# Climate of Texas

## Introduction

This publication consists of a narrative that describes some of the principal climatic features and a number of climatological summaries for stations in various geographic regions of the State. The detailed information presented should be sufficient for general use; however, some users may require additional information.

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The editor of this publication expresses his thanks to those State Climatologists, who, over the years, have made significant and lasting contributions toward the development of this very useful series.

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## Climate of Texas

Topographic Features- Texas is the second largest state in the United States, with a total land area of 267,340 square miles, roughly equal to the combined area of New England, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and North Carolina. About 800 miles separate its northernmost and southernmost points, as well as its westernmost and easternmost points. It is also the second most populous state, and its population density almost exactly equals the national average. Like California, its residents are unevenly distributed. Large stretches of land have less than one person per square mile, but Texas also includes several of the country's most populous metropolitan areas including: Dallas – Fort Worth, San Antonio, Houston and Austin.

Texas contains the largest acreage of cropland in the United States, as well as the largest amounts of pastureland and rangeland. While most of the State is rural, Texas is occupied by the largest amount of urban land of any state. Meanwhile, Texas is second only to Alaska in the amount of the state covered by inland water.

The State has variations in geography commensurate with its size and diverse character. Perhaps the most distinctive region of the State is the portion west of the Pecos River, which is known as the *Trans-Pecos* or *Far West Texas*.

Far West Texas has a Basin and Range topography similar to much of New Mexico, Arizona and Nevada and, like sections of New Mexico and Arizona; it is part of the Chihuahuan Desert. The tallest mountain range is the Guadalupe Range, composed of an ancient coral reef. Guadalupe Peak is 8,749 feet above sea level and is the highest point in Texas. The range is contained in Guadalupe National Park, one of two national parks in Texas. The other, also in Far West Texas, is Big Bend National Park, which contains the Chisos Mountains, several other mountain ranges, and the United States side of three deep canyons along the Rio Grande. The second tallest range is the Davis Mountains, which has the McDonald Observatory.

The climate of Far West Texas has a climate more similar to New Mexico than to the rest of Texas. Winters are cold and generally dry, except for rain and snow that fall mostly in the higher elevations. Summer is the rainy season, and moisture from both the Gulf of Mexico and the Gulf of California contribute to afternoon thunderstorms. Annual precipitation depends on elevation more than location; the dry grasslands near Marfa that form the backdrop of the movie *Giant* do not resemble the rest of the State but have become part of the public consciousness of the Texas natural environment.

Other parts of Texas have neither the topographic relief nor the wide variations of climate of Far West Texas. The terrain changes steadily and continuously from one end of the State to the other, the terrain interrupted only by such features as the Caprock Escarpment (in the Panhandle) and the Balcones Escarpment (along the southern and eastern margin of the hill country). The

terrain descends from northwest to southeast, drained into the Gulf of Mexico by a series of parallel rivers. From the Mexican border to the Oklahoma border, they are the: Rio Grande, Nueces, Guadalupe (which is not near the Guadalupe Range), Colorado (which is not near the Grand Canyon), Brazos, Trinity, Sabine and Red. Other notable rivers include the Pecos, which empties into the Rio Grande, the San Antonio, which empties into the Guadalupe, the San Jacinto, which empties into Galveston Bay, the Neches, which empties into the Sabine, and the Canadian, which flows across the Panhandle from New Mexico to Oklahoma. Seven of these rivers are more than 500 miles long.

The climate changes are even more gradual than the terrain. Annual mean temperatures are coolest to the north and warmest to the south. Annual mean precipitation is heaviest in the east and lightest in the west. Precipitation changes are more substantial than the temperature changes, as the near-desert in the west gradually gives way to annual accumulations close to 60 inches along the Louisiana border.

With subtle variations in climate and terrain, sub-regions of the State of Texas are often more clearly delimited by changes in vegetation or terrain character. Because many transitions are gradual, categorizations are somewhat arbitrary. The following 10 regions correspond roughly to the 10 climatic divisions of Texas. The Trans-Pecos region was discussed earlier in this document. Now the other nine will be described.

The Texas *High Plains* occupies most of the Texas Panhandle and is defined on the north and west by the State boundaries and on the east by the Caprock Escarpment. The High Plains are about as flat as the coastal plains of Texas. The major cities of the High Plains are Amarillo, Lubbock, and on the margin of the Trans-Pecos, the neighboring cities of Midland and Odessa. Much of the High Plains is underlain by the Ogalalla Aquifer, which supplies a large but dwindling water supply to the area's irrigated agriculture. The High Plains are divided in two by a valley carved by the Canadian River, and a branch of the Red River has created the dramatic Palo Duro Canyon. Elsewhere, the High Plains are pockmarked with shallow, intermittent lakes and an occasional district where sand dunes have been set in motion by the wind.

