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The climate of North Carolina

by

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The climate of North Carolina is one of warm summers and mild winters, with abundant precipitation in all seasons. These normal conditions are created, and can be modified, by the atmospheric circulation patterns affecting the State and by the topography of the State itself. Both effects produce variability about the average, variability which is likely to be significant for vegetation development. Consequently the nature of the factors controlling the climate are considered prior to a discussion of the actual climate.

The climatic controls

North Carolina lies between 34°N and 37°N and the weather is dominated by the mid-latitude Westerlies. These constitute an almost permanent feature in the upper troposhere, but near-surface westerly flow is blocked for much of the time by the barrier of the Rocky Mountains. The flow is replaced by an alternation of cold, continental polar (cP) air moving south from Canada and warm maritime tropical (mT) air coming from the Gulf of Mexico and the Atlantic Ocean. The upper air situation and the distribution of surface pressure determines which of these two effects the state at a given time.The relatively narrow contact zone between the two air masses is the Polar Front, which frequently passes over the state. This Polar Front commonly extends across much of the eastern part of the continent and, in the area west of the Mississippi River, acts as a breeding ground for depressions. These are guided by the

upper winds, cross the state from the west, and temporarily overshadow the air mass weather. Finally, the pattern may occasionally be completely disrupted by hurricane passage. The type of weather that is to be expected when each of these situations dominates is summarized in Table 1.

Table 1. Major North Carolina weather types

Weather Type	Associated weather	Occurrence
1. Continental polar air mass (cP)	Cool/cold, dry, cloudless or some scattered cumulus	winter-common summer-infrequent
2. Maritime tropical air mass (mT)	warm, moist, high humidity summer-afternoon thunder, intense localized rain winter-overcast, prolonged light drizzle	winter-frequent summer-common
3. Polar front	rapid temperature change, precipitation common	summer-weak, not too common winter-strong, frequent
4. Depressions	rapid series of weather changes, usually producing cloud and precipitation	summer-common winter-common
5. Hurricanes	high winds, much precipitation	late summer and fall only
6. Others (see text)	ice storms-freezing rain tornadoes-associated with depressions	winter only-infrequent summer and fall-infrequent

The major features of the interaction of these climatic controls must be treated separately for winter and summer. In summer the upper westerlies are relatively weak and diffuse, and do not play a dominating role in controlling surface features. The major influence at this time of year is the Bermuda High, a semi-permanent high pressure anticyclone centered at 35°N, approximately 800 km off the North Carolina coast. From this center the winds spiral outwards in a clockwise direction and are drawn into a diffuse low

pressure region in the south central U.S.A. The result for North Carolina is a southerly or southwesterly flow, the air having been transported a great distance over tropical oceans and arriving as a warm moist airstream. In passing over warm land, convection is initiated and frequent isolated showers, including thunderstorms, are common.

Depressions are further source of summer precipitation, producing abundant rainfall for all areas. These are normally mature depressions with active fronts. Occasionally tornadoes are associated with these fronts. The common depression track is from SW to NE, with the depression center passing directly over the state. The actual track depends greatly on the direction of the upper winds, which in turn are partly influenced by the position of the Bermuda High. This position varies slightly from day to day, and hence is responsible for the details of the track. It may also make significant excursions from its normal position for various lengths of time. Only if it moves westwards does this significantly change conditions within the state. The center of the high may be over eastern North Carolina, which will become a source for the winds blowing outwards from the state. In addition, depressions are forced to take a more northerly and westerly track, and do not affect the state. Both effects produce dry, clear conditions. At the same time the cloudless skies allow maximum solar radiation input, evaporation is rapid, photosynthetic rates are potentially high, and plant water stress is considerable. Fortunately such conditions rarely occur throughout a whole summer, but a continuous period of one or two months may occur every few years.

The major changes that occur as winter approaches are the increase in the strength and organization of the upper westerlies, and an increasingly vigorous continental polar air mass. The westerlies take on a distinct lateral wavelike motion, commonly with a crest (northward extension) over the northern Rockies and a trough over the central and eastern U.S.A. In this trough are the calmer conditions necessary for the formation of the continental polar air mass. Under the influence of the westerlines this air mass is frequently driven south, sweeping across the central plains and reaching North Carolina as a clear, cold, dry airstream. The maritime tropical air that dominated in summer now has insufficient strength to block these excursions. The Bermuda High has moved about 5^{o} farther south, while the continen-

tal interior itself has a tendency to high pressure and hence outward movement of air. Maritime tropical air does enter the state from time to time, but is cooler and, passing over colder land, is more likely to give a steady persistent drizzle from an overcast sky than convective storms.

