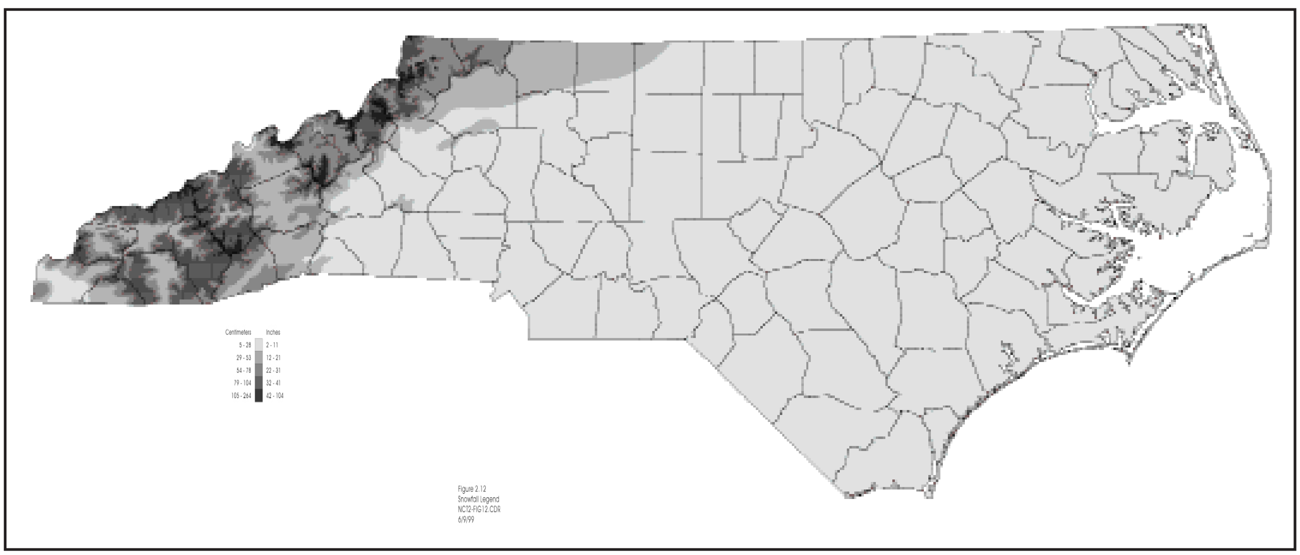


Figure 2.13: Average Annual Snowfall.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

casional nor'easter, hurricane, severe thunderstorm, or tornado can also pack extremely damaging winds. In fact, the highest windspeed in the state was estimated at 322+ kmph (200+ mph) on November 28, 1988 in association with a powerful tornado in Raleigh (State Climate Office 1998). Wind speeds generally increase with increasing elevation. As one moves higher in the atmosphere, the surface of the earth exerts less friction on the movement of air, allowing air to move at higher speeds. Grandfather Mountain, in Avery County, is notorious for having high winds. During the winter of 1997, observers recorded a 298 kmph (185 mph) gust, which set a new maximum speed record for that location (Box 2B).

Sunshine and Relative Humidity

Sunshine and relative humidity vary both diurnally (daily) and seasonally. The number of hours of sunshine received at a site is dependent upon day length and cloud cover, whereas relative humidity is primarily related to air mass characteristics and time of day. Generally speaking, the highest percent of possible sunshine occurs in the summer and fall, which is also when relative humidity is lowest.

CLIMATE DIVISIONS OF NORTH CAROLINA

North Carolina is officially divided into eight climate divisions, as Figure 2.14 indicates. The Coastal Plain and Piedmont are each comprised of northern, central, and southern divisions, whereas the mountains are only divided into northern and southern divisions. However, there are many more climate zones than can be officially recognized. Certainly, the Outer Banks has a distinct climate from other areas of the Coastal Plain and Clingman's Dome a strikingly different climate from Asheville. Nonetheless, for reporting purposes and divisional climatological summaries, no attempt is made by the National Climate Data Center (NCDC) to further subdivide the official climate divisions (Owenby and Ezell 1992).

To help convey the great diversity of climates across the state, Figure 2.14 also includes a sampling of climographs from across the state. A climograph is quite simply a graph of two variables plotted on a monthly basis: average temperature is denoted by a solid line and precipitation is represented by a solid bar graph. Temperature and precipitation are two of the most important elements in determining the climate of a particular location, hence the name climograph.

Banner Elk (1,143 m/3,750 ft), Avery County, is located in the Northern Mountain climate division (see Figure 2.14 for locations of stations) and represents the climate of this division fairly well. Overall, temperatures are cool and precipitation is abundant. The winter months are generally cold and snowfall is common, whereas summer is quite pleasant, with warm days and cool nights. Monthly temperatures average -0.7°C (30.7°F) in January and rise to 18.9°C (66.1°F) in July, whereas the average annual temperature is 9.7°C (49.5°F). Precipitation totals range from 81 mm (3.2 in) in December to 122 mm (4.8 in) in March, averaging 1,285 mm (50.6 in) for the year. Snowfall averages 119 cm (47 in) for the year.

Andrews (533 m/1,750 ft), Cherokee County, is in the Southern Mountain climate division. Temperatures are much milder in the Southern Mountains than in the Northern Mountains, due not only to a more southerly location, but also to lower elevations in the valleys. Average annual temperature in Andrews is 12.7°C (54.8°F), ranging from 1.6°C (34.9°F) in January to 22.5°C (72.5°F) in July. Precipitation totals are high, totaling 1,590 mm (62.6 in) for the year. Snowfall is very light, averaging only 18 cm (7 in) per year.

Clingman's Dome, the highest point in the Great Smoky Mountains (2.025 m/6,642 ft), is located in Swain County and represents the climate expected in the higher elevations of the mountains (corresponding to elevations above 1,524 m (5,000 ft) in the Southern Mountain division and above 1,372 m (4500 ft) in the Northern Mountain division). These higher elevation areas of the mountains experience climate conditions similar to southern Canada. Winters can be quite cold and snowy, while summers are cool, even chilly. Monthly average temperatures range from -3.1°C (26.5°F) in February to 15.0°C (59.0°F) in July; the average annual temperature is a chilly 5.9°C (42.7°F). Precipitation is distributed fairly uniformly throughout the year, yielding an average annual total of 2,085 mm (82.1 in). Snowfall is common nine months out of the year and averages 213 cm (84 in).