The *Low Rolling Plains* are largely rangeland, consisting of grasslands interspersed with forests of mesquite, a short, invasive tree with sweet-smelling wood but sparse shade. They lie east of the High Plains and include the cities of Abilene and Wichita Falls. While surface waterways are much more numerous than in the High Plains, lakes are much less frequent, as the land drops steadily toward the east. Many soils are quite red, and the runoff from this area helps give the Red River its name. This area has the greatest frequency of tornadoes in Texas.

The *Cross Timbers* are also a mixture of grasslands and forest, although the forest includes oak and other species besides mesquite. The greater biological diversity among trees is attributable to higher precipitation totals and slightly warmer temperatures, along with soil variations. Like the Low Rolling Plains, the Cross Timbers slope mainly from west to east. Most lakes are man-made. Fort Worth and Temple are prominent cities on its eastern edge, while Austin, the State capital, sits at the intersection of the Cross Timbers, the Blackland Prairies, and the Edwards Plateau.

The *Edwards Plateau* lies south of the: High Plains, Low Rolling Plains and Cross Timbers, and east of the Trans Pecos. Its southern margin is the Balcones Escarpment, and the region includes both the relatively flat plateau area as well as the high-relief plateau margin where some of the most rugged terrain in Texas (known as the Hill Country) is located. The area is underlain by limestone formations, and many dramatic caves are located here. The vegetation varies from grasslands in the west to forests in the east, with pockets of maple and cypress hundreds of miles from their normal ecosystems. The most prominent city is San Angelo, but its eastern margin abuts Austin and San Antonio and various bedroom communities have developed, attracting people from the cities with its scenic ruggedness and slightly cooler summertime temperatures. Various spring-fed rivers and streams originate along the Balcones Escarpment.

The *Blackland Prairies* are defined by several strips of rich, black soil that extend from San Antonio to Dallas and beyond and eastward to the Piney Woods. Most of the Blackland Prairies are occupied by farming operations, but in the 18th and 19th centuries the prairies formed easy corridors for long-distance travel from west to east. Now, the primary transportation corridor is along the western edge of the Blackland Prairies, along Interstate 35 and a string of major cities from San Antonio to Austin, Temple, Waco, Dallas and Sherman. The prairies are generally flat or rolling, and are devoted primarily to non-irrigated agriculture.

The *Post Oak Savannah* lies mainly east of the Blackland Prairies, but is interlaced with the Prairies in a few areas. The Savannah was a fire-driven ecosystem, with oak trees underlain by grasslands. Now the territory consists of a mosaic of oak woods, tree-studded fields, and open grazing areas, with farming confined mainly to sediment-filled river valleys. The Post Oak Savannah includes Bryan/College Station, home of Texas A&M University.

The *Piney Woods* are the westernmost portion of the mixed evergreen-deciduous forest belt that stretches westward across the Deep South from the Carolinas. The wide variety of trees is dominated by pine and oak, resting on fast-draining, sandy soils. Occasional cleared grasslands are outnumbered by productive forests, both public and private. In the interior of this region is the Big Thicket, a combination of uplands and lowlands with a rich diversity of plant species. In the Piney Woods, tall pines, prickly pear cactus, and palmetto exist side by side. Population centers include Longview, Tyler and Texarkana.

The *Gulf Coastal Plain* is primarily a combination of prairies and marshes. Behind the barrier beach is a set of lagoons and estuaries that form a rich habitat for migratory and resident birds, including a major wintering area for the endangered whooping crane. While tornadoes and floods are the primary weather hazards in the rest of the State, the Gulf Coastal Plain is most vulnerable to hurricanes. Major cities along the coastal plain include Houston, Beaumont, Victoria, Corpus Christi and on a barrier island, Galveston.

The *South Texas Plains* are largely arid and treeless. The largest ranch in Texas, the King Ranch, is here. Widespread areas are covered with dense thickets of subtropical brush. San Antonio is along the northern margin of this region, while Laredo is in its southwestern corner.

The *Lower Rio Grande Valley* is the smallest geographical area described. It consists of alluvial plains that are under widespread irrigated agriculture. The salt and freshwater marshes and other

plant communities host a wide variety of tropical and temperate species of birds, many of which pass through the area en route between North and Central America. The area, often known simply as "the Valley", is a popular wintering area for residents of the central United States. Primary cities include Brownsville and McAllen.
The climate of Texas is determined by geographical features external to the State. To the southeast, the Gulf of Mexico provides a source of warm, moist air throughout the year. During the summer, the entire State comes under the influence of the Gulf, as southeasterly and southerly winds settle into place. Air approaching Texas from the Gulf may have a long history of being over the tropical waters of the Caribbean and the Atlantic, or it may recently have moved offshore from the southeast United States. The latter circumstance leads to air that is more polluted and in summertime is hazier. Tropical Atlantic air is relatively clean and visibility tends to be excellent despite the high humidity. Except for the Trans-Pecos, most of the water that falls as precipitation in Texas has entered the State from the Gulf coast.

