

Climate and Weather Atlas of Kansas

An Introduction

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Educational Series 12
Kansas Geological Survey
Lawrence, Kansas
1995, reprinted 2004

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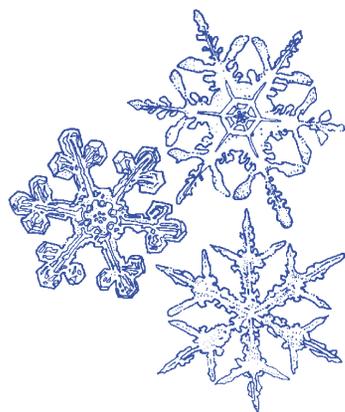
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INTRODUCTION

Because Kansas lies in the center of the continental United States, it is subject to varying weather patterns as air masses move across the state. Much of the severe weather for which Kansas is often noted is due to weather patterns that bring cold dry air into contact with warm moist air. Despite this reputation, the Kansas climate is partly responsible for the fertile soils and world-renowned agricultural industry.

Weather is an important part of our daily lives. We look to the paper, on radio and TV, and more recently on computer networks. Sites on the Internet or World Wide Web provide regional climate and weather information updated on a daily basis. This document is intended to give the general public information about some of the common terms and measurements they encounter in daily life. It cannot be used to plan daily

activities, but provides an overview of the recorded weather and climate of Kansas. For example, this document includes maps of the first and last frost-free days across the state. This information would be of interest to gardeners in planning their activities. Or, it might be used to plan when to go camping or fishing. It would be of no use determining whether to wear a coat on a particular day.

This book is intended to provide basic information on the weather and climate of Kansas. The information is presented as a series of maps of selected climate and climate-related indices that are commonly reported in the media. All the information is derived from data collected across the state and compiled at the State Weather Library at Kansas State University. For more information about these data, the collection of the data,

access to real-time computer information, or other aspects of the weather and climate of Kansas, contact the State Climatologist at:

State Climatologist
Weather Data Library
211 Umberger Hall
Kansas State University
Manhattan, KS 66506-3400

Phone: (785) 532-7019

FAX: (785) 532-6487

Electronic mail: wdl@oznet.ksu.edu

READING THE MAPS

The various measures of climate in this book are displayed using contour maps. A contour map portrays information with a series of lines that each represent a single value. For example, the map of precipitation shows lines for 15 inches, 20 inches, etc. The interval between these contour lines can be said to receive 15 to 20 inches of precipitation per year. In general, as one moves from the 15-inch line toward the 20-inch line, one expects to observe increasingly higher annual precipitation. As successive lines are crossed

west to east, higher values are expected. The shape of the line helps to display the pattern of precipitation across the state.

Although the maps display a clear representation of the general pattern of the various measures of climate, they are derived from weather stations scattered across the state (see map, page 1). Because of this, the process of contouring is an attempt to interpolate or predict the values between measured points. Various methods are used to interpolate contours.

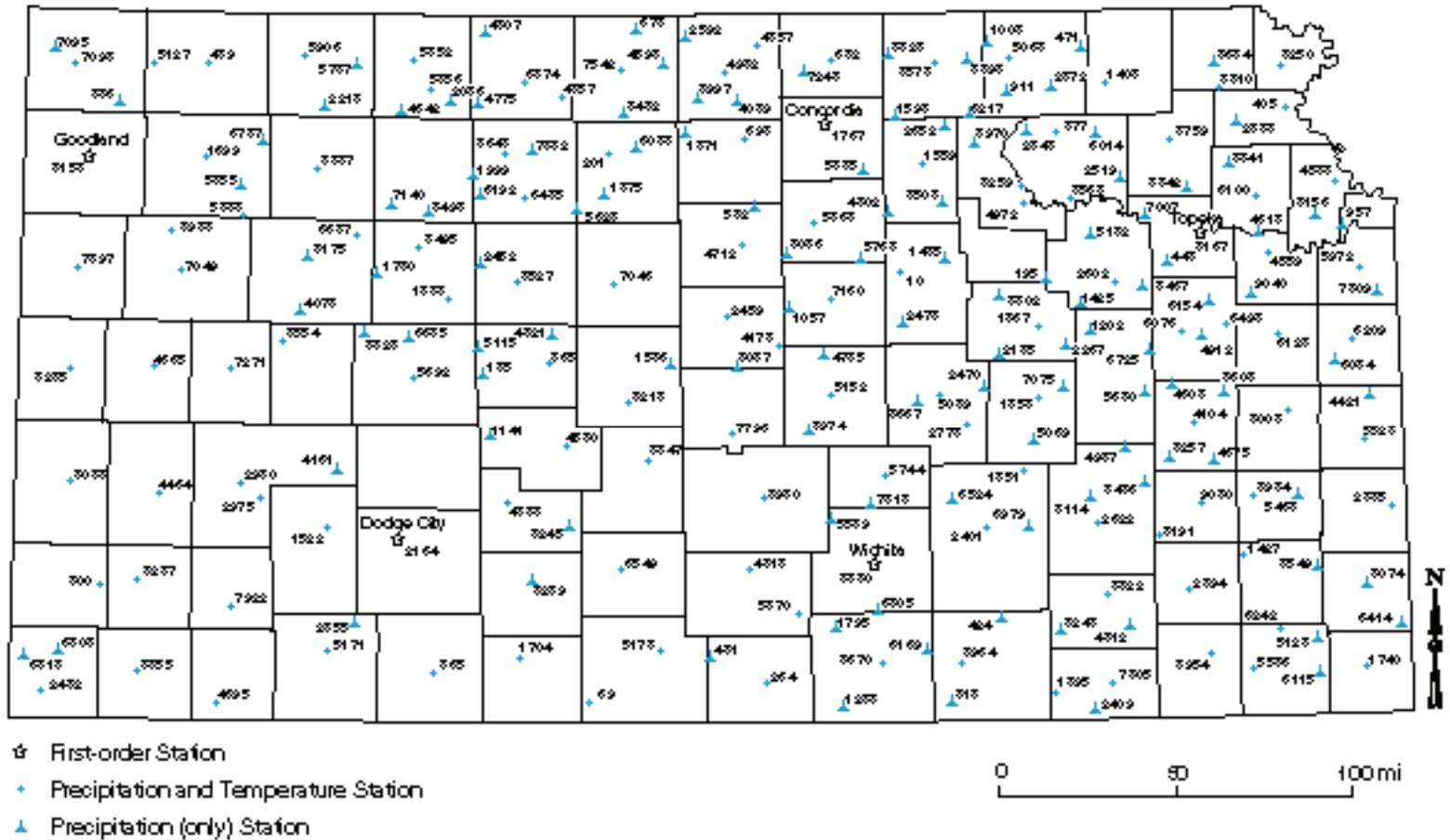
None of the methods used for creating contour maps is exact or 100% perfect. Nevertheless, they are useful in depicting the general pattern of behavior across a region. Readers should keep in mind that the maps in this book are intended for just that purpose. They are not intended to be used for site-specific purposes or weather predictions. However, they can be a useful general guide for persons interested in average or normal values of the various measurements and indices.

STATION LOCATIONS

This map shows the location of the measurement stations where the data used in this atlas were collected. The five stations indicated by stars are first-order stations operated by the National Weather Service. These stations use very accurate instruments and have been in

operation for the longest period of time. The other stations are part of the National Weather Service Cooperative Observer Network. These stations are operated by volunteer observers, who agree to maintain the site and instruments, as well as record, tabulate, and report the

data. The cooperative network is designed to provide the most extensive coverage possible. At least one cooperative station is in operation in every county except Hodgeman. Station-location names are listed on pages 21–22.



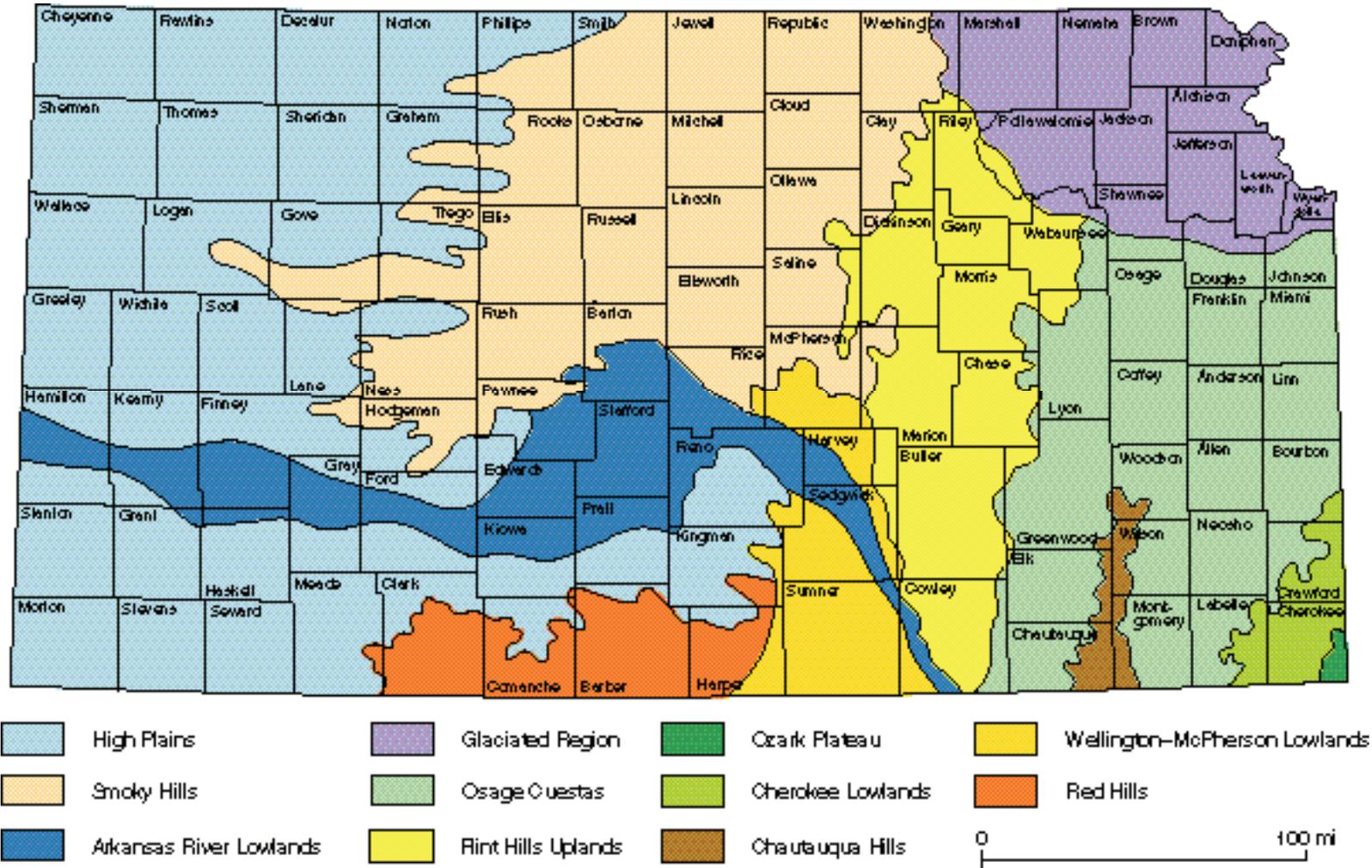
Station Locations

GENERALIZED PHYSIOGRAPHY AND COUNTY NAMES

In order to make the climate maps easier to read, county names and major features are omitted. However, because county names are referred to in the text,

they are included on this map in order to provide a reference to the reader. This map also divides the state into physiographic regions, or areas of similar

land forms, such as hills or plains. The relationship between these regions and climate is discussed on page 19.



Generalized Physiography of Kansas

ANNUAL NORMAL PRECIPITATION 1961–1990

The amount of precipitation (rain and snow) is one of the most important factors in determining the agricultural productivity of Kansas. The map below shows the distribution of precipitation across the state, based on averages calculated over 30 years between 1961 and 1990. Darker tones indicate greater average annual precipitation, while lighter tones denote lesser amounts.

When studying the patterns of precipitation depicted on this map, it is important to remember that the contour lines depict averages, and the chances of any single year having exactly average precipitation are slight. Most years will deviate somewhat from the average. In some parts of the world, such as tropical rain forests, the yearly deviations will not be great; however, in the Great Plains of central North America, deviations from average are often rather large. Also bear in mind that the process of averaging over several years “evens out” the distribution of precipitation both in time and space. In reality, individual precipitation “events” (episodes of rain or snow) are more likely to occur over limited geographical areas, and at certain times of year. In Kansas, about 70–75% of all precipitation falls during the six crop-growing months from April to September. Most of this precipitation is in the form of rainfall accompanying small but intense thunderstorms. At other times of the year, precipitation is less common and more likely to occur as gentler rain or snow showers.

Measurement of Precipitation

The methods used to measure precipitation vary, depending on whether rain or snow is being measured. Rainfall is most often measured using a standardized gauge which resembles an upright cylindrical canister with an opening at the top. During a rainfall event, the opening catches water, which is conducted into a funnel-like device and then into a cylindrical measur-

ing tube. Not all rain gauges are of this type, however. In fact, any container can be used as a rain gauge as long as it has a cross section with a consistent shape and size. Some gauges automatically record rainfall amounts, but most require an attendant who manually records precipitation amounts and empties the gauge prior to the next precipitation event.