Reidsville (271 m/890 ft), Rockingham County, is the fourth station and it is located in the Northern Piedmont climate division. Temperatures remain fairly moderate during the winter months, averaging 2.1°C (35.8°F) for the month of January. Summers, however, are quite warm, as the July average temperature is 24.6°C (76.2°F). The average annual temperature is 13.9°C (57.0°F). The Northern Piedmont is fairly dry in comparison to most places in the state. Rainfall averages 1,125 mm (44.3 in) for the year in Reidsville, and snowfall is 30 cm (12 in).

Monroe (177 m/580 ft), Union County, is a station representative of the Southern Piedmont climate division. Temperatures average 4.9°C (40.8°F) during the month of January, warming to 25.7°C (78.3°F) in July; the annual average temperature is 15.8°C (60.5°F). Precipitation averages 1,219 mm (48.0 in), with snowfall averaging only 10 cm (4 in).

Elizabeth City (2.5 m/8 ft), Pasquotank County, is located in the extreme northeastern corner of the state, in the Northern Coastal Plain climate division. Average temperatures range from 5.1°C (41.2°F) in January to 26.0°C (78.8°F) in July and are influenced by the maritime effect. The annual average temperature is 15.9°C (60.7°F). Precipitation averages 1,232 mm (48.5 in) and snowfall only 15 cm (6 in).

Southport (6 m/20 ft), in the Southern Coastal Plain climate division, experiences a mild climate and is influenced by the maritime effect. Winters are short and mild, whereas summers are long and hot. Monthly average temperatures range from 6.3°C (43.4°F) in January to a very warm 26.4°C (79.5°F) in July. The average annual temperature is 16.7°C (62.1°F). The maritime influence also signals an abundant moisture source, leading to 1,448 mm (57.0 in) of average annual rainfall. Snowfall is rare in this part of North Carolina, averaging only 8 cm (3 cm) a year. The 8 cm (3 in) annual snowfall average is, in fact, deceptive. It is primarily a product of a few major storms that have hit during the 30-year period, as most winters see no measurable snowfall.

Our last station is Cape Hatteras (3 m/11 ft), located in the Northern Coastal Plain climate division, but in fact almost completely surrounded by water on the Outer Banks. Hence, the maritime effect is quite strong in this vicinity, particularly in winter. Due to this strong maritime effect, January temperatures are among the mildest in the state, averaging 7.0°C (44.6°F)—a full 10°C (18°F) warmer than Clingman's Dome. The July monthly average temperature is 25.7°C (78.3°F) and the average annual temperature is 16.7°C (62.0°F). Precipitation is abundant throughout the year, averaging 1,425 mm (56.1 in), whereas snowfall is rare.

Based on the sampling of climographs just discussed, it is possible to classify North Carolina's climate within the widely accepted Modified Köppen Scheme. Within this Modified Köppen Scheme, average temperature and precipitation serve as

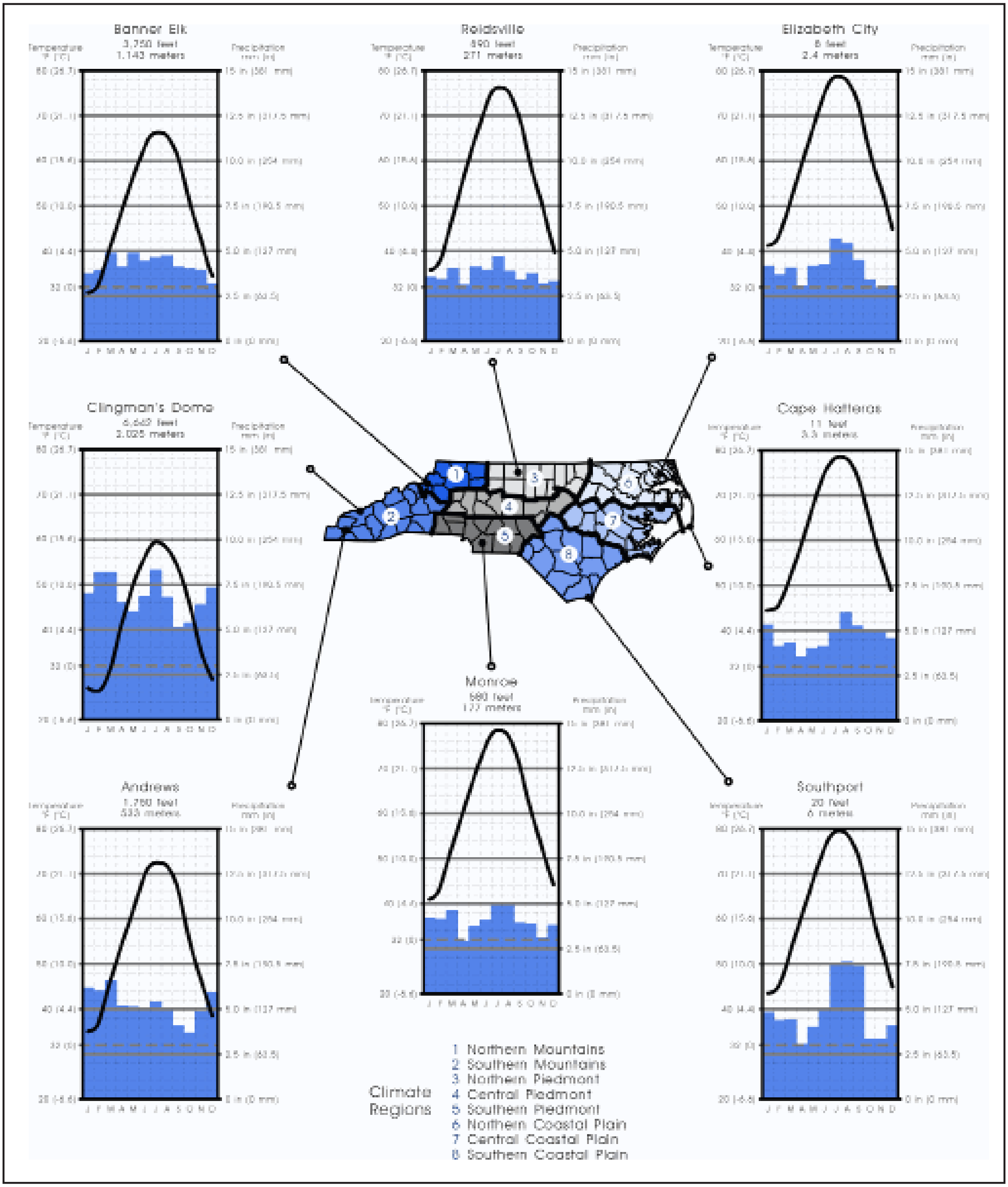


Figure 2.14: Climate Divisions and Selected Climographs.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

Box 2B: Weather Extremes.