The second climate maker is the Mexican High Plain, or Altiplanicie Mexicana. This arid, high-altitude plateau region extends northward from Mexico City nearly to the United States border. Rarely does this air reach ground level in Texas except in the Trans-Pecos region, but it influences the weather throughout the State. When surface winds in Texas are from the south or southeast, winds 10,000 feet above ground are normally from the southwest. Thus, low-level air from the Gulf of Mexico is overlaid with warmer, drier air from the Mexican High Plain. Close to the Mexican border, this warm air 'caps' the humid Gulf air, preventing thunderstorm activity and trapping the humid air close to the ground. As the air masses precede north, particularly during the spring and fall, they progressively move beneath cooler air aloft. While the humid low-level air becomes more unstable, it still cannot convect because of the capping inversion. Eventually, if a frontal system or other disturbance causes larger-scale ascent, the Mexican High Plain air can cool enough to eliminate the cap, suddenly allowing vigorous thunderstorm activity to take place. The combination of the Gulf of Mexico and the Altiplanicie Mexicana makes Texas and the southern Great Plains the worldwide hot spot for severe convection and tornadoes.

The third climate maker is the Rocky Mountains. Arizona, New Mexico and west Texas form one of two relative gaps in the Rocky Mountain Cordillera; the other is along the United States-Canadian border. Westerly winds often blow through this gap, but the Rockies form a broad barrier to westerlies for the rest of the State. In the eastern half of Texas, the least likely wind direction is from the west. The Rockies also block air from moving across them from the east. In particular, cold air masses that reach the United States from the north cannot easily spread westward and instead are funneled southward parallel to the mountains. Such cold air reaches farther south into Texas and beyond than anywhere else on the continent. Nevertheless, it is rare for bitterly cold air to reach the Lower Rio Grande Valley, allowing grapefruit to be one of the area's largest cash crops.

Temperature- Winter in Texas is a season of extremes, both in space and time. Average January low temperatures range from 20 degrees Fahrenheit (° F) along the northern border of the Panhandle to 50 in the Valley. Rapid temperature changes occur in response to a weather phenomenon known as a 'Blue Northern', a cold front that moves from north to south, propelled by cold air that has been trapped against the east side of the Rocky Mountains. These cold fronts are among the strongest in the United States; 20° F temperature drops in one hour are not

uncommon. The temperature drops are accompanied by winds from the north of 20 to 30 mph; low stratus clouds often linger for a day or two before skies become clear.

Ten to twenty blue northers occur during a typical year. Perhaps the most dramatic was February 6, 1933, when the High Plains city of Clarendon reported a high temperature of 69° F and a low temperature of -6, for a one-day temperature range of 75 degrees. Two days later, Seminole tied the all-time minimum temperature record for Texas at -23° F. Over a longer period, the most extreme weather change was 1906, when 101° F was recorded in south Texas on November 17 and -9° F was recorded in north Texas on November 21. More recently, Rio Grande City reached 102° F on February 9, 1960, and three days later a snowstorm hit central and south Texas with eight to 10 inches of snow.

The coldest day in weather records in Texas was February 12, 1899. On that day, over half of the State reached subzero temperatures, and the other recorded instance of -23° F occurred in Tulia. Another massive cold wave took place in late January 1949, when temperatures dropped subzero from Dallas to San Antonio. The Texas Panhandle has the coldest weather: Amarillo once spent 261 consecutive hours below freezing in 1895, and on January 4, 1959 Spearman experienced a "high" temperature of -1° F and a low temperature of -22. Warm temperatures are the norm in the Lower Rio Grande Valley, even in wintertime, and the area supports cold-sensitive crops. When the occasional cold wave hits the Valley, the agricultural damage can be severe, such as the billion dollars of damage caused by the cold wave December 19 - 24, 1989. Unlike the other three seasons, during which Texas receives frequent incursions of polar air, summertime finds Texas experiencing primarily a humid, subtropical climate, with only occasional bursts of cooler air from the north. Typical high temperatures are in the 90s everywhere except in the higher elevations of western Texas and along the immediate coastline, where 80s are more common. The normally high humidity keeps low temperatures warm also; they range from the 70s in the eastern part of the State to the 50s in the high-altitude arid regions of the Trans-Pecos. The warmest temperatures in summertime stretch from the Edwards Plateau across the Low Rolling Plains to the Cross Timbers where readings frequently top 100° F.