Although the principle behind the rain gauge is simple, proper exposure of the gauge is critical for making accurate measurements. The opening must not be obstructed by any object which could prevent rain from falling into the gauge. Because rainfall is often diagonal, the gauge must also be kept away from buildings, high trees, or other objects that can shield the gauge. Ideally, the gauge should be positioned on the ground near the center of a large open area. The opening of the gauge should be high enough to prevent water from splashing into it during very heavy rains.

Rain gauges are often fitted with a shield to reduce the effects of wind.

Determining the amount of precipitation resulting from snowfall requires measuring both the depth and water content of the snow. Water content of snow varies considerably. A frequently used rule-of-thumb states that 10 inches of snow contains 1 inch of liquid water, although the actual ratio can vary from 4:1 to as much as 30:1. Snow measurements are converted to precipitation amounts simply by melting a known amount of snow. Like measuring rainfall, measurement of snow is conceptually simple but difficult in practice. Often, measurements of snow depth are made simply by selecting a flat site and measuring the depth with a calibrated scale, such as a ruler or yard stick. Finding a representative site can be difficult, however. Even light to moderate winds can cause snow to drift, affecting the accuracy of measurements. Usually, the

Record-breaking Incidents of Precipitation for Selected Cities (measured in inches):

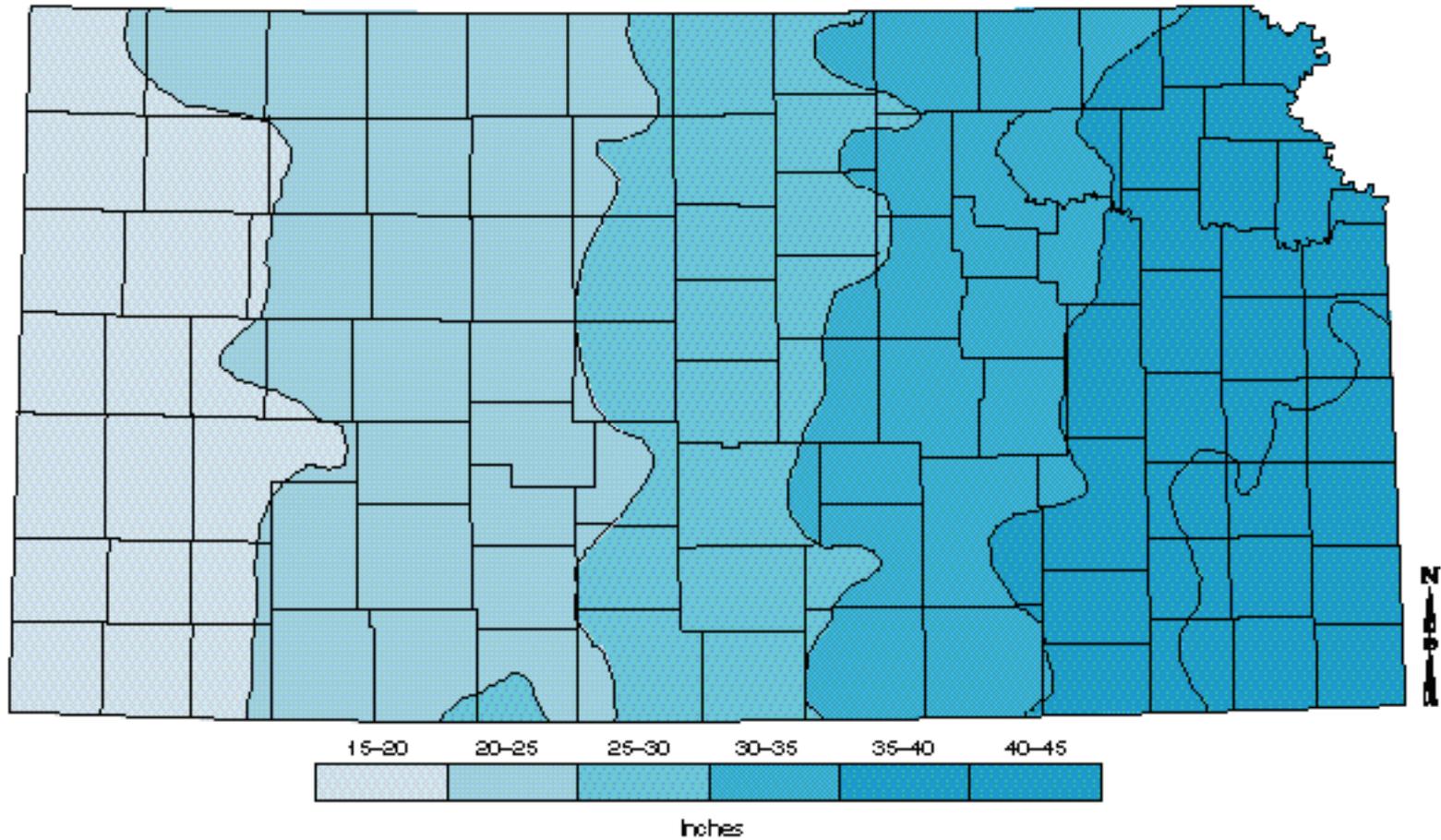
City (County)	Rainfall	Snowfall
Ashland (Clark)	6.52 (October 1920)	16.0 (December 1911)
Colby (Thomas)	4.50 (July 1941)	14.0 (February 1924)
Columbus (Cherokee)	8.40 (June 1948)	17.5 (December 1917)
Elkhart (Morton)	6.80 (July 1911)	20.0 (February 1903)
Emporia (Lyon)	7.03 (November 1928)	11.0 (February 1900)
Hays (Ellis)	5.26 (September 1955)	12.0 (February 1903)
Horton (Brown)	7.15 (October 1973)	14.0 (February 1955)
Independence (Montgomery)	7.69 (May 1984)	19.0 (March 1970)
Manhattan (Riley)	6.28 (June 1977)	18.0 (February 1900)
McPherson (McPherson)	4.37 (August 1980)	20.0 (February 1912)
Medicine Lodge (Barber)	9.00 (September 1923)	14.0 (February 1971)
Minneapolis (Ottawa)	6.34 (September 1942)	14.0 (February 1980)
Ottawa (Franklin)	6.95 (November 1928)	14.0 (March 1912)
Phillipsburg (Phillips)	7.50 (September 1919)	16.0 (November 1953)
Tribune (Greeley)	6.46 (June 1932)	18.0 (March 1987)
Winfield (Cowley)	9.12 (October 1973)	12.0 (February 1938)

average of several measurements taken in a flat area away from trees or structures is used. Sometimes, snow gauges consisting of large cylindrical tubes are used. As with rain gauges, these snow gauges are shielded to reduce the effects of wind. Mean annual snowfall is shown on page 5.

Precipitation Patterns in Kansas

The pattern of precipitation shown on the map indicates a very large contrast in precipitation amounts across the state. Yearly precipitation amounts along the western border are only one-third of those in the southeast corner of the state. These large variations

between east and west are typical of the Great Plains region of central North America, where the climate is transitional between the humid east and the semi-arid and arid western portion of the continent. This transitional pattern greatly affects agricultural



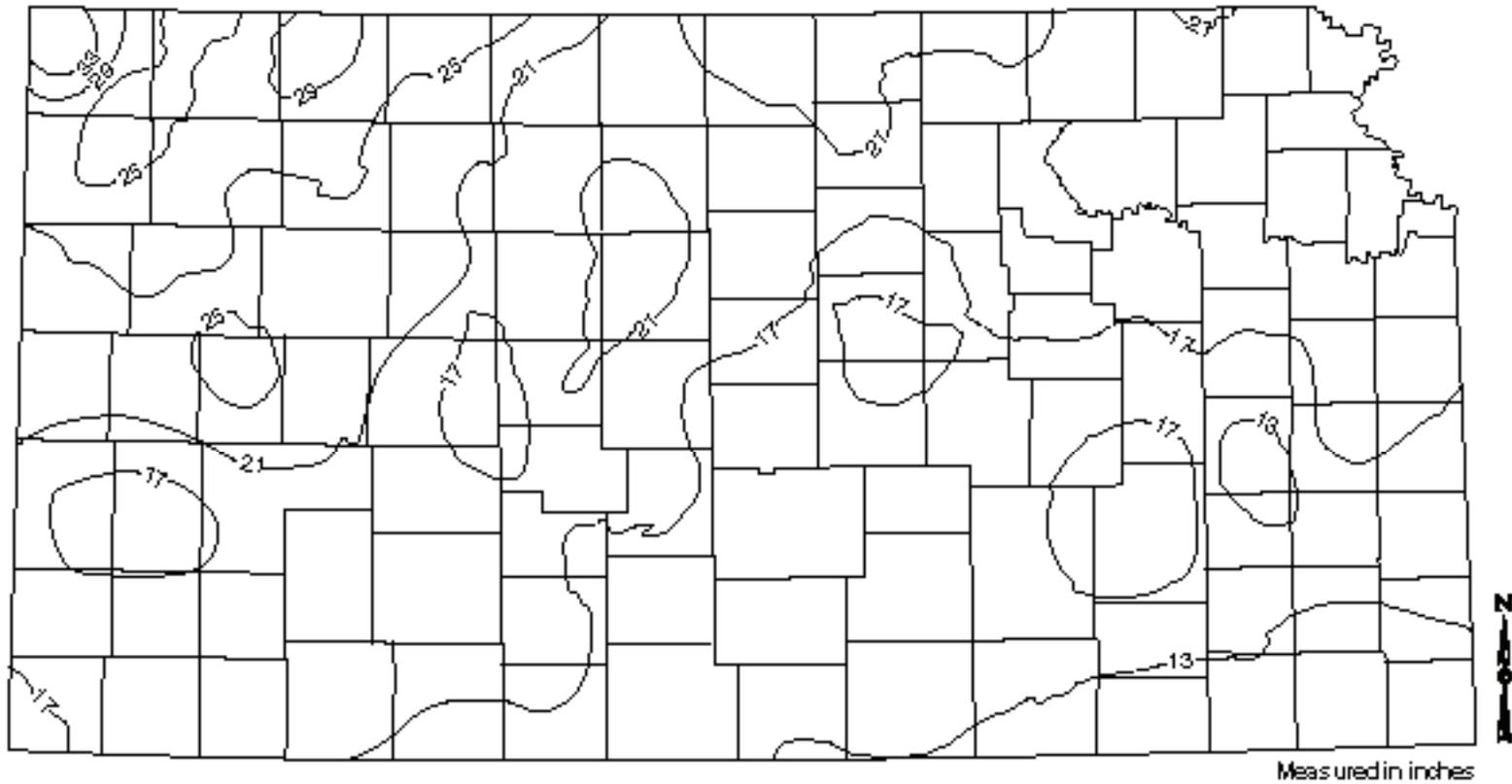
Normal Annual Precipitation

practices within Kansas. West of the so-called “25-inch line,” which nearly divides the state in half, surface water is often in short supply. Irrigation systems that draw water from underground are frequently necessary to produce most cereal and grain crops.

The reasons for the large contrast in precipitation amounts from east to west are related to the location of Kansas in the heart of the North American continent.

The Rocky Mountains, which lie to the west, block the eastward flow of moisture-laden air from the Pacific Ocean, creating a “rainshadow” of low precipitation. As the air rises over the mountains, it loses its moisture content through precipitation. By the time these airflows reach western Kansas, their moisture content is decreased, so they produce little precipitation in the western part of the state. In contrast, eastern

Kansas frequently receives incursions of very moist air from the Gulf of Mexico, particularly during the spring and early summer seasons. This warm, moist air mixes with colder, dry air from the north, producing the intense storms that are so common in eastern Kansas during the spring and early summer. These two mechanisms combine to produce the very large contrast in precipitation within the state of Kansas.



Mean Annual Snowfall

TEMPERATURE

Along with precipitation, temperature is a basic element of the climate of a region. Temperature is of great significance not only to human comfort and well-being, but also to agricultural productivity. The production of cereal grains forms the basis for the agricultural economy of Kansas, and the yearly pattern of temperatures is an important influence on both where and when various crops can be produced.

How Temperature Measurements are Made

Most temperature measurements are made with the familiar mercury-in-glass thermometer. This thermometer works on the principle that most substances expand when heated. Mercury is used because when heated, it expands much more than glass and, when cooled, it contracts more than glass. Because of this difference in relative expansion, the length of the column of mercury in a glass tube can be used as a measure of surrounding temperature. A calibrated scale is placed on or next to the glass tube so that the temperature can be read easily.

The simplest and most common type of thermometer is designed to show the current temperature. The mercury is contained in a small, bulb-like reservoir at the bottom of a glass tube. The mercury column in the tube rises or falls in response to temperature change, its length always indicating current temperature. Other thermometers are specially designed to indicate minimum and maximum temperatures. A maximum thermometer is similar to the mercury thermometer described above, except that a constriction is placed in the tube, near the reservoir. As temperatures increase and the mercury expands, it is forced past the constriction and rises into the tube, but when temperatures fall, the constriction does not allow the mercury column to

fall back into the bulb. Thus, the temperature indicated by the mercury will always be the maximum daily temperature. The maximum thermometer is reset by shaking or whirling it to force the mercury column past the constriction and back into the reservoir.