Minimum Temperature
-36.7°C (-34°F), Mount Mitchell, Yancey County; January 21, 1985.

Maximum Temperature
43.3°C (110°F), Fayetteville, Cumberland County; August 21, 1983.

Annual Precipitation
3,292 mm (129.60 in), Rosman, Transylvania County; 1964.

Daily Precipitation (24 hour period)
564 mm (22.22 in), Altapass, Mitchell County; July 15-16, 1916.

Monthly Snowfall
145 cm (57 in), Boone, Watauga County; March, 1960.

Daily Snowfall (24 hour period)
91 cm (36 in), Mount Mitchell, Yancey County; March 12-13, 1993.

Highest Windspeed
Estimated: 322+ kmph (200+ mph), Raleigh, Wake County; November 28, 1988 (F4 Tornado).
Observed: 298 kmph (185 mph), Grandfather Mountain, Avery County, 1997.

the only data necessary for classification purposes. Divisions among climate zones correspond quite well to actual vegetation patterns, which illustrate the application of such a scheme in describing global climates. The majority of the state, including the Tidewater, Coastal Plain, Piedmont, and lower elevations of the Mountain Region, falls within the Humid Subtropical (Cfa) designation. These areas all have hot summers and mild winters, with an abundance of precipitation distributed fairly equally throughout the year, as indicated by the climographs in Figure 2.14.

As elevation increases in the mountains climate moves toward a Marine West Coast (Cfb) designation. Obviously, our mountain locations are not on the west coast of a continent. However, the moist flow from the Gulf of Mexico and the Atlantic Ocean—combined with orographic lifting—leads to climate conditions very similar to the Pacific Northwest or Western Europe. Summers are generally warm, whereas winters are fairly short and mild. Precipitation is distributed fairly evenly throughout the year and most of the precipitation that falls in the winter is in the form of rain. Fog is also common any month during the year.

At the highest elevations in the mountains, generally above 1524 meters (5,000 ft), a Humid Continental (Dfb) designation is encountered. Here summers are cool and winters can be quite severe with extreme cold, deep snow, and high winds. This climate is similar to northern New England and southern Canada.

North Carolina is characterized as having the greatest climate diversity of any state east of the Rocky Mountains—and rightfully so. Even though the majority of the state is located within the Humid Subtropical zone, it is important to realize that other climate zones exist as elevations increase in the mountains. In addition, topography and the maritime effect lead to important local and regional differences within the Humid Subtropical classification.

SEVERE WEATHER IN NORTH CAROLINA

Tornadoes, hurricanes, nor'easters, snow and ice storms, severe thunderstorms, and floods all impact the state at various times and intensities throughout the year. Our location in the middle latitudes helps to explain why we experience such active weather—particularly during the spring months. North Carolina is a battleground over which contrasting air masses struggle to equalize thermal contrasts, which are most pronounced during spring. The warm waters of the Florida Current off our coast and the Bermuda High help to keep the hurricane threat high during the late summer and early fall, whereas deep troughs in the jet stream and the same warm waters of the Florida Current can give rise to strong winter storms. Frontal and convectional activity can also lead to severe thunderstorms at any time during the year, with the associated hazards of lightning and hail. Floods and flash floods can result from a combination of circumstances at any time throughout the year.

Tornadoes

Tornadoes are the most violent form of severe weather, packing winds up to 483 kmph (300 mph) and leaving a path of widespread devastation. Often spawned by severe thunderstorms associated with frontal activity in the spring, tornadoes are intense

Scale	Category	Winds (kmph)	Winds (mph)	Expected Damage
F0	Weak	64 - 116	40 - 72	light: tree branches broken, sign boards damaged
F1	Weak	117 - 180	73 - 112	moderate: trees snapped, windows broken
F2	Strong	181 - 256	113 - 157	considerable: large trees uprooted, weak structures destroyed
F3	Strong	257 - 332	158 - 206	severe: trees leveled, cars overturned, walls removed from buildings
F4	Violent	333 - 418	207 - 260	devastating: frame houses destroyed
F5	Violent	419 - 512	261 - 318	incredible: structures the size of autos moved over 100 meters (328 ft), steel reinforced structures highly damaged

Table 2.1: Fujita Scale of Tornado Intensity.
Source: Meteorology Today, 1991.

areas of low pressure flanked by rapidly rotating winds. Tornado intensity is classified by the Fujita Scale and ranges from F0 to F5 (Table 2.1), depending upon wind speed and damage (Ahrens 1991; Eagleman 1990). Table 2.1 further details the Fujita Scale. Tornadoes are a threat across the state, although topographic irregularities render them much less common in the mountains. Figure 2.15 highlights the paths of the most destructive tornadoes to hit the state since 1900. Memorable tornado outbreaks include March 28, 1984, when a strong low pressure system produced 22 tornadoes across North and South Carolina during a six-hour period, some of which were classified at F4 intensity (Cheney and Morrison 1985) (see also Figure 11.4).

Category	Winds (kmph)	Winds (mph)
1	119-153	74-95
2	154-177	96-110
3	178-209	111-130
4	210-250	131-155
5	250+	155+

Table 2.2: Saffir-Simpson Hurricane Classification System.
Source: Meteorology Today: An Introduction to Weather, Climate, and the Environment, 1991.