The record high temperature for Texas is 120° F, set in 1936 and tied in 1994. During unusually warm summers, the temperature occasionally exceeds 110° F, as it did for 10 consecutive days in Wichita Falls in 1980. While severe heat waves cause increased mortality, air conditioning is common so impacts are not nearly as great as they would be in the Midwest or Northeast under comparable conditions. Plentiful drive-through windows are an indication of the reluctance of Texans to leave their air-conditioned vehicles.

Precipitation- Monthly average precipitation ranges from less than half an inch in west Texas to over four inches in parts of East Texas. Significant amounts of snow are confined almost entirely to the mountainous Trans-Pecos region and the High Plains. Measurable snow falls south of the High Plains but usually melts almost as fast as it falls. Average annual snowfall is a foot in Amarillo, six inches in Abilene, three inches in Dallas, and an inch in Austin. The record accumulation for one year is 65 inches in Romero in 1923. Accumulations of over two feet have on occasion occurred somewhere in the State in all months from December through March, and an 18 inch snowstorm struck Sweetwater, in the Low Rolling Plains, April 1996.

Historically, the most severe snowstorm in Texas took place on February 2 - 5, 1956. A storm total of 33 inches was recorded in Hale Center, and 20 persons died from the snow and cold in the High Plains. Ten died in another High Plains blizzard in January 1957. Two other dramatic High Plains blizzards were in February 1964 and February 1971. Both storms featured over two feet of snow. Winds were stronger in 1971, when 60 mph gusts produced 12 feet snowdrifts; drifts in 1964 were a "mere" eight to 10 feet.

From central Texas southward, most winters bring no accumulation of snowfall. Freak snowstorms occur only once every few decades, but no corner of the State is immune. Memorable freak snowstorms include the February 1895 snowstorm that brought 20 inches of snow to southeast Texas from Houston to Orange, the December 1929 snowstorm that brought over two feet of snow to central Texas, the April 1983 snowstorm whose 16.5 inches in El Paso set their all-time record, and the January 1985 snowstorm that dumped 13.5 inches on San Antonio. The latter snowstorm accounted for several decades' worth of snowfall for the normally snow-free city. Brownsville has made it more than a century without any accumulation of snowfall, but records from the 1800s show that such an event is possible.

While snowstorms are the primary winter threat in the High Plains, the other parts of northern and central Texas are subject to occasional ice storms. Like snow, ice can occur almost anywhere in the State, but ice storms are most common north and east of Austin to the Arkansas border. The most significant recent ice storms were a pair of storms in December 2000, each of which struck northeast Texas with up to six inches of ice. The final damage tally was $156 million (2000 figure) and power took weeks to restore in some areas.

Wintertime low pressure systems sometimes form in the Gulf of Mexico. Normally, the only significant impact to the State of Texas is steady rain, because such storms almost never intensify significantly before moving east. The most remarkable exception was the February 13, 1969 coastal storm, which possessed the strength of a minimal hurricane. Wind gusts approached 100 mph at two coastal locations and tides were nine feet above normal.

Despite the threat of the rare snow or ice storm, winters in most parts of Texas are mild and pleasant. Sunshine averages at least 45 percent of maximum possible along the coast. In Houston, the growing season is 300 days long; in Dallas, 235. In less than half the State does the latest freeze typically occur after April 1$^{st}$.

Springtime is the most pleasant season of the year in most parts of Texas. The highlight of spring is the wildflower display along roadsides and in fields. The first spring wildflower to appear is the State flower, the bluebonnet, in late March or early April. The bluebonnet is followed closely by the: Indian paintbrush, showy primrose and Plains coreopsis. By May and June the variety of wildflowers reaches its peak, and drives through the countryside are a popular weekend activity.

Spring is also the peak season for severe weather in Texas. Significant severe weather events are triggered by an upper-level disturbance approaching Texas from the Four Corners area of the United States. Ahead of the upper-level trough, low-level southerly winds from the Gulf of Mexico advance moisture northward across Texas and into Oklahoma and Kansas. To the west,

winds descend from the Continental Divide. In the lee of the Rocky Mountains, across the High Plains or the Low Rolling Plains, a dryline forms between the two air masses: the moist air from the Gulf of Mexico and the drier air from the higher elevations to the west. The dryline runs from north to south and is predominantly a windshift line and a moisture discontinuity rather than a strong contrast in temperature.

As cool air aloft approaches Texas, it first encounters moist, unstable air along the dryline. Ascent along the dryline makes thunderstorms more likely to occur there. Often a chain of thunderstorms will form along the dryline in mid-afternoon, and by sunset coalesce into a squall line that advances eastward across Texas. This type of evolution is most common in May, the wettest month of the year in many parts of Texas.