In contrast to the maximum thermometer, the minimum thermometer contains a low-density liquid, usually alcohol. A small, dumb-bell shaped index is placed within the tube so that it touches the top of the alcohol column. As temperature decreases, the alcohol contracts and the index is pulled toward the reservoir by the effect of surface tension with the top of the alcohol column. When temperatures rise, however, the

alcohol can flow around the index without moving it. The index will therefore always remain at the point of the lowest temperature. The minimum thermometer is reset by tilting to return the index to the top of the alcohol column. Because the index is free to move, the minimum thermometer must always be mounted horizontally.

Temperature measurement depends not only on accurate thermometers, but also on proper exposure of the thermometer to air. Thermometers must be kept away from sources of radiant energy, because the instrument itself will absorb the radiation and heat up, affecting the accuracy of measurements. Thermom-

Record-breaking Temperatures for Selected Cities (measured in °F):

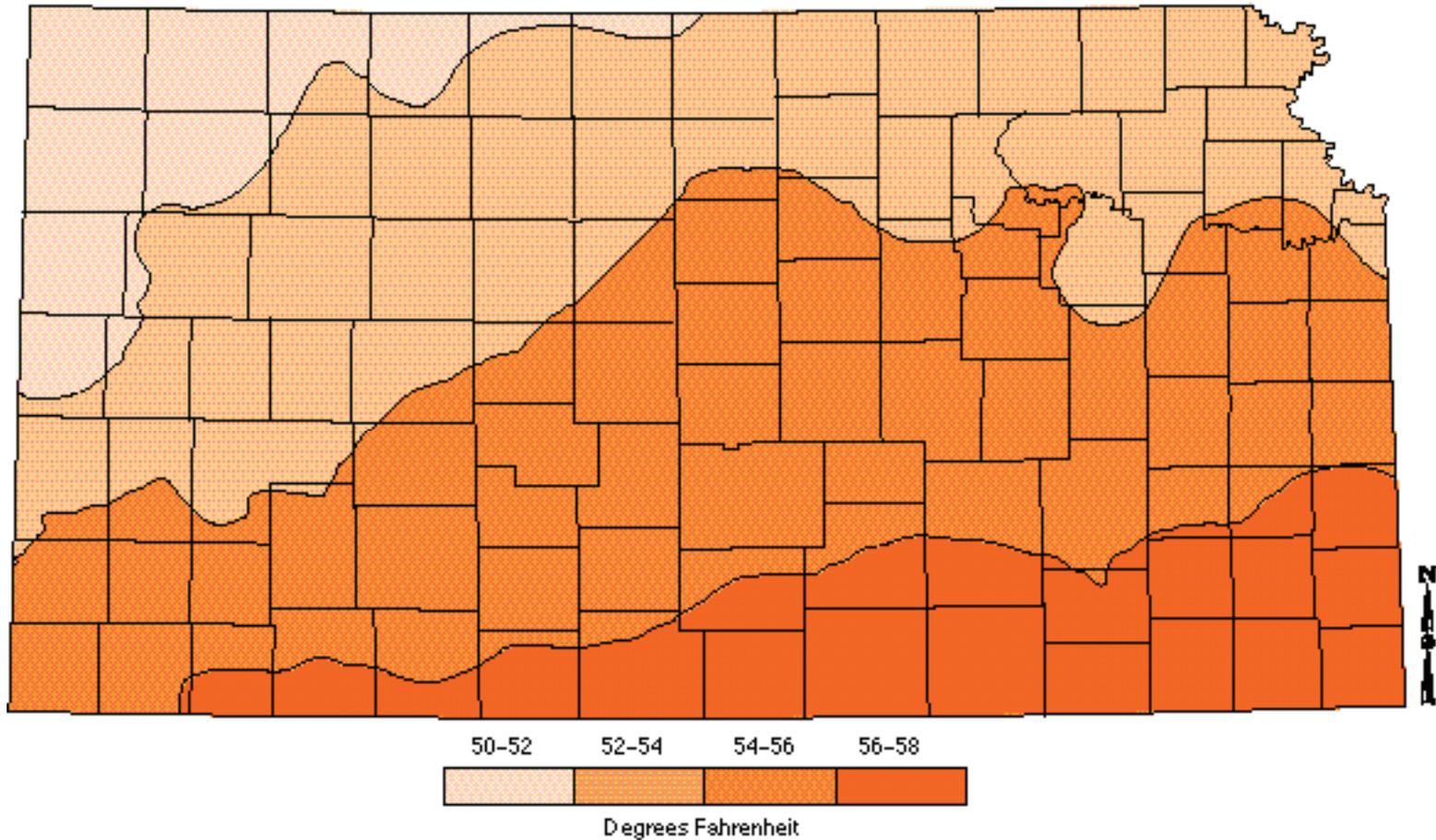
City	Highest Temperature	Lowest Temperature
Ashland (Clark)	114 (June 1911)	-19 (January 1988)
Colby (Thomas)	113 (July 1940)	-28 (January 1912)
Columbus (Cherokee)	117 (July 1954)	-28 (February 1905)
Concordia (Cloud)	109 (July 1980)	-26 (December 1989)
Dodge City (Ford)	109 (July 1986)	-21 (December 1989)
Elkhart (Morton)	110 (June 1980)	-22 (January 1984)
Emporia (Lyon)	116 (August 1936)	-24 (January 1947)
Goodland (Sherman)	111 (July 1940)	-27 (December 1989)
Hays (Ellis)	117 (July 1934)	-26 (February 1905)
Horton (Brown)	112 (August 1936)	-30 (January 1947)
Independence (Montgomery)	116 (August 1936)	-23 (February 1905)
Manhattan (Riley)	116 (August 1936)	-31 (January 1947)
McPherson (McPherson)	117 (August 1936)	-22 (January 1963)
Medicine Lodge (Barber)	118 (August 1936)	-22 (February 1905)
Minneapolis (Ottawa)	119 (August 1936)	-28 (February 1905)
Ottawa (Franklin)	118 (July 1954)	-28 (February 1905)
Phillipsburg (Phillips)	120 (July 1936)	-28 (December 1989)
Topeka (Shawnee)	110 (August 1984)	-26 (December 1989)
Tribune (Greeley)	108 (July 1936)	-25 (January 1984)
Wichita (Sedgwick)	113 (July 1954)	-21 (February 1982)
Winfield (Cowley)	118 (August 1936)	-27 (February 1905)

eters should therefore be shielded from direct sunlight, as well as from surfaces that radiate heat such as buildings and the ground. Good ventilation is also important, because stagnant air around the thermometer will not represent true air temperature. The height at which air temperature is measured and the surface over which the measurements are made can also have signifi-

cant effect on measured values. Whenever possible, thermometers are placed in a louvered white wooden box at a height of about one meter, preferably over a grass surface far away from buildings. Such a shelter protects the thermometer from solar radiation, while allowing air to circulate freely around the thermometer.

Temperature Maps

On the following pages, maps depicting various types of temperature information are presented. The data for these maps were obtained from the temperature-measurement sites shown on the map on page 1. Some of the measurement sites were not used in making these



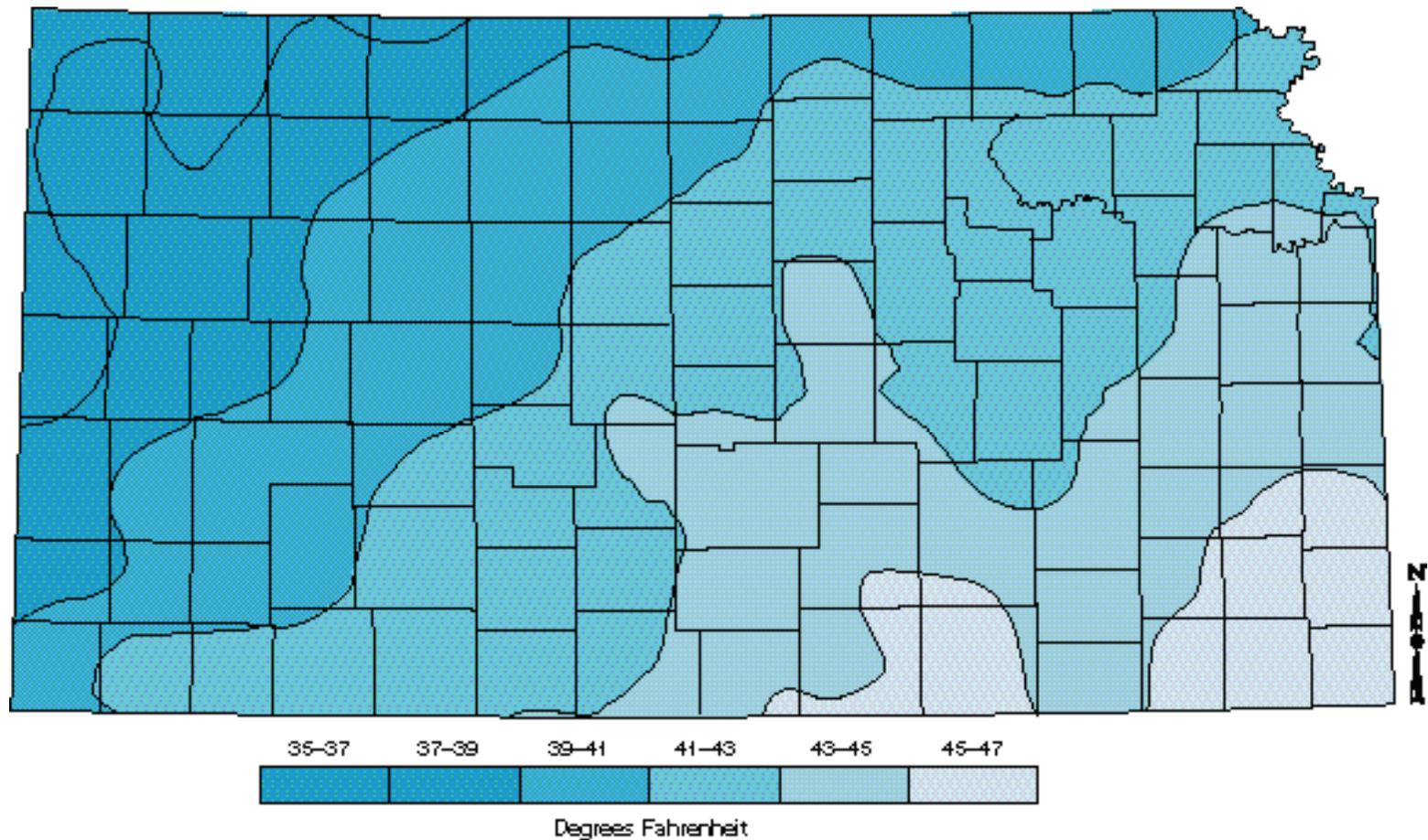
Average Annual Mean Temperature

maps, however. Any measurement site located near a body of water (such as a dam site) was eliminated because water heats and cools much more slowly than the surrounding land, affecting nearby air temperatures and producing temperature measurements that are not representative of the surroundings. The time of day at which temperatures are recorded can also greatly influence minimum and maximum values. At most (but not

all) stations, observations are taken at midnight. To ensure consistency in the maps, readings from those stations which were not recorded at midnight were adjusted using a formula developed by the National Climatic Data Center in Asheville, North Carolina.