Throughout the winter there is an alternation between mT and cP air, primarily as the westerlies vary their wave position. The Polar Front, where the two air masses meet, therefore passes frequently across the state. The result is a series of rapid changes from warm cloudy conditions to a clear dry cold situation. Temperatures commonly change $10^{o}C$ - $15^{o}C$ in a few hours and rain is likely.

Winter depressions, although taking tracks similar to summer, are much more active. They tend to have a higher wind speed and more "stormy" conditions, although they give about the same amount of precipitation. Occasional depressions which form on the Polar Front close to the Rocky Mountain foothill move with the upper westerlies rather farther south than usual. They incorporate some air from the Gulf within them. This warm moist air increases their vigor and they progress northeastwards across the southeastern states giving great amounts of precipitation. Frequently this is in form of snow. However, as they move north, they "rain out" and snowfall totals decrease northwards, with North Carolina receiving only a few inches. A similar situation, but with slightly different temperature requirements leads to the development of ice storms, rain freezes on impact with any surface object. The result is a tremendous ice load on vegetation with frequent structural damage or even complete destruction.

Hurricanes are a phenomenon of late summer and fall. Their frequency, intensity and tracks are very variable. The storms commonly move in from the south, bringing high winds and heavy rainfall. Intense storms affecting the coast, such as Hazel (1954) and Donna (1960), destroy beaches, dunes, property and vegetation on the Outer Banks, and cause severe flooding in the outer Coastal Plain. In the mountains flash flooding is associated with the heavy rains, such as those caused by Gracie (1959). Hurricanes passing over the Piedmont are usually less destructive since the topography is somewhat less conducive to flash floods. Hurricanes can have a beneficial effect at times. Gladys (1968), a relatively weak storm, passed over the state after an ex-

tended period during which the Bermuda High was centered over the Outer Banks. The storm therefore not only brought rainfall, but also altered the general situation, since following the passage, the Bermuda High moved back to its more normal position and depressions were once again able to enter the state.

Superimposed on the general controls of the N.C. climate are local modifications caused by distance from the ocean and by topographic effects. The increasing distances from the ocean as one moves westwards is climatically expressed as a modification of the temperature and rainfall regimes. There is a slight increase in annual temperature range and a marked increase in the range of temperature extremes, as one moves inland from the effect of the thermal lag of ocean water. Near the coast itself, and sometimes extending across the whole of the outer coastal plain, sea breeze effects serve to decrease the maximum summer temperatures and ensure a relatively low annual temperature range. The sea breeze also generates some rainfall, so that annual totals decrease inland across the coastal plain. Once onto the Piedmont, however, rainfall amounts and temperatures are most significantly influenced by altitude and topography.

The increase in altitude to the west leads to lower average annual temperatures, a decrease in the length of the frost-free season, an increase in the percentage of precipitation that falls as snow, and an increase in the length of time that snow covers the ground. Precipitation, however, is the element that is most severely influenced by topography. Air from the south or east, usually mT air, is forced to rise as it crosses the Piedmont and mountains. It is cooled and clouds are formed. Precipitation results. Once over the crest of the mountains, however, the descending air is warmed, clouds dissipate and rain ceases. When winds from the west occur, the reverse is the case, giving a wet west side and a dry east side. The westerly air, however, has diverse origins. It may be warm moist mT air from the Gulf, which will create heavy rainfall, or the air may be cold dry cP air, leading to light rain or snow. Alternatively, it may be part of a depression circulation, which will again lead to heavy precipitation. The depression itself may be influenced by the presence of the mountains, and it is not uncommon for a depression to remain virtually stationary over the western part of the state for several days, giving a prolonged period of steady rain. For the mountains

generally, however, the air may come from the either direction, so that there is no side that is devoid of rain on an annual basis. The only dry regions within the mountains are those small isolated valley areas which are sheltered from the wind on all sides.

The climate of North Carolina

The atmospheric and topographic controls produce the day-to-day weather in the state, which in turn produces the climate of the area. The climate is here presented in terms of average statistics for the various parameters, to give a general indication of the normal environment of the vegetation. Unusual atmospheric events or topographic situations are not considered explicitly, they must be inferred from the previous discussion in order to obtain a full appreciation of both the overall climate and its inherent small-scale variability within North Carolina.

Table 2. Average temperatures in North Carolina (^{o}C)

	Winter			Summer		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Coastal Plain	2	10	13	21	27	32
Piedmont	-1	7	10	18	24	32
Mountains	-4	4	10	15	21	29

The temporal and spatial distribution of temperature is summarized in Table 2. No attempt has been made to provide actual values for a "typical" station, instead general figures for the three main regions have been chosen to give representative values.* The major spatial trend, the decreasing temperature from east to west, is clearly evident. The annual range of the mean daily values is about $17^{o}C$ throughout the state. The ranges for the extreme values, however, increase inland, reflecting the effect of continentality.