Hurricanes

Tropical cyclones, known as hurricanes in the tropical Atlantic and eastern Pacific when sustained winds exceed 119 kmph (74 mph), are well-organized and strong storms that elicit much attention—particularly when they threaten coastal locations. Initially forming as tropical waves, or areas of low pressure off the coast of West Africa, they can quickly reach tropical storm and hurricane strength when upper level conditions are favorable. Table 2.2 details the Saffir-Simpson hurricane classification system, while Figure 2.15 shows the tracks of those hurricanes that have affected North Carolina since 1900. Due to North Carolina's protruding coastline, hurricanes that curve northward after tracking towards the west-northwest constitute a serious threat to the state. Cape Hatteras and Cape Lookout are particularly

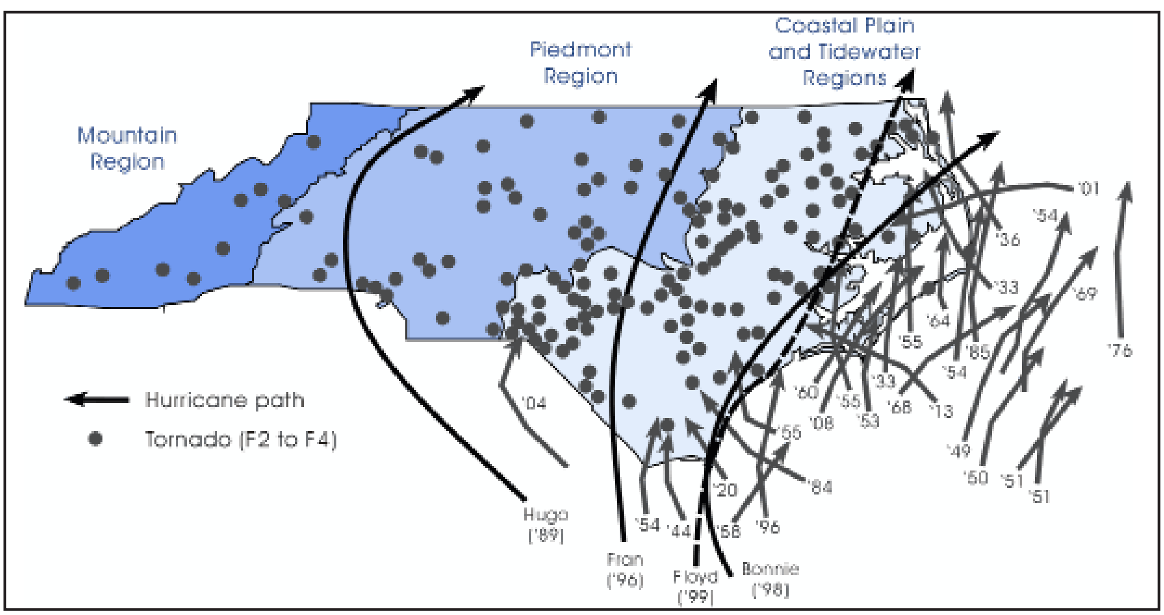


Figure 2.15: Major Hurricanes and Tornadoes Since 1900.
Source: Modified from Soule, P.T., 1993, 65-68.

Box 2C: Hurricanes Hugo, Fran, and Bon-

Due to our subtropical location and warm offshore waters, Tidewater and Coastal Plain locations are particularly susceptible to tropical storms and hurricanes. Even Piedmont and mountain areas are not immune to the occasional land-falling hurricane that moves inland, dumping large amounts of rainfall and spawning high winds. Three hurricanes that recently affected the state, Hugo, Fran, and Bonnie, had major impacts in all regions and continue to be entrenched our minds.

Hurricane Hugo made landfall a few minutes after midnight in the Charleston, SC, area on September 22, 1989, as a Category 4 hurricane, packing winds of 221kmph (137 mph) (National Research Council 1994). After pummeling large sections of South Carolina, Hugo entered North Carolina in the vicinity of Charlotte later that day and continued north roughly paralleling I-77 (NOAA 1989). Even though Hugo had weakened considerably by the time it reached Charlotte, sustained winds were still on the order of 113kmph (70 mph), with peak gusts of 140 kmph (87 mph). Extremely heavy rainfall associated with Hugo also caused widespread flooding in portions of the northern mountains. At the time Hugo struck, it was the strongest hurricane to hit the Atlantic Coast north of Florida in the 20th century. According to experts at the National Hurricane Center in Coral Gables, FL, Hugo represented a one in 200-year event for the Charlotte area (Garloch and Horan 1989). Hugo will be remembered for the damage to property and for bringing hurricane conditions to inland areas such as Charlotte.

Hurricane Fran also impacted areas far inland during the period of September 5-6 in 1996, most notably portions of the eastern Piedmont and the Triangle area of Raleigh, Durham, and Chapel Hill. Sustained winds approaching hurricane force (119 kmph/74 mph) pounded the Triangle area for several hours, while heavy rains also contributed to the problems. Some areas reported up to 254 mm (10 in) of rainfall, which fell on already saturated soils. Fran left more than a million homes and businesses without power for an extended period of time and claimed 14 lives in the state (Raleigh News and Observer 1996a; 1996b).

Worldwide 1998 proved to be a very active and deadly hurricane season. In a span of 35 days, August 19 through September 23, ten named tropical cyclones formed, while four of these made landfall in the United States. One of these Hurricanes, Bonnie, developed as a tropical storm over the tropical Atlantic on August 19, 1998, and moved in a west-northwest direction. On August 26, Bonnie neared the coast of North Carolina just to the west of Cape Fear and Wilmington, then turned north moving slowly over the Tidewater region towards Kitty Hawk early on August 28. Winds were recorded as high as 185 kmph (115 mph), which made it a Class 3 hurricane. Once Bonnie struck shore it quickly weakened; still it managed to damage the Outer Banks area and ocean-front developments. In addition to the physical damages three deaths were associated with Bonnie (NOAA 1998).

These three hurricanes clearly illustrate nature's force and the impact on people and environments in North Carolina. The environmental impacts of Hurricane Floyd are detailed in Chapter 8; whereas settlement and economic impacts are discussed in Chapter 11.

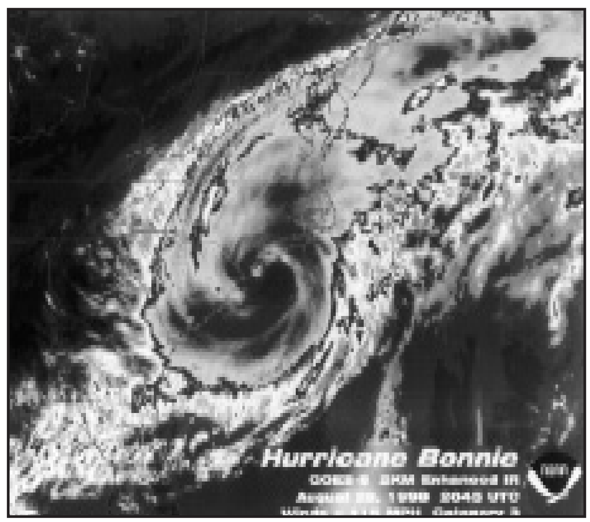


Photo courtesy of NOAA.

vulnerable to hurricane strikes. Box 2C highlights some recent hurricanes which all caused extensive damage across the state.