Temperature varies considerably over the course of a year, making it difficult to adequately summarize using a single map. Seven maps are used to provide a

more complete description of temperatures in Kansas. The temperature data on the maps are presented in the form of "means," which is a term used by scientists to indicate an average. Thus, average annual mean temperature (shown on the first map) is the average of all the yearly averages in the 30-year period from 1961 to 1990. Similarly, the mean minimum and maximum



Mean Annual Minimum Temperature

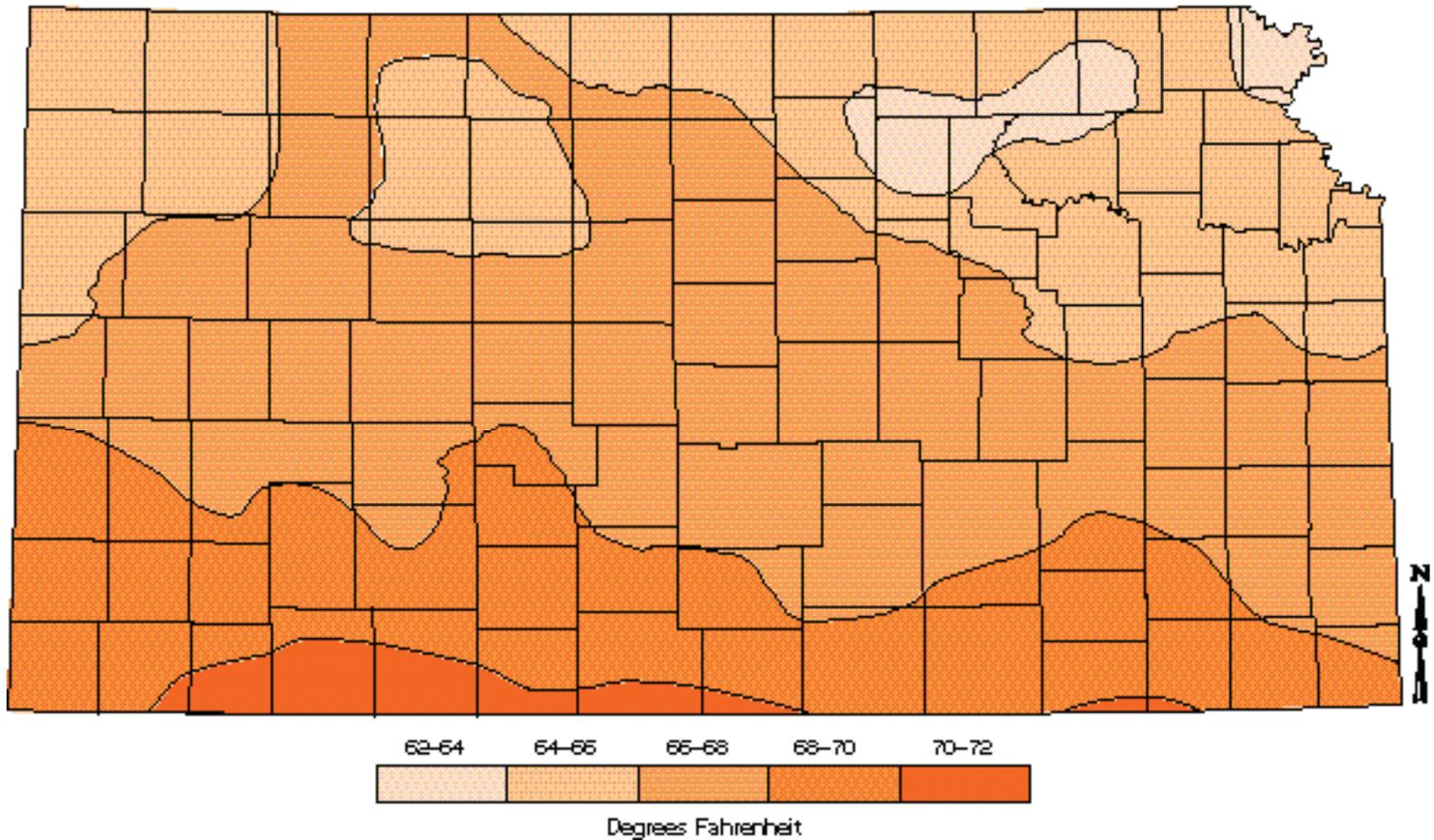
temperatures (depicted on the next two maps) are the average of minimum and maximum values for each year. Mean temperatures for each individual season are shown on the next four maps.

When viewing the maps, it is important to remember that the conditions in any given year are quite likely to deviate from the mean conditions. This is especially true for areas such as Kansas that are located near the

center of a continent. Conditions in Kansas can deviate quite widely from mean conditions; for example, a year or two of relatively low temperatures may be followed by a period of exceptionally hot weather.

The pattern of temperatures in all seven maps clearly shows the effect of latitude. Mean, minimum, and maximum values are greater in southern Kansas and decrease going northward. This trend within the state is

actually part of a larger global pattern in which mean temperatures are greater nearer the equator and steadily decrease going toward the poles. This global pattern reflects the fact that incoming solar radiation (which provides the energy to heat the air) is much more intense near the equator and tropics compared to the higher latitudes. Notice also that the contour lines of temperature (called isotherms) do not run exactly east-



Mean Annual Maximum Temperature

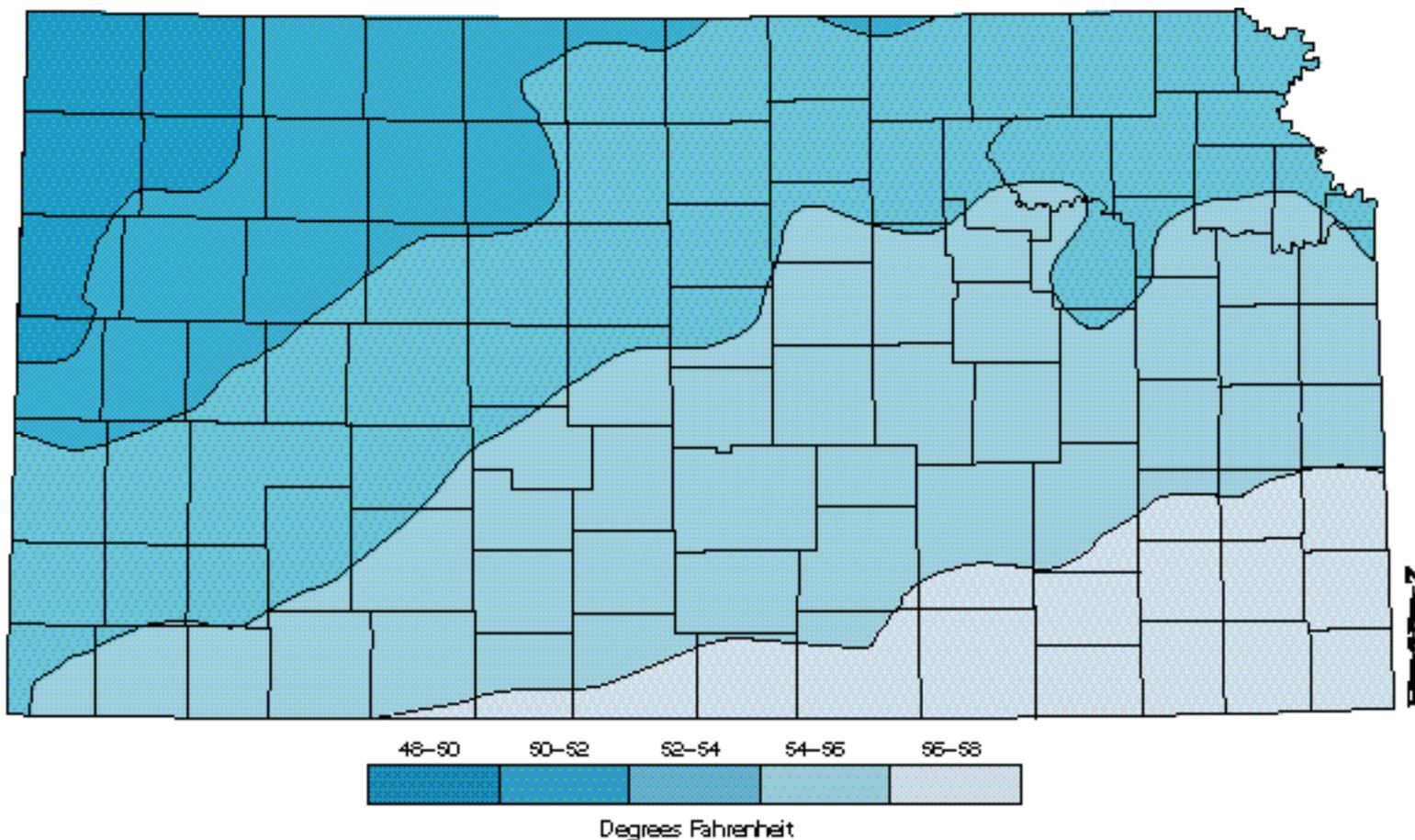
west. Instead, they trend generally from the northeast to southwest. This pattern reflects another significant influence on temperatures—changes in elevation. In Kansas, elevations range from as low as 680 ft in southeastern Kansas to 4,039 ft in the west. Air temperatures decrease by about 2° to 3° for every 1,000 ft of altitude gained; therefore, mean temperature will be

about 6° to 9° lower for the same latitude at the western border compared to the eastern border.

Seasonal Maps

When comparing the mean temperatures shown on the following four maps, notice the large seasonal

contrast. In Kansas, the seasons are defined as follows: Spring (March–May), Summer (June–August), Fall (September–November), and Winter (December–February). Summertime temperatures are much greater than those in winter, fall, or spring (and vary greatly from the average annual mean temperature [page 7]). This may not seem especially noteworthy, but it reflects

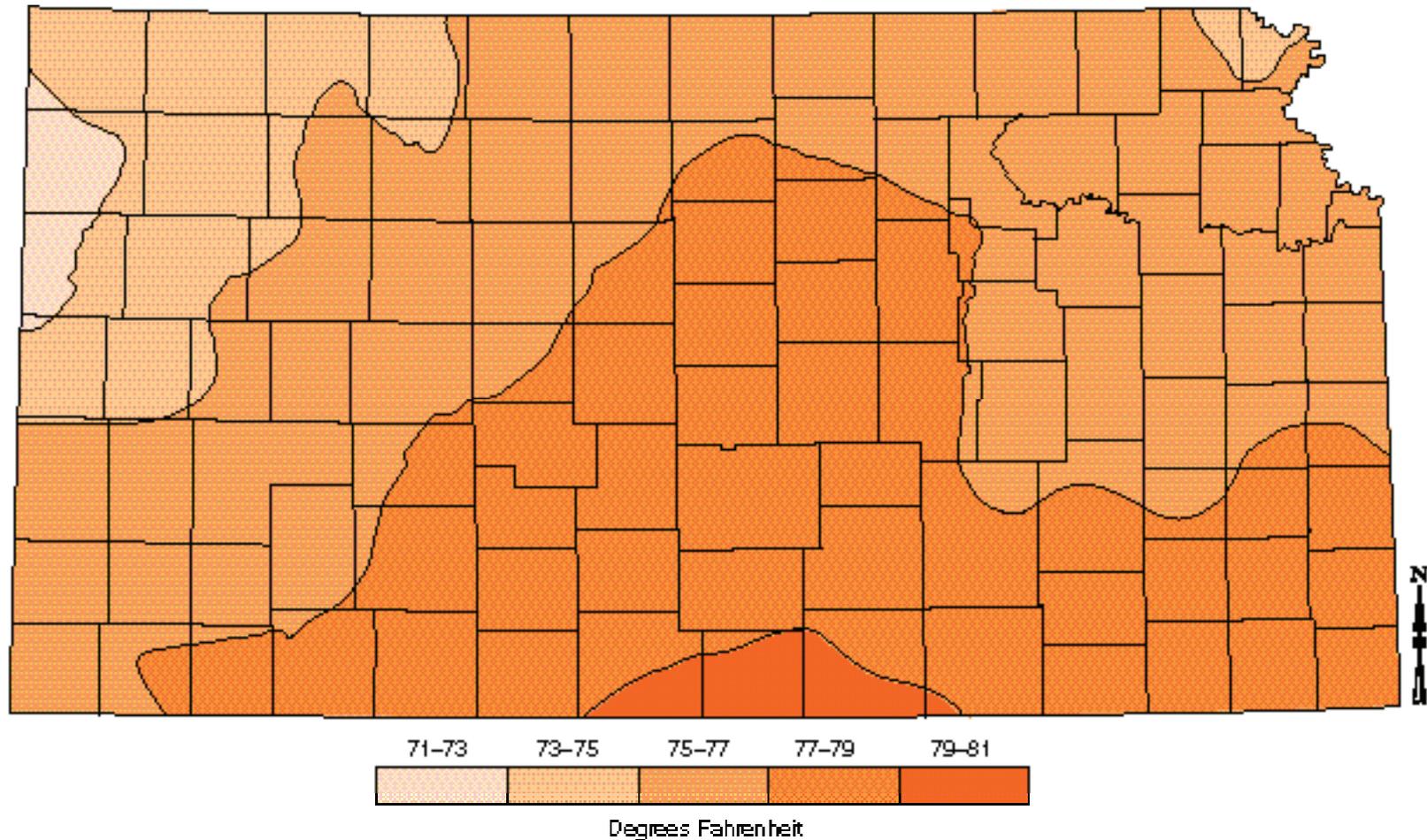


Seasonal Mean Temperature—Spring

an important characteristic of Kansas climate. A climate such as that of Kansas, which shows these large seasonal temperature contrasts, is called a *continental* climate. As the name suggests, these climates occur in the interior of continents. In contrast, *maritime* climates are found in coastal areas or near large bodies of water. Maritime climates are characterized by very little seasonal temperature variation. The reason for

the difference lies in the very different thermal properties of water versus land. Water is much more thermally conservative than land; that is, it heats up and cools off much more slowly when subjected to solar radiation. This resistance to temperature change means that air-temperature measurements for sites near bodies of water will generally not be as warm in summer nor as cold in winter as would an inland site at the same latitude. All bodies of water exhibit this influence

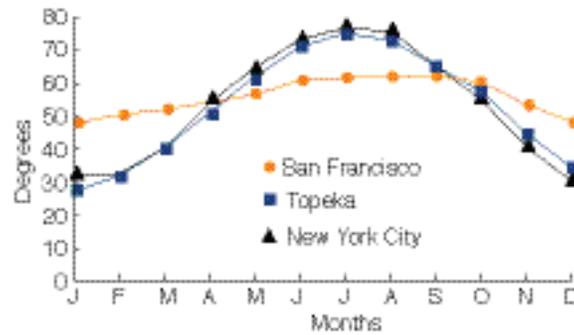
over temperature, but the size of the surrounding area affected depends on the size of the water body. Recall that measurement sites near lakes were eliminated prior to constructing the temperature maps. The temperature measurements from these sites were unrepresentative even though they are near relatively small water bodies. A very large body of water, such as an ocean, can affect temperatures for hundreds of miles inland.