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* Climate diagrams for various stations are included in the introductory chapter by H. LIETH in this volume.

Temperature is also summarized by presentation of maps of the length of the frost-free season (Fig. 1) and the annual sum of growing degree days (Fig. 2)*. Both show the expected east-west trend. The frost-free season on the coast is almost twice as long as in the mountains, the last frost occurs in March on the coast and in May in the mountains. The variation of growing degree days shows a very simple regular pattern, with the effect of altitude being very clearly marked.

The spatial pattern of annual rainfall totals is more complex than the temperature pattern, in that there is a major maximum in the mountains and a secondary maximum along the coast (Fig. 3). Certain areas of the mountains, however, especially the Asheville basin, are among the driest points in the state. The whole state receives over 1220 mm annually, and there is no dry season. A slight minimum occurs in fall, when both convective and depression activity is weak, and an equally slight maximum occurs in summer, mainly because of the greater frequency of convective showers from the mT air mass. Annual snowfall is in excess of 250 mm throughout the mountain region, gradually decreasing eastwards to less than 50 mm on the coast. In sheltered areas of the mountains snow may persist continuously for several months, but once onto the Piedmont the snow is unlikely to lie for more than a week after one of the two or three snowfalls that occur annually.

The annual potential evaporation pattern closely follows the distribution of growing degree days. Values slightly in excess of 1220 mm occur in the southeast and on the Outer Banks, the figure decreasing to 800 mm in the western mountains. For the whole state, therefore, precipitation exceeds potential evaporation on an annual basis. Further, the summer precipitation maximum ensures that water deficits of more than 25 mm over an extended period of time are very unusual. An exception occurs in the Asheville basin where higher values are common. Deficits of several mm do occur, of course, for limited times in summer, especially when the Bermuda High moves inland. In winter, water surpluses of more than 250 mm are the rule, with 375 mm surplus

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* This map, and subsequent ones, are presented in "English" units. The basic data and published primary sources use this system. Since the emphasis here is on spatial distributions, the system chosen is of minor consequence. For particular points, however, unit conversion is a simple process.

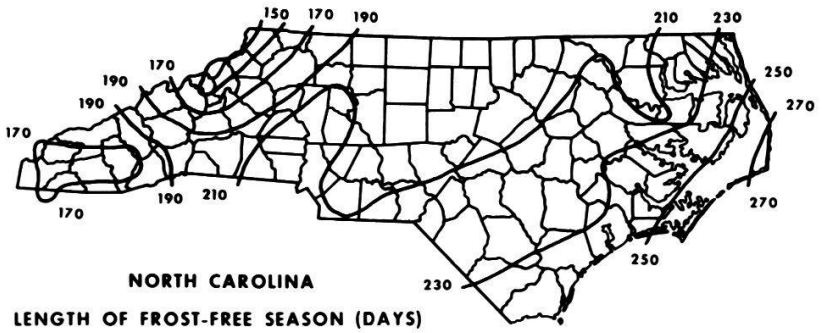

Fig. 1. North Carolina, length of frost free seasons (days).

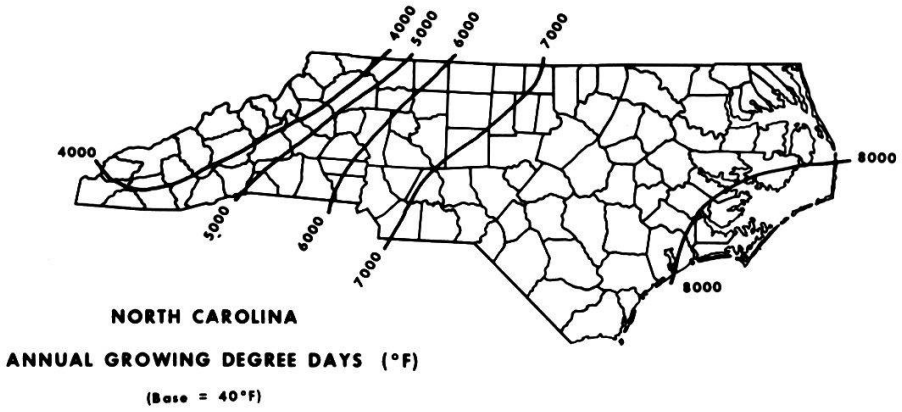

Fig. 2. North Carolina, annual growing degree days (^{o}F), base = 40^{o}F (4,5^{o}C) (4000^{o}F = 2204^{o}C)