Nor'easters

Nor'easters are mid-latitude wave cyclones that intensify substantially off the east coast of the United States. Those that intensify in and near the Cape Hatteras areas are referred to as "Hatteras lows" and are renowned for their destructive nature. Although some nor'easters have winds well over hurricane strength, these storms are not classified as hurricanes because of their extratropical characteristics: well-defined frontal boundaries, association with upper level troughs in the jet streams, and absence of a warm core (Barnes 1998). The name "nor'easter," of course, stems from the fact that winds are consistently northeasterly as the storm moves across coastal locations. Nor'easters can bring extremely high wind velocities, high waves and storm surges, heavy rain or snow, severe weather, and even blizzard conditions and extreme cold to affected areas (Hidore 1993). In fact, the Blizzard of '93 (Box 2D) was just such an example, bringing high wind, rain, and severe weather to eastern portions of the state and blizzard conditions to western portions. Nor'easters occur much more frequently than hurricanes; consequently, the impact of these storms on the Outer Banks is substantial. During a 42-year period, Hidore (1993) identified 1,300 nor'easters, or an average of 31 per year.

Snow and Ice Storms

Snow and ice storms occur quite frequently in the mountains, but are less common as we move from northwest to southeast across the state. Our mountains are in a very favorable position for heavy snow when all the ingredients come together—namely moisture from the Gulf of Mexico and the Atlantic, a deep trough in the upper level jet stream, and cold air from Canada. Box 2D highlights two memorable months—March 1960 and March 1993—when major winter storms affected much of the state.

Occasionally, atmospheric inversions signify increasing temperatures at higher elevations. As a major storm arrives, temperatures will be below freezing at the surface, but above freezing in the lower to middle levels of the atmosphere, or some combination of the two. Freezing rain and sleet then become the dominant forms of precipitation, creating a thick coating of ice on the ground, trees, and powerlines (Ahrens 1991).

Severe Thunderstorms

Severe thunderstorms and the associated hazards are a threat across the state throughout the year. The most violent of these thunderstorms often occur during the spring months in association with frontal activity, as contrasting air masses use the state as a battleground. However, strong cold fronts can spawn severe thunderstorms at any time during the year, and summer convectional activity often leads to their formation. These thunderstorms can pack extremely high winds in the form of microbursts (strong and localized downward-moving winds), which can cause an airplane to actually fall out of the sky and crash. Lightning and hail are other hazards associated with severe thunderstorms. Lightning strikes are a significant hazard across the state, but particularly on golf courses and on high peaks and ridges. Likewise, hail can do serious damage to property, autos for example, if the hailstones are large enough.

Floods and Flash Floods

Floods are a threat any time of the year, under a variety of circumstances. Intense winter mid-latitude cyclones that bring large amounts of warm, moist air from both the Gulf of Mexico and the Atlantic, when combined with orographic lifting, can produce sustained periods of heavy rain in mountain locations. In addition, a snowpack can add to the runoff and potential for flooding. The occasional hurricane that tracks inland can mean very heavy rainfall, leading to high probabilities of flooding. Hurricanes Hugo and Fran both caused extensive flood damage across the state when they moved inland (Box 2C). However, they did not match the flooding of Hurricanes Dennis and Floyd's one-two punch, as they arrived one week apart (Chapters 8 and 11). Flash floods are much more unpredictable and localized. Usually the result of severe thunderstorms with extremely heavy rainfall over short periods of time, flash floods are a dangerous hazard in mountain valleys and low lying areas.

North Carolina certainly has its share of severe weather. Tornadoes, hurricanes, nor'easters, winter storms, severe thunderstorms, and floods wreak havoc across the state each and every year. It is essential that we, as citizens of this state, learn to recognize the conditions under which severe weather may develop and take the necessary precautions.

El Niño (ENSO) and La Niña.

These conditions of the earth's surface are often the focal point of cause when severe weather occurs, and Box 2E details this phenomena.

APPLIED CLIMATOLOGY

Certain climate indicators can be very useful to predict energy needs and agricultural potential in an area. Degree days and the average annual frost-free period are great examples of how different measures of thermal characteristics have wide-ranging applications.

Degree Days

Degree days can be differentiated between heating degree days (HDDs) and cooling degree days (CDDs) and are simply a measure of thermal stress on the heating and cooling needs of a home or building. The base temperature for both HDDs and CDDs is 65°F. HDDs occur at any time during the year when the average daily temperature is below 65°F. For example, if Boone recorded an average daily temperature of 20°F on a given day, then 45 HDDs would be tallied, as 65 minus 20 equals 45. Seasonal and annual HDDs are totaled, providing a general description of the severity or duration of cold. Figure 2.16 shows average annual HDDs across the state. HDDs range from 2,470 along coastal locations, to over 8,000 along the highest elevations in the mountains.

Cooling degree days (CDDs), on the other hand, refer to how many degrees the average daily temperature is above the 65°F base. Seasonal and annual totals are also tallied. Figure 2.17 indicates that the higher elevations of the Mountains experience the lowest CDDs (in fact, the highest elevations average 0 CDDs!), whereas southern and eastern sections range up to 1,926 CDDs.

Growing Season

Climate indicators are important in determining the agricultural capabilities of a given area. One of the most useful indicators is the average length of the growing season, defined as the number of days (or weeks) between the last spring freeze and first fall freeze. Peaches, for example, need a relatively long growing season and are very sensitive to spring freezes. Figure 2.18 displays the average date of the last spring freeze across the state, ranging from March 3 on the Outer Banks to late May and early June in some of the coldest mountain locations. It is worth noting that the mountain slopes' (that is, those locations that are neither ridge nor valley) average date of last spring

Box 2D: Memorable March Storms.

Major snowstorms and blizzards, though infrequent across most of the state, are certainly not unprecedented. Perhaps two of the most memorable periods for heavy snow, wind, and cold came during the month of March, in 1960 and 1993. North Carolina residents of all ages will no doubt be talking about these two events for years to come.