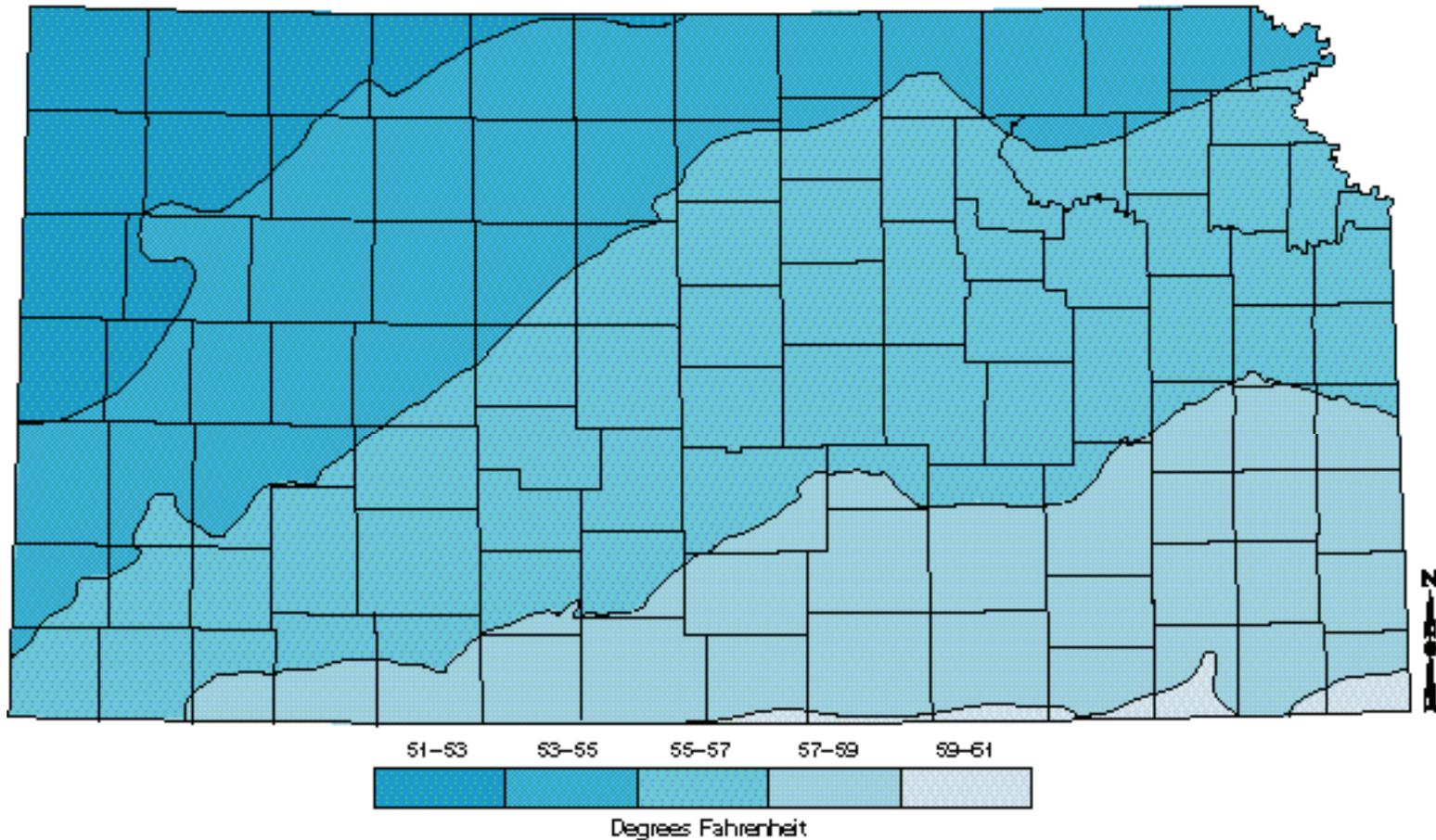
Seasonal Mean Temperature—Summer

The graph shown at right illustrates the idea of continentality by showing monthly mean temperatures for three sites in the United States which are all at approximately the same latitude. Notice that winters are much warmer and summers are cooler in San Francisco compared to New York City or Topeka. San Francisco is located near the Pacific Ocean, and thus features a maritime climate. New York City is also located near an ocean, but its yearly temperature

Continentality Illustrated by Monthly Mean Temperatures



Month	San Francisco	Topeka	New York City
January	48	28	32
February	51	33	33
March	53	41	41
April	55	55	52
May	58	65	62
June	62	74	72
July	63	78	77
August	63	77	75
September	64	68	68
October	61	58	59
November	55	43	47
December	50	32	36

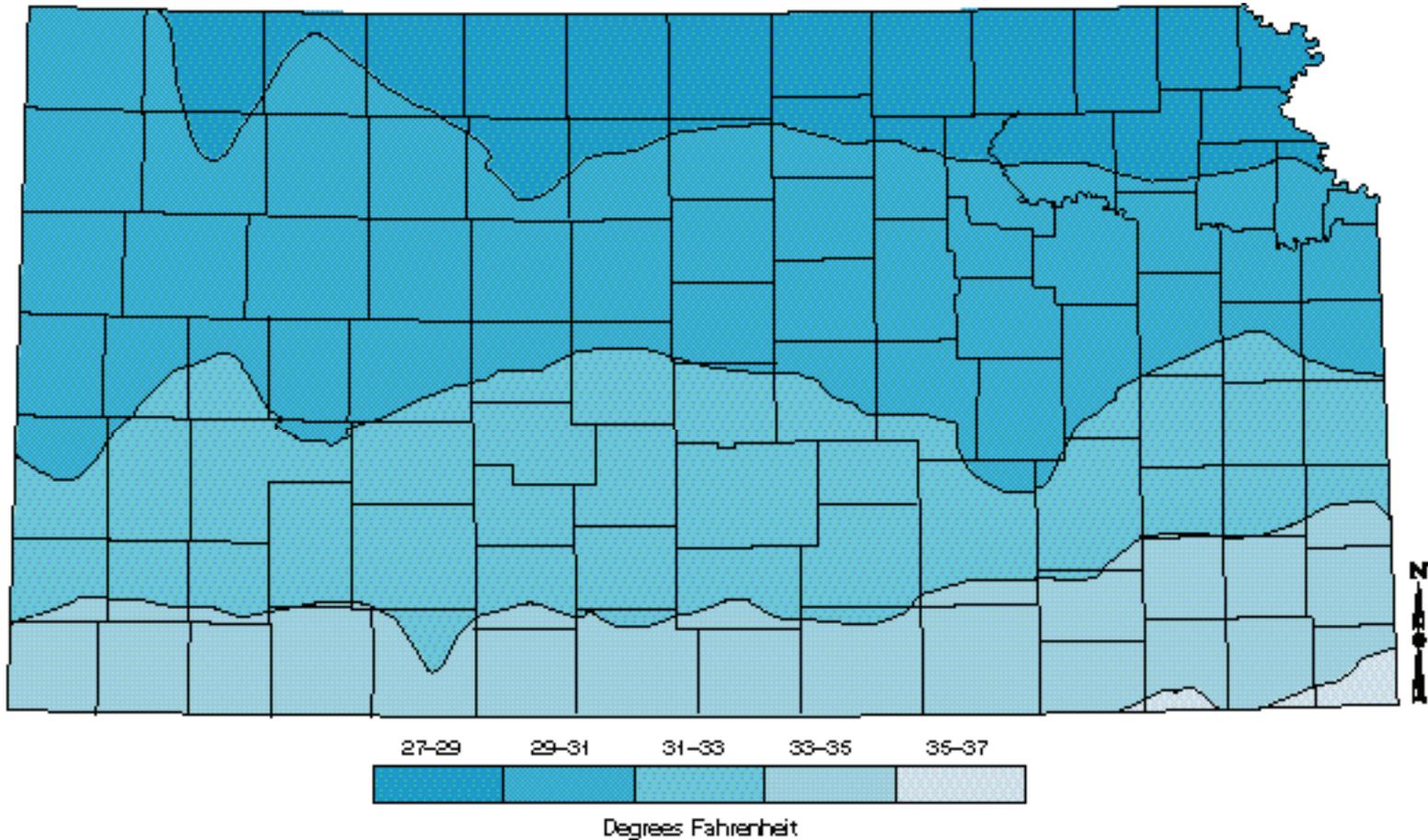


Seasonal Mean Temperature—Fall

pattern is much more typical of a continental region. In North America, weather patterns generally move from west to east. Therefore, the climate of New York City, located on the east coast, is much more influenced by the landmass to the west than the ocean to the east. However, variability of temperatures in New York City is less than that in Topeka. San Francisco, situated on the west coast, receives the full influence of the ocean. Topeka, located near the center of the North American continent, is unaffected by either ocean and therefore exhibits marked seasonal variation.

Record-breaking Kansas Weather Incidents

Lowest temperature:	-40°F	Lebanon	February 13, 1905	
Highest temperature:	121°F	Fredonia	July 18, 1936	
	121°F	near Alton	July 24, 1936	
Rainfall:	(single event)	12.59 inches	Burlington	March 31, 1941
	(annual)	71.99 inches	Hiawatha	1973
Tornadoes (avg/yr):	38			
Tornado deaths (avg/yr):	3			
Total lightning deaths (1959–1990):	55			
Deadliest tornado:	80 people killed	Udall	May 25, 1955	
Other:	Largest hailstone recorded anywhere	Coffeyville	September 3, 1970	
	1.67 pounds, 17.5-inch circumference			



Seasonal Mean Temperature – Winter

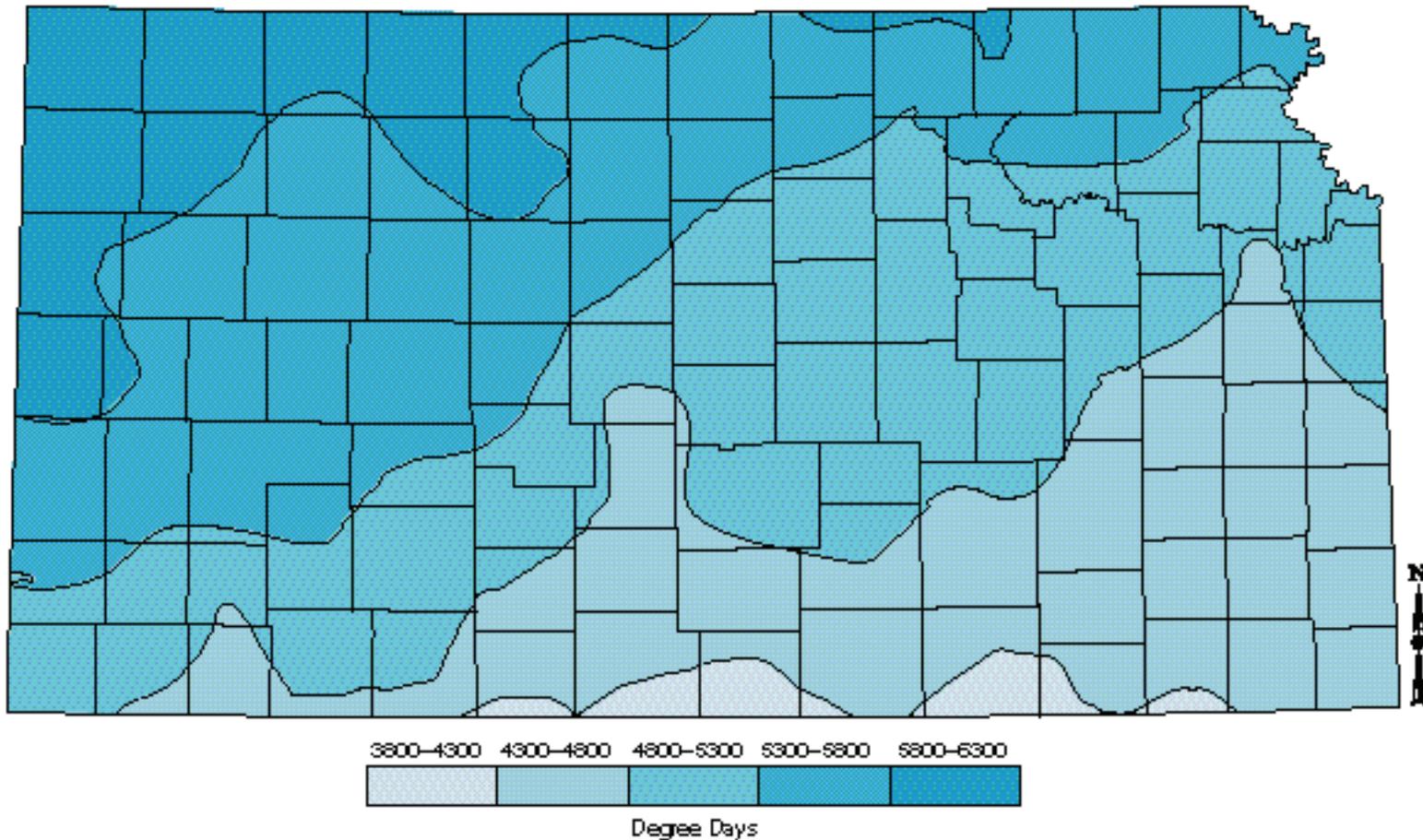
HEATING AND COOLING DEGREE DAYS

Heating and cooling degree days are frequently used as an indicator of how much energy will be required to heat or cool buildings or residences. With current concerns for energy conservation and utility prices, engineers often take into account the annual average number of degree days when designing a building in a certain area.