Tornadoes are most prevalent in May as well. Earlier in the season, tornadoes are most common in North Texas, between Dallas and Wichita Falls, but by May, the peak area for tornadoes moves westward to the Low Rolling Plains. Tornadoes can occur in any part of Texas, but they are relatively uncommon in the western Trans-Pecos and extreme south Texas, although an F3 tornado did occur on March 15, 1983 in Cameron County, in the Valley. The intensity of tornadoes is rated on a proxy scale (based upon the damage produced) from F0 to F5 . F0 tornadoes are the most common, but the relatively rare F3 or stronger tornadoes are responsible for a majority of the deaths.

The most devastating tornado in Texas history occurred on May 11, 1953. On that day a tornado struck Waco, killing 114 and injuring 597. Over 1500 homes and other buildings were destroyed. A few hours earlier, another tornado had hit San Angelo, killing 11 and injuring 159. The Waco tornado tied the May 18, 1902 tornado that struck Goliad for the most deadly tornado in Texas history.

If not for improvements in severe weather warnings, the April 10, 1979 tornado that struck Wichita Falls might have had the highest death toll of all. Even so, 42 people lost their lives, 1740 persons were injured, and 20,000 were left homeless. But surely the most impressive tornado ever recorded in Texas was the long-track tornado of April 9, 1947, which touched down in the Panhandle and stayed on the ground for an incredible 221 miles. The tornado killed 68 and injured 201 in Texas alone, before passing across Oklahoma, where it struck and destroyed Woodward, and lifting off in Kansas.

Other memorable Texas tornadoes include the April 12, 1957 Rocksprings tornado, which killed 72 and injured over 200 out of a population of 800; the May 15, 1896 Sherman tornado which killed 75; the May 22, 1987 Saragossa tornado, which destroyed 85 percent of the town, killing 30 and injuring 121 out of a population of 183; the May 11, 1970 Lubbock tornado, which damaged 25 percent of the town, killing 26 and injuring 500; and the F5 Jarrell tornado of May 27, 1997, which killed 27 and injured 12.

In addition to tornadoes, severe weather can also include hail, heavy rainfall, and strong straight-line winds. Heavy rainfall will be considered in the summer section. Strong straight-line winds can occasionally be damaging, such as the May 17, 1986 gust front that struck Lake Livingston during a fishing tournament with estimated 90 mph winds, capsizing boats and causing five

drowning deaths. Such winds are caused by air aloft cooled by evaporating rainwater and brought down to the ground.
Hail can cause the greatest amount of monetary damage. Hail forms when ice aloft encounters large amounts of supercooled water. On May 5, 1995, the most expensive single thunderstorm event struck the Dallas-Fort Worth area, dropping large hail on an outdoor festival in Fort Worth before causing flash flooding in Dallas. Most of the 20 deaths were from the flash flood, but most of the 109 injuries were caused by the hail. Total damages were estimated at $2 billion (1995 figure).

In urban areas hail dents cars and damages roofs; in agricultural areas hail destroys crops. On August 24, 1979, a hailstorm in the High Plains destroyed 150,000 acres of crops and damaged another 550,000 acres. Another more recent hailstorm in Howard County on May 10, 1996, produced hailstones up to 5" in diameter and caused 48 injuries. Texas hailstorms have been known to cover the ground to a depth of 18 inches (May 5, 1995, Parker County), drift to three feet (the Parker County storm, as well as May 16, 1917 in Ballinger), and produce stones weighing as much as 22 ounces (Dallas, May 8, 1926).

Summer produces the most equitable distribution of rainfall. In western portions of the Trans-Pecos and High Plains, July and August are the wettest months of the year, as moisture drawn inland from the Gulf of California and the Gulf of Mexico leads to frequent afternoon thunderstorms. Thunderstorms are also common elsewhere in the State, but the departure of the jet stream to the north means that severe thunderstorms are a rarity.

Despite the continued rainfall, the high temperatures mean that normal evaporation exceeds precipitation in all areas of the State. Below-normal precipitation can cause significant environmental stress, and the State is most susceptible to drought during summertime as a result. The reduced evaporation from the soil and plants under drought conditions also causes temperatures to be just a little bit warmer, making the situation even worse.

From the early days of Texas history recorded by Spaniards exploring the Southwest, drought has been a recurring problem. A drought in central Texas dried up the San Gabriel River in 1756, forcing the abandonment of a settlement of missionaries and Native Americans. Stephen F. Austin's first colonists also were hit by drought. Their initial corn crop was snuffed out in 1822, forcing the once ambitious farmers into desperate hunters.

The most severe drought in Texas during the past century began in 1950 and continued until March 1957. Other major droughts include 1886 - 1887, 1893, 1917, 1933 - 1935, and sporadically during 1998 - 2002. Because much of the agriculture and all of the ranching is non-irrigated, even just a few consecutive months of substantially below-normal precipitation can cause an emergency situation.