March 1960

March 1960 broke all temperature and snowfall records on a monthly basis for most locations across the state. Cold, high pressure dominated the weather in the interior of the United States, whereas stormy low pressure persisted across the Gulf Coast and Southeastern Coast (Hardie 1960). Therefore, the state was under the alternating influence of both of these patterns the entire month. The first major storm came on March 2, a Wednesday, and was followed by other storms on the 9th and the 16th, also Wednesdays (Winston-Salem Journal 1960). Heavy snow also fell on the coast on the 12th. The 18 to 23 centimeters (7 to 9 in) that fell on the Outer Banks was ten times the sum of all previous March snowfalls at Cape Hatteras (Hardie 1960)!

In the mountains, snow was almost a daily occurrence and wreaked havoc, particularly in the northern mountain areas of Watauga and Ashe counties, where the Red Cross and National Guard were called on to airlift food and other supplies into the region (Hardie 1960; Minor 1960; Watauga Democrat 1960). The 145 centimeters (57 in) of snow that fell in Boone, Watauga County, during the month still stands as the state record. Most Piedmont locations saw between 25 and 51 centimeters (10 and 20 in) of snow, with snow covering the ground for over two weeks.

Blizzard of '93

Thirty-three years later, western portions of the state experienced the most intense winter storm of memory. The Blizzard of '93, as it was crowned, paralyzed all of the mountains and portions of the Piedmont with heavy snow, high winds, and bitter cold.

Developing along a stationary front in the Gulf of Mexico on Thursday, March 12, the storm deepened rapidly and tracked northeastward, spreading snow into the western mountains by Friday afternoon and across the rest of the mountains during the evening and night. By Saturday morning, most valley locations in the mountains had already received 30 to 61 centimeters (12 to 24 in), with even more at higher elevations (Goodge and Hammer 1993).

As the storm continued to track towards the northeast Saturday morning, winds abruptly shifted to the northwest and increased in strength. There were even some reports that this wind shift was accompanied by thunder. By Saturday afternoon, temperatures had plummeted into the teens in valley locations and the snow continued to pile up. In addition, high winds, gusting up to 80 kmph (50 mph) in valley locations, created whiteout conditions and made for much drifting of the newly fallen snow. Consequently, all roads remained impassable except to special emergency vehicles. Even the snowplows were getting stuck! Most, if not all, towns and counties in the mountains imposed curfews and martial law as conditions continued to deteriorate throughout Saturday afternoon and evening (Goodge and Hammer 1993; The Blowing Rocket 1993).

One measure of the storm's intensity, the minimum central pressure, broke records across the Southeast, including 969 millibars (28.60 in) in Raleigh and 978 millibars (28.89 in) in Asheville. Snowfall totals were extreme; mountain areas saw between two and three feet, with higher elevations reporting up to six feet. Snowdrifts reached epic proportions; roads and cars were buried in up to 6 meters (20 ft) of snow. The extreme cold that followed the storm also set records. In fact, Waynesville, Haywood County, reported a low of -22°C (-8°F) on Monday morning, March 15, which was the coldest reading in the lower 48 states.

freeze is significantly earlier than the lower elevation valleys; as Figure 2.18 attempts to portray. This is associated with the cold air drainage and thermal belt concept discussed earlier in this chapter. During periods of clear weather with good radiational cooling, cold air drains down mountain slopes to collect in the lowest topographic features. Consequently, the coldest areas, and those most susceptible to late and early-season frosts, are the valley bottoms.

Figure 2.19 shows the average date of first fall freeze across the state. Once again, there is great temporal variability ranging from mid-September in some mountain locations to early December along the Outer Banks, thanks to the maritime effect. The thermal belts, once again, show up fairly clearly in the mountains.

On the basis of the average dates of the last spring freeze and first fall freeze, it is possible to calculate the average length of the growing season. Figure 2.20 indicates that the growing season averages a relatively short 100 to 144 days across the northern mountains and the normally colder valleys of the southern mountains. The thermal belts and the Asheville Basin in the mountains experience much longer growing seasons, however, reaching upwards of 197 days in the immediate vicinity of

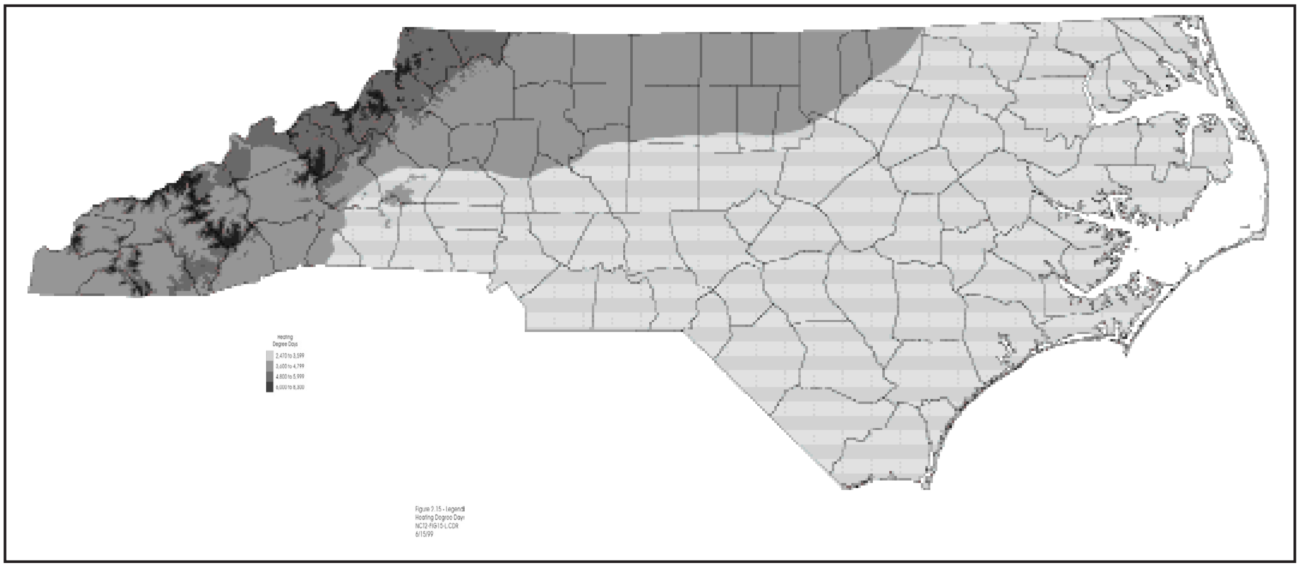


Figure 2.16: Average Annual Heating Degree Days.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