How are Annual Average Degree Days Calculated?

Heating and cooling degree days are calculated based on the amount by which the daily mean temperature falls below or exceeds some accepted threshold temperature. In North America, the threshold temperature is generally 65°F (18°C). Heating degree days are

calculated by determining how much the daily mean temperature falls below this threshold, while cooling degree days are figured by how much the daily mean temperature exceeds the threshold. Thus, if the mean temperature for a given day was 40°F, then heating degree days would be determined by subtract



Mean Annual Heating Degree Days

ing $65 - 40 = 25$ heating degree days. Similarly, if the daily mean temperature was 80°F , then cooling degree days would be determined by $80 - 65 = 15$ cooling degree days. Notice that any given day can (and probably will) account for several heating or cooling degree days. Annual degree days are determined by simply summing the daily total values. The data depicted on these maps are the average sums of heating and cooling degree days for the thirty-year period between 1961 and 1990, and represent the total

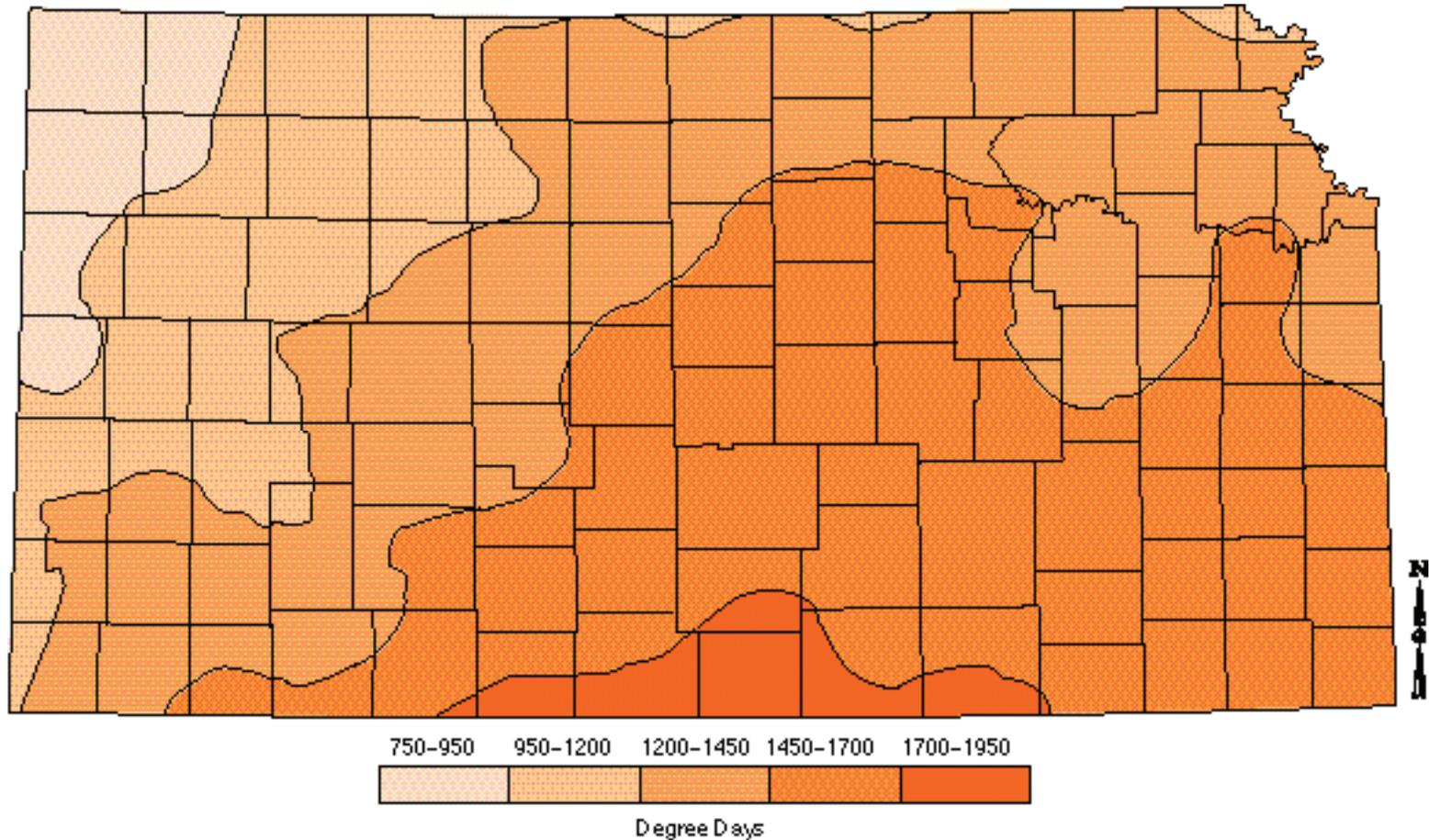
degrees of temperature per year that need to be heated (heating degree days) or cooled (cooling degree days) to maintain the 65°F target temperature.

Uses of Degree Days

Degree days have been proven to be among the most useful of all climate data for several practical applications. Architects and engineers consider the number of heating and cooling degree days when

designing the air conditioning and heating systems of buildings. Fuel distributors often base their prices and delivery schedules on cumulative number of degree days. Utilities such as power companies use average degree-day data to try to anticipate power needs, and also to implement priority-use policies in cases where capacity falls short of demand.

Degree days also are useful for directly comparing energy costs for heating and cooling. Individual homeowners can use this information to make deci



Mean Annual Cooling Degree Days

sions on where to live and what energy costs will be at various locations. For example, a homeowner in Goodland, with about 6,200 heating degree days annually, can expect to pay higher heating bills than one in Topeka, where annual heating degree days average less than 5,000. However, the Topekan will generally pay higher costs for air conditioning, since Topeka averages around 1,300 cooling degree days per year, compared to less than 1,000 in Goodland. By comparison, a resident of International Falls, Minnesota (which averages only about 175 cooling degree days annually), will spend little or nothing for air conditioning, since 400 cooling degree days is generally considered the minimum for which air conditioning is needed to maintain comfortable temperatures. International Falls

experiences over 10,000 heating degree days per year, however, so our Minnesotan can expect to pay over twice what a Topeka resident would pay for heating (provided, of course, that energy costs were the same per degree day at each location).

Patterns of Degree Days in Kansas

The pattern of both heating and cooling degree days in Kansas is directly comparable to that of the minimum and maximum temperature (see maps on pages 7 and 8). The trend of cooling degree days goes from higher values in the south to lower values in the north. Since cooling degree days are an indicator of heat, and temperatures are generally higher in southern

Kansas, this pattern is consistent with temperature data. Heating degree days show a similar pattern, but in this case values are smaller in the south and get progressively larger going northward. This reflects the influence of temperature patterns, since a larger number of heating degree days indicates lower temperatures, and temperatures are generally lower in the northern part of the state. As were the isotherms, the contour lines of both heating and cooling degree days are oriented southwest to northeast, rather than north to south. Again, this reflects the influence of altitude on temperature distribution within the state (see the discussion of the temperature maps for further information).



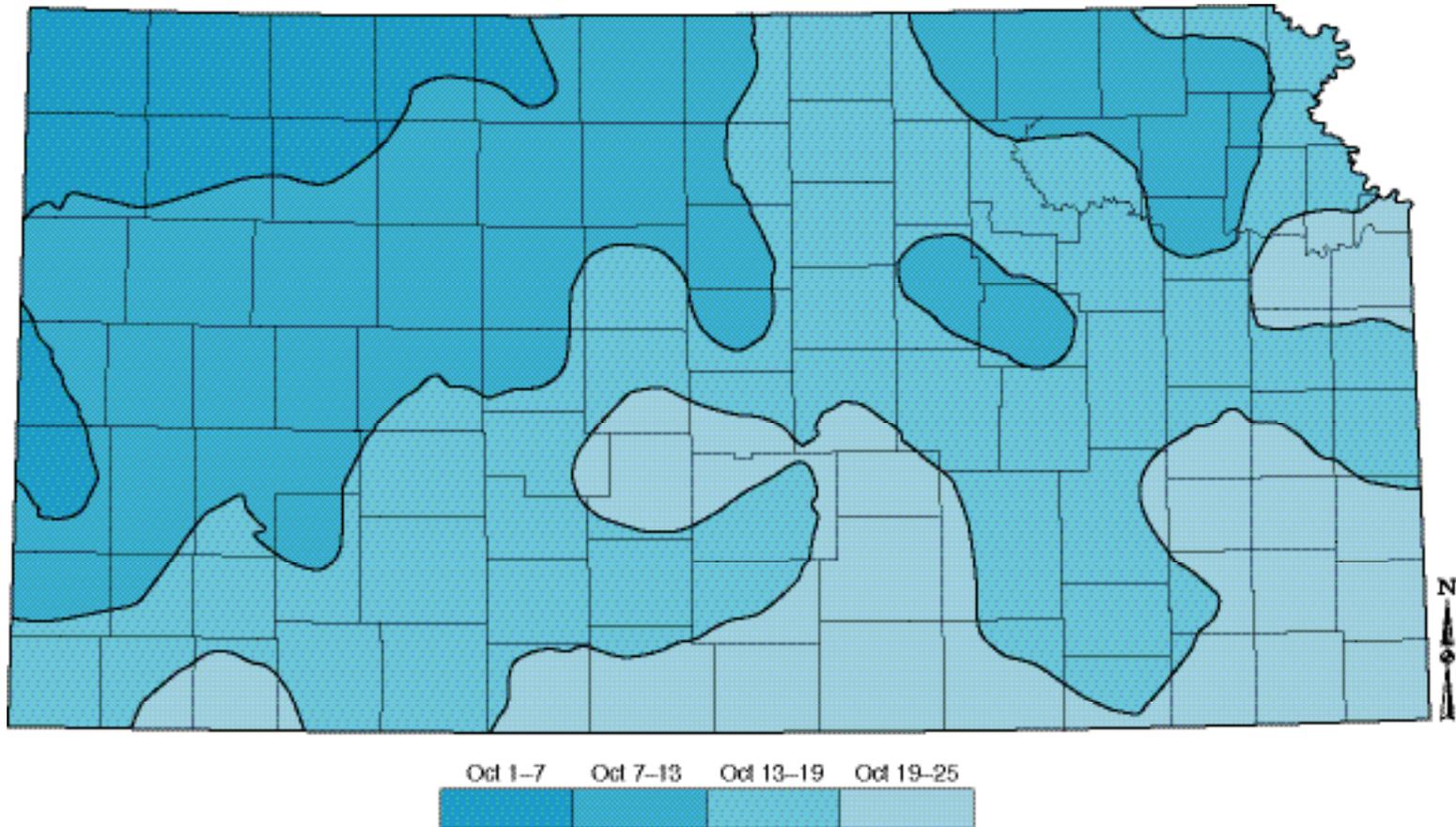
FREEZE DATE

The following two maps show the average annual date of the first and last freeze. In these maps, a “freeze” is considered to be a period in which the temperature falls below 32° F, the freezing point of water. Although this may seem self-evident, other temperature thresholds, such as 28°F, are sometimes used to define a freeze. It is important to consider which definition of a freeze is being used. Two processes can

result in a freeze. The most common process occurs when a very cold mass of air moves into an area, lowering the surface temperature below freezing. Climatologists call this an *advection frost*. Advection frosts are most common in Kansas during the winter months. The other type of freeze occurs on very clear nights. Without a layer of cloud cover to act as a blanket to hold heat, the surface can cool off very quickly. This

type of freeze is called a *radiation frost*, because the ground radiates enough heat to lower its temperature below freezing temperatures. Ice crystals then form on cold objects at the surface. Of the two processes, the advection frost is the one most often associated with a true freeze.