The 1930's drought was only serious in northern portions of the State, which adjoined the infamous Dust Bowl region. Dust storms, which occur in the Texas High Plains once or twice in a normal year, were particularly common in 1935, when streetlights were sometimes necessary during daytime. The 1950's drought also produced an increase in dust storms. Most dust storms occur during the first few months of the year, when strong winds from the west or north are

common in the Panhandle. On rare occasions, such as January 25, 1965, a dust storm will affect most of the State. This one brought visibilities below 100 feet in Lubbock and caused three inches of dust to accumulate in the rain gage at Reese Air Force Base.

Floods can occur in any season in Texas, but they are most common in summer. Flood causes include slow-moving tropical systems or their remnants, stalled fronts, mesoscale convective systems enhanced by low-level jets and thunderstorms that develop repeatedly over the same location. Rainfall rates and storm totals can be quite impressive.

To organize the discussion, Texas floods are categorized as flash floods, area floods and river floods. A flash flood involves an intense burst of rain of short duration, producing rapidly rising water along a stream or set of streams that sometimes catches people by surprise and sweeps them away. An area flood involves intense but prolonged rainfall over hundreds of square miles that overwhelms the ability of creeks and rivers to drain the water away and may include several individual flash floods. Finally, a river flood is caused by several days of rainfall, so that the most serious flooding occurs downstream as the floodwaters make their way toward the Gulf of Mexico.

The most significant flood in Texas history was an area flood that took place during September 8 - 10, 1921. The torrential rains rival those anywhere in the world. For example, in 12 hours 32 inches of rain fell at Thrall, which is situated east of Austin. The station's 24 hour total was 38.4 inches. The heavy rain extended as far southwest as San Antonio, leaving a death toll of 215. The costliest flood in Texas history was caused by Tropical Storm Allison, which made landfall on June 4, 2001, and remained in the State for several days. On June 8 - 9, torrential rains fell directly over Houston at rates of up to four inches per hour. In one evening, many parts of central Houston received over a foot of rain, and storm totals just east of the city approached 35 inches. The resulting floods caused 22 deaths, destroyed or damaged over 48,000 homes, and caused $5.2 billion (2001 figure) in damage. Seven years earlier, the October 1994 flood, with 29 inches of rain, hit areas north and west of Houston, cutting Houston off nearly completely from the outside world, and the pipelines ruptured by the flood caused the San Jacinto River to catch fire.

Other memorable area floods include the Southcentral Flood of October 17 - 19, 1998. Up to 30 inches of rain in 24 hours caused floodwaters that killed 25, injured 2,000, destroyed 3,000 homes, and caused $500 million (1998 figure) in damage from San Antonio to Victoria. The Northeast Texas Flood of April 1966 was created from 20 to 26 inches of rain, and left 33 dead. The September 11, 1952 flood in the Edwards Plateau area resulted from 20.7 inches of rain in 24 hours and killed five persons.

Areas along the Brazos River have been subjected to two devastating floods. The first, on June 27 - July 1, 1899, caused the river to fill its floodplain to 12 miles wide, and 35 persons died. In response, levees were constructed along the river to hold back floodwaters. The folly of that attempt was revealed in December 1 - 5, 1913, when over 30 inches of rain fell in some areas. The levees could not contain the massive floodwaters, and when the levees were overtopped or broken, the sudden rush of water killed 187.

The Rio Grande has also been the site of two substantial floods. The first, in September 1932, occurred from Del Rio to the Gulf of Mexico, causing 10 deaths. The second, June 26 - 27, 1954, was remarkable both because it took place in the middle of a drought and because the rainfall totals, up to 27 inches along the Pecos River, exceeded the normal rainfall for the entire year.

Flash floods affect a much smaller area but can cause significant loss of life because of their suddenness. On August 23 - 24, 1882, the town of Ben Ficklin was devastated by a flash flood that killed 45. In response, the county seat was moved to San Angelo, and Ben Ficklin no longer exists. In early August 1978 the remnants of tropical system Amelia dropped 30 inches of rain in Albany; the resulting flash flood killed 27. The west Texas town of Sanderson was partially destroyed by a flash flood on June 11, 1965 that caused 26 deaths. In Austin on May 24 - 25, 1981, rainfall rates of 5.5 inches per hour caused a flash flood that killed 13 and injured 100.

Some floods are notable not for their damage or death toll but for their impressive precipitation totals. The United States record for precipitation in a 24-hour period is held by the remnants of tropical storm Claudette, which dumped an estimated 43 inches of rain in one day near Alvin, south of Houston. Other impressive totals include 12.8 inches in 4 ½ hours (Beaumont, May 18, 1923), 15.7 inches in 10 hours (Matagorda, June 1, 1911), and 20.6 inches in 19 hours (Montell, late June 1913).