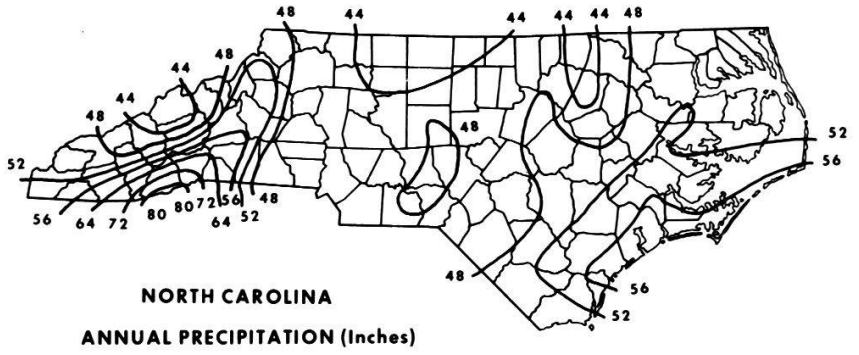

Fig. 3. North Carolina. Annual precipitation (inches).
(4 inches = 10 cm; 44 inches = 112 cm; 80 inches = 203 cm).

being common in the mountains and on the outer coastal plain.

In general the climate of North Carolina is favorable for vegetation growth. The state has a long growing season and adequate precipitation. Summer water availability is not a problem on a long term basis except in rare conditions or isolated places, while winter recharge is usually adequate. Severe winters are possible in the mountains, but rarely occur over the rest of the state. Isolated events, such as ice storms or hurricanes, occasionally disrupt the pattern. The topographic and atmospheric controls, therefore, create a variety of environments within the state which support a great diversity of vegetation types.

Summary

North Carolina has a humide mid-latitude climate, with warm to hot summers, cool winters, and precipitation at all seasons. The precipitation is derived from both eastward moving depressions and from warm moist maritime tropical air, arriving from the south and southeast. Total annual precipitation exceeds 1100 mm throughout the state, with maxima occurring along the coast, where sea breeze effects enhance totals, and in the mountains, where orographic effects dominate. Snowfall exceeds 250 mm in the mountains and snow may persist for several months. Only light snow of short duration is common in the rest of the state. Temperatures are largely determined by the type of air mass affecting the state. Maritime tropical air dominates in summer, giving high temperatures. In other seasons maritime tropical air alternates with the much colder continental polar air mass, and rapid temperature variations are mainly the result of altitude. Along the coast, temperatures average 10°C in winter and 27°C in summer. Values decrease westwards and are typically 6°C lower in the mountains. The coast has 250 frost free days, while the mountains have less than 200. Despite high summer temperature, large water deficits are uncommon because of high rainfall totals, and soil moisture is generally plentifully available for vegetation growth.

Zusammenfassung

North Carolina hat ein feuchtes Klima mittlerer Breiten mit warmen bis heissen Sommern und kühlen Wintern. Die Niederschläge sind über das ganze Jahr verteilt. Sie werden einenteils von ostwärts wandernden Zyklonen gebracht, andernteils stammen sie von warmen und feuchten maritimen tropischen Luftströmen, die vom Süden und Südosten heranziehen. Die gesamten jährlichen Niederschläge übersteigen im ganzen Staat 1100 mm; die grössten Mengen treten längs der Küste auf, wo die Meereswinde zusätzliche Niederschläge bringen,

sowie aus orographischen Gründen in den Bergen. Dort fallen auch über 250 mm Schnee, der während mehrere Monate liegen bleiben kann. Im übrigen Teil des Staates kommt in der Regel nur leichter und kurz dauernder Schneefall vor. Die Temperaturen werden hauptsächlich durch die Art der Luftmassen bestimmt, die den Staat erreichen. Maritime tropische Luft mit hohen Temperaturen herrscht im Sommer vor. In den anderen Jahreszeiten wechselt tropische Luft mit der viel kälteren kontinentalen Polarluft. Rascher Temperaturwechsel ist häufig. Temperaturdifferenzen innerhalb des Staates sind vor allem auf die Höhenunterschiede zurückzuführen. Längs der Küste betragen die Mitteltemperaturen im Winter 10°C und im Sommer 27°C. Westwärts nehmen die Werte ab und sind in den Bergen im Mittel etwa 6°C niedriger. Das Küstengebiet hat 250 frostfreie Tage, die Berge weniger als 200. Trotz der hohen Sommertemperaturen sind wegen der häufigen Niederschläge nur selten Wasserdefizite zu beobachten, und im Boden ist für das Wachstum der Vegetation im allgemeinen genügend Wasser vorhanden.

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