Freeze dates are very significant for agricultural producers, because most crops grown in Kansas have



Average Annual Date of First Freeze

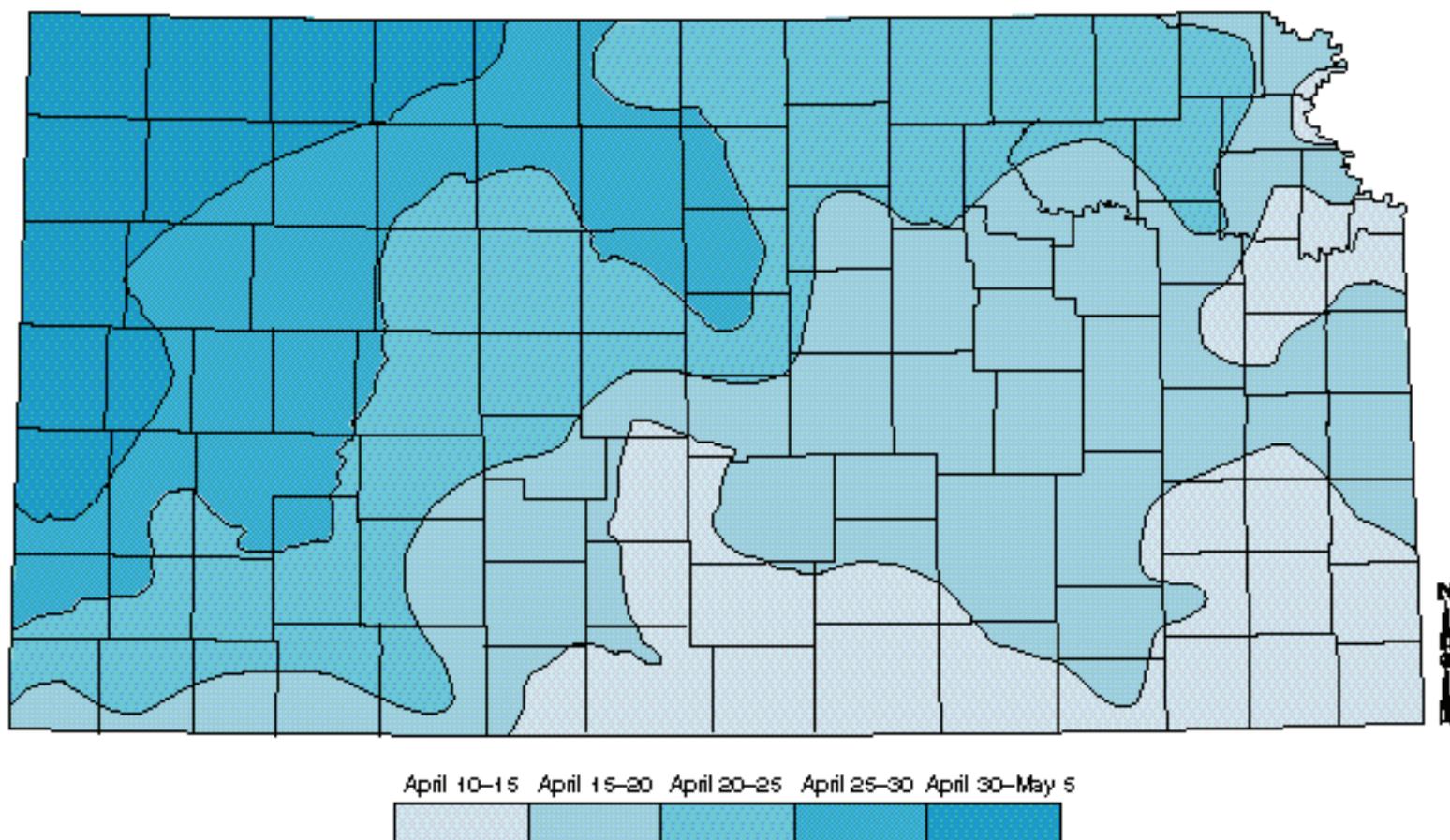
very limited resistance to frost. The agricultural significance of a late frost in the spring can be devastating, because this is the time when most field crops are in the most vulnerable stage of their development. These seedlings have very little resistance to freeze effects, and they can be damaged by freezing, or dried up when soil water is frozen. More mature crops can also be damaged by freezing, resulting in reduced yields or even loss of the crop if the freeze is very severe.

Since freeze-control measures, such as those used for orchard crops, are not feasible for field crops like the ones produced in Kansas, farmers must be very careful to plant their crops at the proper times to minimize the dangers of frost.

Gardeners also need to know freeze dates when planning their gardens. Most ornamental plants are very susceptible to frost. Vegetable gardens must also be planted after the danger of frost has passed, because

germinating seedlings are liable to be killed outright by a freeze unless a cold-resistant variety is used. A planting guide, which lists optimal times for planting, is often included on seed packets. It is important to consider the amount of time a plant requires to mature, so that early fall frosts can be avoided.

In addition to their significance for agriculture and gardening, the dates of first and last freeze are significant for other reasons as well. It is well known that,



Average Annual Date of Last Freeze

unlike most other substances, water expands when it freezes. This simple effect can be observed by placing a half-filled ice tray in the freezer, then observing the ice cubes that form. The cubes will occupy a larger volume than did the liquid water. Water in the soil also expands when frozen, and this can have some serious consequences. If the soil water alternately freezes and thaws repeatedly, a phenomenon called “frost-heave” can occur. Frost-heave can disturb soil and affect plant growth. Large trees are occasionally toppled by the effects of frost-heave. Winter wheat crops can be killed even before they germinate by excessive frost-heave. A similar problem, called frost-wedging, can also occur when water collects beneath roads and sidewalks. Many of the cracks that are visible in roads or sidewalks are the result of numerous cycles of freeze and thaw, occurring over several years. Potholes are a good example of the effects of frost-wedging on heavily used roads. Buildings can also be damaged by frost-wedging, particularly when the building is built of stone and contains numerous cracks or crevices in which water can collect and freeze. The longer the frost season in a year, the greater the hazard of freeze damage. Comparing the two maps of average first and last freeze dates gives the length of both the “frozen” and “frost-free” portions of a typical year. Of course,

the ground will probably not be continuously frozen the entire period between the two frost dates. Substantial periods of frozen ground can be expected, however.

The pattern of first and last freeze dates shown on the maps is similar to the temperature maps shown on pages 7–13; however, there are some significant differences. As expected the average date of last freeze occurs earliest in the southeastern portion of the state and latest in the northwest, but topographical variation also influences the pattern. Most of us are familiar with the variation in the amount of sunlight received through a north-facing vs. south-facing window in a house. Topography affects the surface in a similar way, allowing some slopes to receive more solar energy and heat up more, while others receive less. Areas not affected by topography receive solar energy much more uniformly and therefore have a longer frost-free period. For example, look at the average date of the last freeze in Butler, Greenwood, and Elk counties, and then compare it to other counties at the same latitude such as Kingman or Woodson. The counties located in the Flint Hills (Butler, Greenwood, and Elk) experience their last freeze after the two counties located in less hilly terrain. A most unusual circumstance occurs in central Kansas, where Stafford County experiences its last freeze about three weeks earlier than northern

Ellsworth County (part of the Smoky Hills), only 50 miles away.

The average annual date of first freeze also reflects the effects of both temperature gradient and topography. Once again, the Flint Hills clearly stand out as a region where first freeze occurs earlier. Parts of Dickinson, Geary, and Morris counties, located in the heart of the Flint Hills, freeze on average three weeks earlier than southern Rice County, a relatively flat area. Again, this is a distance of only about 50 miles, and only a very slight change in latitude. The big difference is the topographic setting. The more gradually changing terrain in western Kansas results in a much more uniform pattern than in the east.

While the information shown on these maps is valid for any location, it is important to bear in mind how very small changes in topographic setting can have significant effects on freeze dates. Thus, a site located on the south side of a hill in the Flint Hills may experience first frost later (and last frost earlier) than a location on the northern side of the same hill. These maps are not designed to show variation at these smaller scales, but such small-scale variations should be kept in mind when deciding where to locate field or garden plots.

GLOSSARY

Air Mass A large body of air characterized by homogeneous physical properties at any given altitude.

Anemometer An instrument that measures wind speed. Usually, it consists of three or four cups mounted on crossarms that spin in response to moving air.

Annual Mean The average of twelve monthly means.

Atmosphere The gaseous portion of the planet.

Climate A description of aggregate weather conditions.

Cloud A dense concentration of ice crystals or suspended water droplets.

Daily Mean An average for a day obtained by averaging the 24 hourly readings or by averaging the

daily low and high.

Freezing A change of state between liquid and solid matter.

Front A boundary separating air masses of differing properties. A *Cold Front* is a boundary with advancing cold air. A *Warm Front* is a front with advancing warm air.

Humidity A general term describing moisture in the atmosphere.

Meteorology The study of atmospheric phenomena, especially over shorter time periods.

Monthly Mean A mean determined by averaging the daily means.

Normal The average value of a meteorological element over a fixed period of years, usually recognized as standard. In the United States, 30-year normals are frequently used.

Precipitation Water in some form which falls from the atmosphere. Can be in the form of liquid (rain or drizzle) or solid (snow, hail, sleet).

Thermometer An instrument for measuring temperature. There are several types of thermometers; some measure maximum or minimum temperature.

STATION LOCATIONS AND NAMES

KS 10 ABILENE 2 W	KS 1858 COTTONWOOD FALLS	KS 3810 HORTON	KS 5115 MC CRACKEN
KS 69 AETNA 2 S	KS 1867 COUNCIL GROVE LAK	KS 3822 HOWARD 5 NE	KS 5123 MC CUNE 6 SW
KS 135 ALEXANDER	KS 1875 COVERT	KS 3837 HOXIE	KS 5127 MC DONALD
KS 195 ALTA VISTA	KS 1999 DAMAR	KS 3842 HOYT	KS 5132 MC FARLAND
KS 201 ALTON 6 ESE	KS 2086 DENSMORE	KS 3847 HUDSON	KS 5152 MC PHERSON
KS 264 ANTHONY	KS 2135 DIAMOND SPRINGS	KS 3855 HUGOTON	KS 5171 MEADE
KS 313 ARKANSAS CITY	KS 2164 DODGE CITY WSO AP	KS 3930 HUTCHINSON 10 SW	KS 5173 MEDICINE LODGE 2
KS 365 ASHLAND	KS 2213 DRESDEN	KS 3954 INDEPENDENCE	KS 5335 MILTONVALE
KS 405 ATCHISON	KS 2267 DUNLAP 2 N	KS 3974 INMAN	KS 5355 MINGO 5 E
KS 424 ATLANTA	KS 2388 EFFINGHAM 1 N	KS 3984 IOLA 1 W	KS 5363 MINNEAPOLIS
KS 431 ATTICA 6 WNW	KS 2401 EL DORADO	KS 3997 IONIA	KS 5463 MORAN
KS 439 ATWOOD 2 SW	KS 2409 ELGIN	KS 4073 JEROME 1 S	KS 5528 MOUND CITY
KS 443 AUBURN 1 N	KS 2432 ELKHART 6 NNE	KS 4089 JEWELL	KS 5536 MOUND VALLEY 3 WS
KS 471 AXTELL	KS 2452 ELLIS	KS 4104 JOHN REDMOND LAKE	KS 5539 MOUNT HOPE
KS 532 BARNARD	KS 2459 ELLSWORTH	KS 4161 KALVESTA 1 W	KS 5628 NATOMA
KS 673 BELLAIRE 12 N	KS 2470 ELMDALE 10 WNW	KS 4178 KANOPOLIS LAKE	KS 5680 NEOSHO RAPIDS 1 N
KS 682 BELLEVILLE	KS 2478 ELMO 1 NW	KS 4313 KINGMAN	KS 5692 NESS CITY
KS 693 BELOIT	KS 2519 EMMETT	KS 4333 KINSLEY	KS 5744 NEWTON 2 SW
KS 800 BIG BOW 2 S	KS 2592 ESBON 7 N	KS 3239 KIOWA	KS 5768 NILES
KS 836 BIRD CITY 10 S	KS 2602 ESKRIDGE 1 SE	KS 4357 KIRWIN DAM	KS 5787 NORCATUR 3 SW
KS 865 BISON	KS 2622 EUREKA	KS 4421 LA CYGNE	KS 5852 NORTON DAM
KS 877 BLAINE	KS 2652 FACT	KS 4464 LAKIN	KS 5856 NORTON 9 SSE
KS 911 BLUE RAPIDS	KS 2773 FLORENCE	KS 4530 LARNED	KS 5870 NORWICH
KS 957 BONNER SPRINGS	KS 2835 FORT SCOTT	KS 4559 LAWRENCE	KS 5888 OAKLEY
KS 1003 BREMEN	KS 2848 FOSTORIA 7 NW	KS 4588 LEAVENWORTH 4 ESE	KS 5906 OBERLIN
KS 1057 BROOKVILLE	KS 2855 FOWLER 3 NNE	KS 4598 LEBANON	KS 5972 OLATHE 3 E
KS 1141 BURDETT	KS 2872 FRANKFORT	KS 4608 LEBO	KS 6014 ONAGA
KS 1202 BUSHONG	KS 2894 FREDONIA 1 E	KS 4613 LECOMPTON	KS 6076 OSAGE CITY
KS 1233 CALDWELL	KS 2975 GARDEN CITY FAA A	KS 4642 LENORA	KS 6084 OSAWATOMIE
KS 1351 CASSODAY	KS 2980 GARDEN CITY EXP S	KS 4665 LEOTI	KS 6088 OSBORNE
KS 1371 CAWKER CITY	KS 3008 GARNETT 1 E	KS 4675 LE ROY	KS 6100 OSKALOOSA
KS 1383 CEDAR BLUFF DAM	KS 3037 GENESEO	KS 4695 LIBERAL	KS 6115 OSWEGO 1 N
KS 1395 CEDAR VALE	KS 3074 GIRARD	KS 4712 LINCOLN 1 ESE	KS 6128 OTTAWA
KS 1408 CENTRALIA	KS 3153 GOODLAND WSO AP	KS 4735 LINDSBORG	KS 6154 OVERBROOK 2 WSW
KS 1425 CHALK	KS 3175 GOVE	KS 4775 LOGAN	KS 6169 OXFORD
KS 1427 CHANUTE FAA AP	KS 3218 GREAT BEND	KS 4802 LONGFORD	KS 6192 PALCO 1 SSW
KS 1435 CHAPMAN	KS 3248 GRENOLA 1 N	KS 4807 LONG ISLAND	KS 6209 PAOLA
KS 1522 CIMARRON	KS 3257 GRIDLEY	KS 4812 LONGTON	KS 6217 PARALLEL
KS 1536 CLAFLIN	KS 3323 HADDAM	KS 4821 LORETTA	KS 6242 PARSONS 2 NW
KS 1559 CLAY CENTER	KS 3398 HANOVER 4 S	KS 4857 LOVEWELL DAM	KS 6305 PECK 3 WSW
KS 1593 CLIFTON	KS 3432 HARLAN	KS 4912 LYNDON 3 ENE	KS 6374 PHILLIPSBURG 1 SS
KS 1699 COLBY 1 SW	KS 3467 HARVEYVILLE 3 N	KS 4937 MADISON	KS 6414 PITTSBURG
KS 1704 COLDWATER	KS 3527 HAYS 1 S	KS 4972 MANHATTAN	KS 6435 PLAINVILLE
KS 1730 COLLYER 10 S	KS 3554 HEALY	KS 4982 MANKATO	KS 6498 POMONA LAKE
KS 1740 COLUMBUS 1 SW	KS 3634 HIAWATHA 5 SSE	KS 5039 MARION LAKE	KS 6524 POTWIN
KS 1767 CONCORDIA WSO AP	KS 3667 HILLSBORO	KS 5063 MARYSVILLE	KS 6549 PRATT 4 W
KS 1795 CONWAY SPRINGS	KS 3759 HOLTON	KS 5069 MATFIELD GREEN 2	