Summer drifts slowly into fall as cold fronts from the north penetrate farther and farther toward the Gulf Coast. The color changing of the leaves that begins autumn in the northern United States takes place near the end of fall in Texas. Colors can be impressive in areas such as northeast Texas. In October or November, one or two outbreaks of severe weather commonly occur each year, but the primary weather phenomenon in late summer and early fall is the hurricane.

The most deadly weather disaster in United States history was the Galveston hurricane of September 8 - 9, 1900. With only a few hours' warning, this Category 4 hurricane produced a storm surge that inundated most of the city and killed an estimated 8,000 persons. Rather than abandoning the city, residents built a seawall and elevated the main part of town by several feet. The next major hurricane, on August 16 - 19, 1915, killed the comparatively small total of 275. The last time a significant hurricane hit the area was Alicia on August 15 - 21, 1983. The death toll was only 18, but 1,800 were injured and the final damage total was $3 billion (1983 figure).

The second-largest port city in the late 1800s (behind Galveston) was Indianola, on the coast between present-day Victoria and Corpus Christi. Over 175 were killed by a hurricane that made a direct hit on September 16, 1875. Eleven years later, on August 20, 1886, every building was damaged or destroyed by a hurricane. After the second hurricane, the town site was abandoned and Indianola now consists of a few vacation homes, a cemetery, a memorial and the end of the road. In contrast, Corpus Christi survived the hurricane of September 14, 1919 and its 286 deaths to become the second largest coastal city in Texas.

In recent years, the death toll from hurricanes has steadily decreased, due to improved warnings and evacuation procedures, but the damages have increased as coastal areas become more

populated. Besides Alicia, other significant named storms to strike Texas include Carla (September 8 - 14, 1961), which was the strongest recorded hurricane ever to make landfall in Texas. Winds reached an estimated 175 mph, but an evacuation of 500,000 limited the death toll to 34. Celia made landfall near Corpus Christi on August 3, 1971 and brought winds up to 160 mph. Its $450 million damage total held the Texas record until Alicia in 1983. Beulah, a unique storm, hit South Texas on September 18 - 23, 1967. Sustained winds were not especially intense, but the hurricane dropped up to 36 inches of rainfall and spawned 115 tornadoes.

The occasional tropical systems or their remnants combine to make September the wettest month on average in much of East and South Texas. Parts of West Texas also experience their heaviest rainfall on average during September, due to the influence of the remnants of tropical systems from the eastern Pacific Ocean. This rainfall is not as reliable as the spring rains, because it tends to come in one or two major events. Because of this, fall can also see prolonged dry weather. Some of the driest months in Texas history occurred in October and November, including October 1952 when rainfall across the State averaged only 0.02 of an inch.

Climate and the Economy- This tour of Texas weather throughout the year has emphasized some of the more interesting weather events that have taken place. Of course, normal weather is relatively ordinary, and the typical conditions are detailed in the paragraphs that follow. Lest one think that Texas weather is inherently dangerous, it is worth noting that most dangerous weather can easily be avoided. Snow, ice and hail are thwarted by staying indoors when this type of weather threatens. Flood fatalities may usually be avoided by avoiding houses in or near floodplains and by not driving through water during or after rainstorms. Evacuations let people outrun hurricanes, except on barrier islands with limited access or when residents stop taking evacuation orders seriously. Even most tornadoes can be protected against by taking refuge in a sturdy interior room. Most Texans cannot understand how people could possibly live in California and be subject to the danger of earthquakes.

Texas is a windy state. The windiest spot with regular weather observations is Guadalupe Pass, a major east-west gap in the Trans-Pecos Mountains. Sustained winds over 40 mph are common during springtime. Many areas in the Trans-Pecos are being considered for wind power generation due to their frequent moderate to strong winds.

During spring and summer, the central third of Texas frequently experiences a low-level jet, a band of strong winds (25 - 60 mph) just above the ground that channels warm, moist air northward. Sometimes the low-level jet is induced by the leeside development of a strong low pressure center. Other times the low-level jet is merely a consequence of the broad terrain slope that marks the eastern edge of the High Plains. In either case, the jet tends to be strongest at night, and may not be felt or experienced until sunrise when low clouds are witnessed to be traveling rapidly northward.

Also predominantly during the summer, coastal areas of Texas are subject to the sea breeze. Due to the latitude of Texas, the sea breeze tends to occur late in the day, and winds tend to rotate clockwise with time during the late afternoon and evening. The strongest winds just above the ground tend to be in the middle of the night, making the sea breeze winds difficult to distinguish from the effects of the low-level jet.