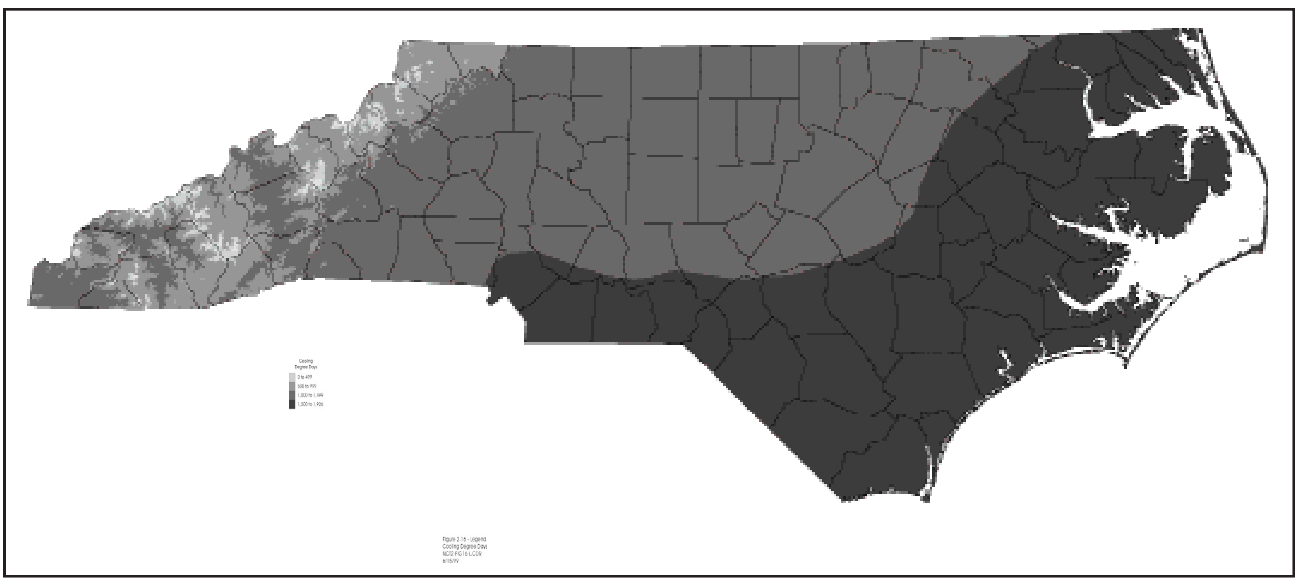


Figure 2.17: Average Annual Cooling Degree Days.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

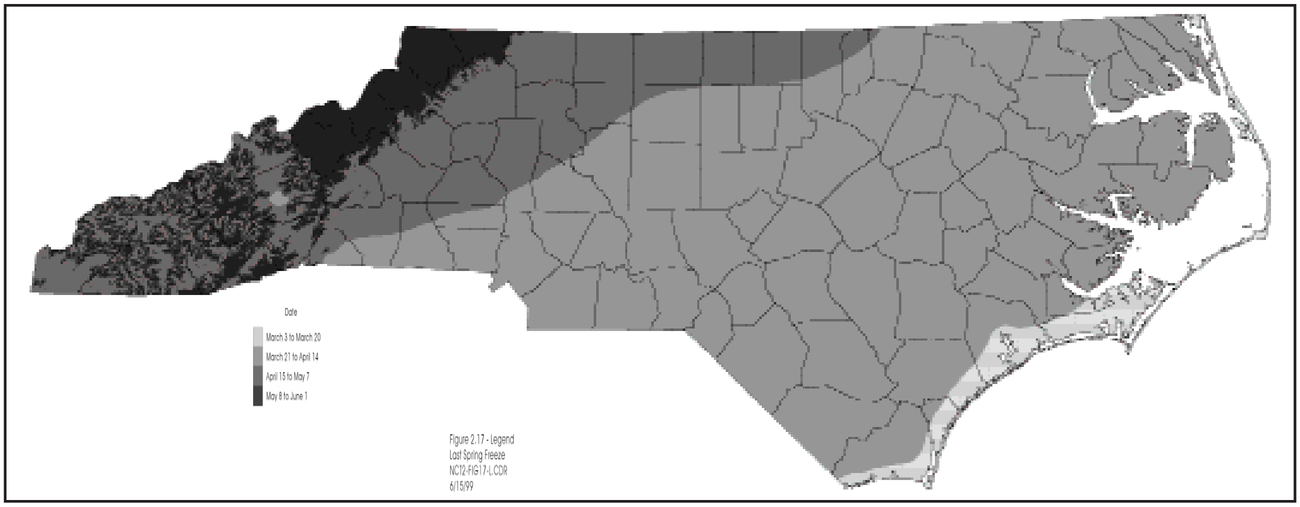


Figure 2.18: Average Date of Last Spring Freeze.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