KS 6637	QUINTER	KS 8830	WICHITA WSO AP	NE 1680	CLAY CENTER	CO 1564	CHEYENNE WELLS
KS 6685	RANSOM	KS 8964	WINFIELD NO 1	NE 2065	CULBERTSON	CO 2446	EADS
KS 6725	READING 2 N	KS 8970	WINKLER	NE 2306	DEWEESE	CO 2932	FLAGLER
KS 6787	REXFORD	KS 8988	WINONA	NE 2690	ELWOOD	CO 2944	FLEMING
KS 6808	RICHFIELD 1 NE	KS 9040	WORDEN	NE 2741	ENDERS LAKE	CO 3828	HASWELL
KS 6813	RICHFIELD 10 WSW	KS 9080	YATES CENTER	NE 2820	FAIRBURY	CO 4076	HOLLY
KS 6979	ROSALIA	MO 143	AMITY	NE 2850	FALLS CITY	CO 4082	HOLYOKE
KS 7007	ROSSVILLE	MO 164	ANDERSON	NE 2935	FIRTH	CO 4242	IDALIA
KS 7046	RUSSELL FAA AP	MO 204	APPLETON CITY	NE 3035	FRANKLIN	CO 4388	JOHN MARTIN
KS 7049	RUSSELL SPRINGS	MO 608	BETHANY	NE 3175	GENEVA	CO 4413	JULESBURG
KS 7075	SAFFORDVILLE	MO 1141	BURLINGTON JUNCTION	NE 3485	GUIDE ROCK	CO 4603	KIT CARSON
KS 7093	SAINT FRANCIS	MO 1145	BUTLER	NE 3515	HAIGLER	CO 4770	LAMAR
KS 7095	SAINT FRANCIS 8 N	MO 1356	CARTHAGE	NE 3581	HARBINE	CO 4834	LAS ANIMAS
KS 7140	SAINT PETER 4 ENE	MO 1383	CASSVILLE	NE 3589	HARDY	CO 4945	LEROY
KS 7160	SALINA FAA AP	MO 1822	CONCEPTION	NE 3595	HARLAN CO. LAKE	CO 6192	OTIS
KS 7248	SCANDIA	MO 2474	EDGERTON	NE 3690	HAYES CENTER	CO 7515	SEDGWICK
KS 7271	SCOTT CITY	MO 2511	ELDORADO SPRINGS	NE 3735	HEBRON	CO 7862	SPRINGFIELD
KS 7305	SEDAN	MO 2729	FAIRFAX	NE 3910	HOLDREGE	CO 7866	SPRINGFIELD 7WSW
KS 7313	SEDGWICK	MO 3369	GRANT CITY	NE 4043	HUBBELL	CO 7992	STONINGTON
KS 7397	SHARON SPRINGS	MO 3568	HAMILTON	NE 4110	IMPERIAL	CO 8008	STRATTON
KS 7542	SMITH CENTER	MO 3649	HARRISONVILLE	NE 4604	LAMAR	CO 9243	WRAY
KS 7796	STERLING	MO 4315	JOPLIN	NE 5310	MC COOK	CO 9295	YUMA
KS 7809	STILWELL	MO 4358	KANSAS CITY	NE 5311	MC COOK 16NNW	OK 535	BARNSDALL
KS 7832	STOCKTON	MO 4505	KING CITY	NE 5388	MEDICINE CREEK	OK 548	BARTLESVILLE
KS 7922	SUBLETTE	MO 4705	LAMAR	NE 5565	MINDEN	OK 593	BEAVER
KS 8038	SYRACUSE	MO 4850	LEES SUMMIT	NE 5780	NAPONEE	OK 755	BILLINGS
KS 8086	TESCOTT	MO 5027	LOCKWOOD	NE 5840	NELSON	OK 908	BOISE CITY
KS 8114	THRALL 5 S	MO 5340	MARYVILLE	NE 6365	ORLEANS	OK 1243	BUFFALO
KS 8156	TONGANOXIE 4 ENE	MO 5704	MONETT	NE 6480	PALISADE	OK 1724	CHEROKEE
KS 8167	TOPEKA WSFO AP	MO 5834	MOUNTAIN GROVE	NE 6570	PAWNEE CITY	OK 3250	FORAKER
KS 8191	TORONTO LAKE	MO 5862	MT VERNON	NE 7002	RAGAN	OK 3304	FORT SUPPLY
KS 8235	TRIBUNE 1 W	MO 5976	NEOSHO	NE 7070	RED CLOUD	OK 3628	GOODWELL
KS 8245	TROUSDALE 1 NE	MO 5987	NEVADA	NE 7110	RED WILLOW	OK 3740	GREAT SALT PLAINS
KS 8250	TROY 4 WSW	MO 6357	OREGON	NE 8202	STERLING	OK 4019	HELENA
KS 8259	TUTTLE CREEK LAKE	MO 6678	PIERCE CITY	NE 8215	STOCKVILLE	OK 4258	HOLLOW
KS 8287	ULYSSES 1 SE	MO 6775	POLO	NE 8320	SUPERIOR	OK 4298	HOOKER
KS 8323	UTICA	MO 7435	ST JOSEPH	NE 8410	TABLE ROCK	OK 4393	HULAH DAM
KS 8341	VALLEY FALLS	MO 7645	SELIGMAN	NE 8465	TECUMSEH	OK 4573	JEFFERSON
KS 8436	VIRGIL	MO 8289	TARKIO	NE 8628	TRENTON DAM	OK 4766	KENTON
KS 8495	WAKEENEY	MO 8664	WACO	NE 8735	UPLAND	OK 5045	LAVERNE
KS 8498	WAKEENEY 9 N	NE 427	ATLANTA	NE 8875	VIRGINIA	OK 5855	MIAMI
KS 8503	WAKEFIELD	NE 435	AUBURN	NE 9020	WAUNETA	OK 6278	NEWKIRK
KS 8549	WALNUT 3 S	NE 520	BARNESTON	NE 9150	WESTERN	OK 6935	PAWHUSKA
KS 8563	WAMEGO	NE 640	BEAVER CITY	NE 9325	WILSONVILLE	OK 7201	PONCA CITY
KS 8578	WASHINGTON	NE 760	BENKLEMAN	NE 9475	WYMORE	OK 7358	QUAPAW
KS 8608	WAVERLY 3 SSE	NE 810	BERTRAND	CO 834	BONNY LAKE	OK 7534	REGNIER
KS 8648	WEBSTER DAM	NE 961	BLUE HILL	CO 895	BRANDON	OK 7556	RENFROW
KS 8670	WELLINGTON 2 S	NE 1240	BRUNING	CO 1121	BURLINGTON	OK 9203	VINITA
KS 8802	WHITE CITY	NE 1415	CAMBRIDGE	CO 1268	CAMPO	OK 9404	WAYNOKA

RELATED READINGS

The Weather Book. Williams, Jack. Vintage Books. 1992.

This is a readily available publication that provides an easy-to-understand guide to weather and climate in the United States. It includes many graphics, side notes of interesting facts, state-by-state climate information, and a glossary.

Science With Weather. Heddle, Rebecca, and Paul Shipton. Usborne Publishing Co., Inc., NY. 1993.

Filled with scientific activities, this book is designed to help young children learn about the weather. Easily performed experiments include how to measure the wind's speed, how to make a barometer, and how to forecast weather by looking at clouds. This would be of particular use to elementary students.

Simple Weather Experiments with Everyday Materials. Mandell, Muriel. Sterling Publishing Co., Inc., NY. 1990.

A very nontechnical explanation of physical weather, this book provides a number of easily performed experiments. This would be of particular use to elementary students.

Weather in the Lab. Baker, T. R. TAB Books. 1993.

This is a more advanced text geared toward middle school and high school classes. It includes a number of laboratory experiments and includes questions, observations, and post-lab activities. The book also includes a variety of appendices which relate to long-term activities, environmental questions, a materials checklist, sources of equipment, and answers to the laboratory questions.

Meteorology Today, An Introduction to Weather, Climate, and the Environment. Ahrens, C. D. West Publishing Company. 1985.

This is a beginning meteorology text geared toward college students. Includes special focus topics in various areas. It also includes an additional reading list and a glossary of meteorological terms.

Snowflakes. Sugarman, Joan. Little, Brown and Company. 1985.

Easy-to-read text describes how the seemingly infinite varieties of snowflakes are formed. Instructions for catching and preserving the shapes of snowflakes are included in this nontechnical discussion.

OTHER PUBLICATIONS OF INTEREST AVAILABLE FROM THE KANSAS GEOLOGICAL SURVEY

Educational Series

- Ancient life found in Kansas rocks (common fossils of Kansas)**, by *R. B. Williams*, 1975, Kansas Geological Survey, Educational Series 1, 44 p.
- Kansas rocks and minerals**, by *L. L. Tolsted* and *A. Swineford*, revised by *Rex Buchanan* and reprinted 1986, Kansas Geological Survey, Educational Series 2, 64 p.
- Kansas clays for the ceramic hobbyist**, by *D. A. Grisafe* and *M. Bauleke*, 1977, Kansas Geological Survey, Educational Series 3, 35 p.
- Kansas geomaps**, by *D. W. Steeples* and *R. C. Buchanan*, revised and reprinted 1984, Kansas Geological Survey, Educational Series 4, 30 p.
- From sea to prairie—a primer of Kansas geology**, by *C. S. Evans*, 1988, Kansas Geological Survey, Educational Series 6, 60 p.
- Petroleum: a primer for Kansas**, by *D. L. Baars*, *W. L. Watney*, *D. W. Steeples*, and *E. A. Brostuen*, 1989, Kansas Geological Survey, Educational Series 7, 40 p.
- A guide to finding Kansas maps**, by *C. S. Evans*, 1990, Kansas Geological Survey, Educational Series 8, 80 p.
- Caves in Kansas**, by *J. Young* and *J. Beard*, 1993, Kansas Geological Survey, Educational Series 9, 50 p.
- Kansas ground water: An introduction to the state's water quantity, quality, and management issues**, compiled by *R. Buchanan* and *R. W. Buddemeier*, 1993, Kansas Geological Survey, Educational Series 10, 44 p.
- Wichita's building blocks—A guide to building stones and geological features**, by *L. H. Skelton*, 1996, Kansas Geological Survey, Educational Series 11, 32 p.
- Primer on industrial minerals for Kansas**, by *D. A. Grisafe*, 1999, Kansas Geological Survey, Educational Series 13, 32 p.
- An atlas of the Kansas High Plains aquifer**, by *J. A. Schloss*, *R. W. Buddemeier*, and *B. B. Wilson*, eds., 2000, Kansas Geological Survey, Educational Series 14, 92 p.
- A Kansan's guide to science: An introduction to evolution and the nature of science, including origins of the universe and the Earth and the history of life**, by *P. Cartwright*, *R. L. Kaesler*, *B. S. Lieberman*, and *A. L. Melott*, 2000, Kansas Geological Survey, Educational Series 15, 19 p.

Also Available:

- Roadside Kansas—A traveler's guide to its geology and landmarks**, by *R. C. Buchanan* and *J. R. McCauley*, reprinted 1990, University Press of Kansas, 379 p.
- Kansas geology—An introduction to landscapes, rocks, minerals, and fossils**, ed. by *R. C. Buchanan*, 1984, University Press of Kansas, 212 p.
- Land of the post rock, its origins, history, and people**, by *G. Muilenburg* and *A. Swineford*, 1975, University Press of Kansas, 221 p.
- Geologic highway map of Kansas**, 1988, Western Geographics, scale 1:1,000,000 (folded only)
- Fossils of Kansas**, 2002, by Kansas Geological Survey and KU Museum of Natural History, poster (two-sided), 19 x 23 inches.

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