Ground water is a significant resource throughout much of the State, supplying most of the total water used for municipal, industrial and irrigation purposes. The underground sources of water, known as aquifers, are under varying degrees of stress due to water usage. Widespread irrigation in the High Plains is rapidly depleting the Ogalalla Aquifer, and most of the area is expected to revert to ranching or dryland agriculture by 2020. In contrast, the Edwards Aquifer, which supplies Austin and San Antonio, is a near-surface limestone aquifer that is the source of a few rivers and is rapidly recharged by rainfall. Ecological restrictions prevent this aquifer from being permanently depleted.

Except along the border with Mexico and the edges of the Edwards Plateau, rivers are not major foci of recreational opportunities. Much more recreation takes place on the numerous man-made lakes in Texas. These lakes have been constructed for a variety of purposes, including flood control, power generation, water supply and recreation.

Relative humidity is highest in the coastal region and decreases gradually inland as the distance from the Gulf of Mexico increases. Mean annual relative humidity at midday varies from slightly more than 60 percent near the coast to 35 percent in the El Paso area. On the whole, there is a range of approximately 10 percent between the high summer and low winter averages. As temperatures increase, relative humidity generally decrease, and when temperatures fall the relative humidity tends to rise. The lowest relative humidity is found generally in the daytime, especially in the afternoon, while the highest values usually occur in the early morning.

The climate of Texas is such that summer air conditioning is desirable in all parts of the State. While it is true that residents of the High Plains area enjoy cool summers occasionally when little air conditioning is needed, more often than not July and August temperatures rise to the point where some cooling adds measurably to human comfort.

Air quality is generally improving across Texas despite the steady increase in population. The most significant causes of poor air quality in Texas are ozone and particulate matter.
With regard to ozone, Houston has historically been one of the worst cities in the country. Ozone, a component of smog, is produced by chemical reactions involving hydrocarbons and compounds produced by high-temperature combustion such as occurs in automobile engines. Houston is particularly susceptible to high ozone because of the significant concentration of petrochemical refining plants in the area. Dallas-Fort Worth also has an ozone problem, and several other metropolitan areas are close to the federal standard.

Meteorological conditions conducive to high levels of ozone include clear skies, light winds, and possibly a low-level temperature inversion. Sunlight is strongest in June and July, but because of the strength of the Bermuda High during early summer, high levels of ozone are most likely in August and September. Along the coast, the sea breeze strongly affects both stagnation and transport. The highest levels of ozone are expected when winds are light during the day and stronger from the southeast or southwest during the afternoon.

Particulate matter includes a variety of small suspended particles, or aerosols. Mineral dust, from soil, is picked up by strong winds and spread as a dust storm. Most of this type of dust originates in the High Plains or eastern New Mexico. Some dust also reaches Texas during the

summertime all the way from the Sahara Desert. Soot, or aerosols from smoke, is a serious problem in El Paso and its companion city across the Rio Grande, Juarez. Aqueous aerosols, containing sulfur or nitrogen compounds, typically originates from the central and eastern United States; normal Texas air usually features good visibility. On rare occasions during the spring, smoke from agricultural fires in Mexico and Central America reach Texas and reduce visibility.

A different sort of health problem is produced by pollen. The variety of wildflowers presents a wide range of possible allergens during spring and summer. In winter, the Ashe Juniper in the Edwards Plateau area produces a burst of pollen that causes hay fever for many people.

Both temperature and precipitation exhibit long-term variability on multi-year to multi-decade timescales. The general tendency is for slightly increasing temperatures, but precipitation shows no noticeable long-term trend. Annual precipitation seems to be related to a strong western United States multi-decade oscillation, possibly caused by sea surface temperature variations in the North Pacific.

The increase in temperature depends strongly on local conditions. Increased urbanization will cause an increase in surface temperatures. Conversely, irrigated agriculture causes locally cool conditions.

A strong signal in Texas climate is produced by El Niño. When equatorial Pacific sea surface temperatures are warm, winters in Texas tend to be cool and wet. Conversely, when La Niña dominates, winters tend to be warm and dry. Strong blue northers are most likely during years in which equatorial Pacific temperatures are near normal.

Accurate techniques have not yet been developed to predict spring, summer or fall weather in Texas more than a few months in advance. The ability, in particular, to predict summertime rainfall would be of tremendous economic value to the agricultural industry in Texas.

**For Further Reading**

To learn more about Texas's climate and weather, consult the following resources:

The Texas Almanac, published by the Dallas Morning News and distributed by the Texas A&M University Press Consortium, updated every two years

Texas Weather, by George W. Bomar, published in 1995 by the University of Texas Press

One Hundred Years of Texas Weather, 1880 - 1979, by John F. Griffiths and Greg Ainsworth, published in 1981 by the Office of the State Climatologist, Department of Atmospheric Sciences, Texas A&M University