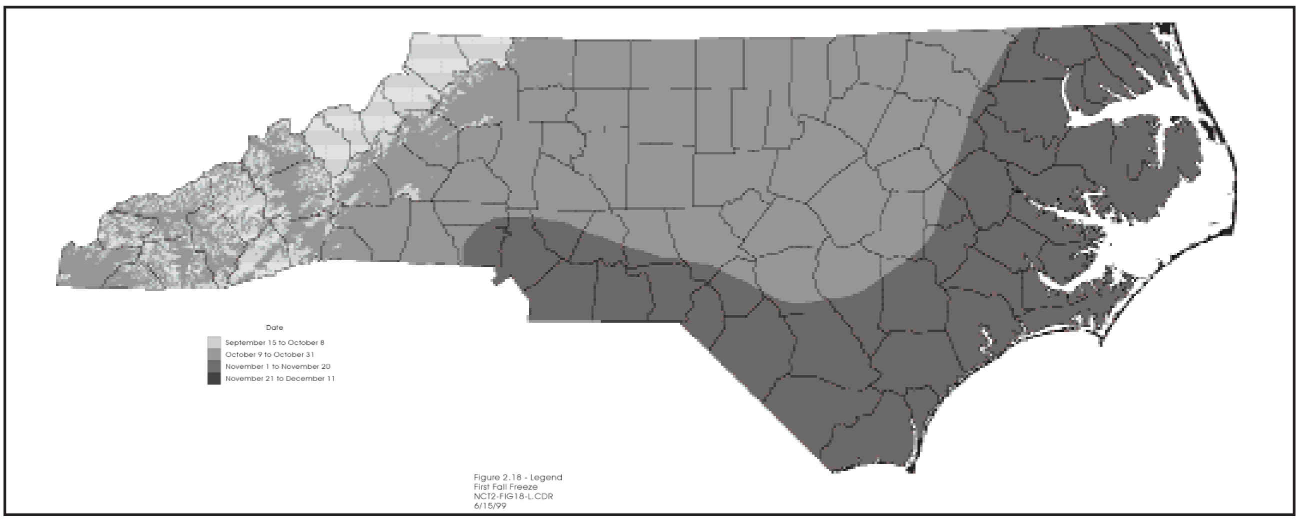


Figure 2.19: Average Date of First Fall Freeze.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

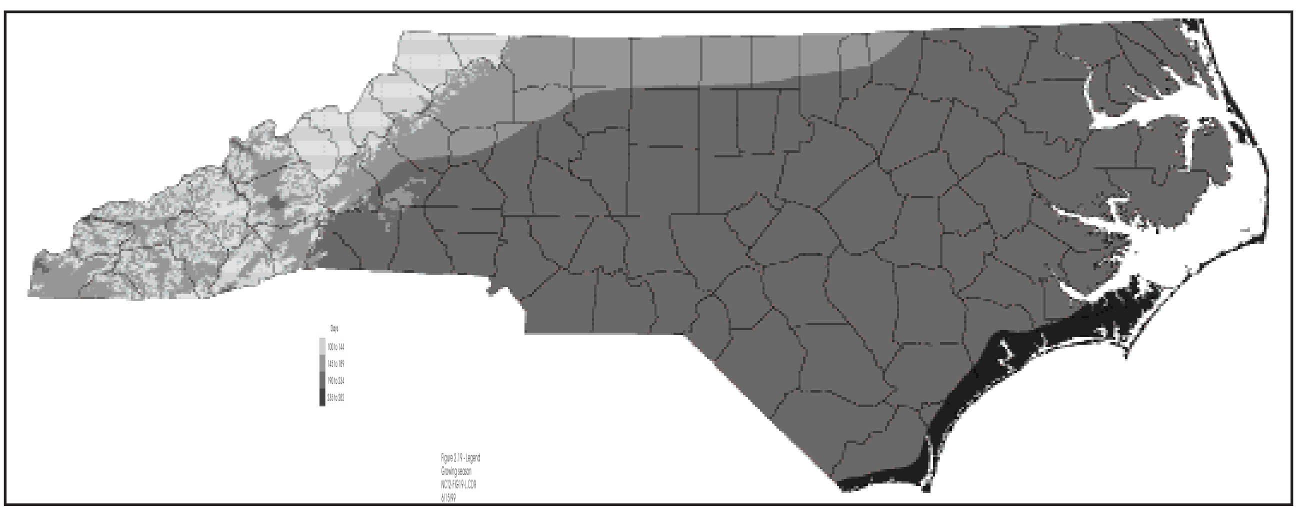


Figure 2.20: Average Length of Growing Season.
Source: Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Days 1961-1990: North Carolina.

Box 2E: El Niño (ENSO) and La Niña.

Changes in sea surface temperatures (SSTs) in the eastern South Pacific have major impacts on weather patterns around the globe, even in our state. El Niño, Spanish for "the child," in reference to the "Christ Child," refers to the periodic warming of ocean waters around Christmas off the west coast of South America, in the vicinity of Peru. This is most often accompanied by a flip-flop of pressure cells in the South Pacific, known as the Southern Oscillation; hence the term ENSO, or El Niño-Southern Oscillation (Trenberth 1991). La Niña is just the opposite; at irregular intervals, SSTs are below normal in large portions of the eastern South Pacific. Each of these perturbations in the oceanic/atmospheric system has strikingly different influences on weather patterns in North Carolina (Philander 1990).

ENSO is perhaps the event we are most familiar with, particularly after the exceedingly wet winter and spring of 1998—an ENSO year. Precipitation for the four-month period, January through April, was above normal across the entire state, with some areas reporting in excess of 200 percent of normal values. The mountains and portions of the Piedmont saw the greatest departure from normal, whereas northeastern sections, particularly the Outer Banks, were just slightly above normal. Above 1,372 meters (4,500 ft), a lot of the precipitation fell in the form of snow. Mount Mitchell reported 330 centimeters (130 in) during the four-month period, approximately 200 percent of normal values. As a footnote, the highest peak east of the Mississippi reported a seasonal total of 452 centimeters (178 in), approximately 171 percent of normal. Temperatures, on the other hand, were generally slightly above normal for the period (State Climate Office 1998).

So why can we expect above normal precipitation during the winter months in association with ENSO? It all is related to the upper level jet streams. During ENSO years, the subtropical jet stream is generally much more active and brings storm after storm into California. These more frequent and more intense storms eventually move across the country and have a tendency to redevelop and strengthen even further in the Gulf of Mexico, eventually affecting us. ENSO years also see a drastic reduction in the number of hurricanes forming in the Atlantic and Caribbean basins, presumably due to the stronger than normal upper-level westerly winds in association with the subtropical jet stream. The resulting vertical wind shear prevents the tropical waves from developing further (Gray and Sheaffer 1991).

La Niña events have historically led to warmer and slightly drier conditions across North Carolina, although hurricane formation is enhanced by little to no westerly vertical wind shear in the Atlantic and Caribbean basins (NOAA 1998). Consequently, we are much more vulnerable to flooding rains and high winds in association with a land-falling hurricane during La Niña years. The La Niña event of 1998 resulted in a very active Atlantic hurricane season. In fact, there were four hurricanes in the Atlantic basin at the same time, presumably for the first time in over a century (New York Times 1998).

ENSO and La Niña events have major impacts on the oceanic and atmospheric circulation on a global scale. These phenomena influence weather patterns in our state and serve as a great example of the teleconnections that exist not only between the ocean and atmosphere, but also among different geographic regions of the world. Therefore, what occurs off the west coast of Peru does indeed impact our lives, as do many other physical and human processes around the world.