B

Appendix B Climate Overview of the Oak Ridge Area

B.1. Regional Climate

The climate of the Oak Ridge area and its surroundings may be broadly classified as humid subtropical. The term *humid* indicates that the region receives an overall surplus of precipitation compared with the level of evaporation and transpiration normally experienced throughout the year. The *subtropical* designation indicates that the region experiences a wide range of seasonal temperatures. Subtropical areas are typified by significant differences in temperature between summer and winter. Also, in humid subtropical climates, at least 4 months have an average temperature above 10°C (50°F). Monthly precipitation does not differ significantly throughout the year, but the types of precipitation may vary.

Oak Ridge winters are characterized by large-scale midlatitude cyclones that produce significant precipitation events roughly every 3 to 5 days. These wet periods are occasionally followed by arctic air outbreaks. Although snow and ice are not associated with many of these systems, occasional snowfall does result. Winter cloud cover tends to be enhanced by the regional terrain due to cold-air wedging and moisture trapping.

Severe thunderstorms, which can occur at any time of the year, are most frequent during spring and rarely occur in winter. The Cumberland Mountains and Cumberland Plateau frequently inhibit the intensity of severe systems that traverse the region to the east, particularly those moving from west to east, because of the downward momentum created as the storms move off higher terrain into the Great Valley. Summers are characterized by very warm, humid conditions. Occasional frontal systems may produce organized lines of thunderstorms and rare damaging tornadoes.

More frequently, however, summer precipitation results from air mass thundershowers that form as a consequence of daytime heating, rising humid air, and local terrain features. Although fall precipitation is usually adequate, August through October often are the driest months of the year. Precipitation during the fall tends to be less cyclical than in other seasons, but it is occasionally enhanced by decaying tropical cyclones. In November, midlatitude cyclones begin to dominate the weather and typically continue to do so until May.

Decadal-scale climate changes regularly affect the East Tennessee region. Most of these changes appear related to the hemispheric temperature and precipitation effects caused by the frequencies and phases of the El Niño–Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO). The ENSO is a recurring climate pattern involving changes in the temperature of waters in the central and eastern tropical Pacific Ocean. About every 3 to 7 years, the surface waters across a large swath of the tropical Pacific Ocean warm or cool by anywhere from 1°C to 3°C compared to normal. The PDO is a long-term climate pattern that affects the temperature of the Pacific Ocean and the weather patterns around it. The PDO is a naturally occurring phenomenon that shifts between warm and cool phases, with each phase lasting around 20–30 years. The PDO can strongly affect global weather and is important in long-range weather forecasting (Dutton 2021). The AMO is an ongoing series of long-duration changes in the sea surface temperature of the North Atlantic Ocean, with cool and warm phases that may last for 20–40 years each and a difference of about −17.2°C (1.0°F) between extremes. These changes are natural and have been occurring for at least the past 1,000 years.

These medium- and long-range sea surface temperature patterns collectively influence decadal-scale and longer regional temperature and precipitation trends in eastern Tennessee. The AMO shifted from a cold sea surface temperature phase to a warm sea surface temperature phase in the mid-1990s; these warmer temperatures have generally continued through the present. The PDO entered an either cool or transitional sea surface temperature phase around 2000. Although the ENSO pattern frequently caused warmer eastern Pacific sea surface temperatures during the 1990s, that warming subsided somewhat in the 2000s. The El Niño returned to prominence during the 2010s. A very strong El Niño occurred in 2015–2016, causing above-normal temperatures both locally and across much of the globe by 2016. Additionally, evidence exists that human-induced climate change may be affecting local temperatures via well-mixed greenhouse gases, land-cover change, carbon soot, aerosols, and other first-order influences. Solar influences on the jet stream via changes to the stratospheric temperature gradient over the 11-year solar cycle also contribute to interannual climate variability (Ineson et al. 2011). Perhaps in part because of the effects of the AMO and ENSO, the Oak Ridge climate warmed about 1.2°C from the 1970s to the 1990s and through the 2010s increased by less than 0.2°C from the value observed in the 1990s. This slight warming trend has continued into the early 2020s. The late-20th-century warming appears to have lengthened the growing season (i.e., the period with temperatures above 0°C, or 32°F) by about 2 to 3 weeks over the past 30 years, primarily by increasing minimum temperatures. Similar trends were noted through the 2000s and 2010s, with an average of 10 fewer days per year of minimum temperatures below 0°C. This effect is presumably related to changes in the interaction of the surface boundary layer with greenhouse gases and/or aerosol concentration changes. The effects of greenhouse gases on the nocturnal inversion layer (and thus on minimum temperatures) represent a redistribution of heat in the lower portion of the surface atmospheric layer. Temperature averages for individual years may vary significantly, as observed in the more than 1°C difference between the average temperatures for 2014 (14.8°C) and 2015 (16.0°C), largely the result of the recent strong El Niño. During the post-El Niño years of 2017 and 2018, the annual average temperature at ORNL returned to approximately the same level as in 2014 (i.e., 14.5°C in 2018) but rose again in 2019 under the influence of weak El Niño conditions (15.2°C). The average temperature declined in 2020 to 14.7°C with the onset of La Niña conditions, which persisted into early 2023 before positive sea surface temperature anomalies (i.e., strengthening El Niño conditions) returned and lasted through the early summer of 2024. Through the remainder of the year, conditions were generally neutral.

B.2. Winds

Five major terrain-related wind regimes regularly affect the Great Valley of eastern Tennessee:

- Pressure-driven channeling
- Downward-momentum transport or vertically coupled flow
- Forced channeling
- Along-valley and mountain-valley thermal circulations
- Down sloping

Pressure-driven channeling and vertically coupled flow affect winds on scales comparable to that of the Great Valley (hundreds of kilometers). Forced channeling occurs on similar scales but is also quite important at small spatial scales, such as those characterizing the ridge-and-valley terrain within ORR (Birdwell 2011). Along-valley and mountain-valley circulations are thermally driven and occur within a broad range of spatial scales. Thermally driven flows are more prevalent under conditions of clear skies and low humidity, favoring summer and especially fall months. Down sloping is frequently responsible for a slight temperature elevation when the Cumberland Mountains are on the windward side of ORR. Such windward flow also favors reduced wind speeds.

Forced channeling is defined as the direct deflection of wind by terrain. Because it necessitates some degree of vertical motion transfer, forced channeling is less pronounced during periods when cool air is trapped under warmer air just off the surface (i.e., inversion). Although it may result from interactions between large valleys and mountain ranges (such as the Great Valley and the surrounding mountains), forced channeling is especially important in narrow, small valleys such as those within ORR and the Great Valley (Kossman and Sturman 2002).

Forced channeling is the dominant large-scale wind mechanism within the Central Great Valley, influencing 50–60 percent of all winds observed in the area. For up-valley (southwest to northeast) flow cases, these winds are frequently associated with large wind shifts (45°–90°) when they initiate or terminate. At small scales, ridge-and-valley terrain produces forced-channeled local flow in more than 90 percent of cases.

Large-scale forced channeling occurs regularly within the Great Valley when northwest-to-north winds (perpendicular to the axis of the Central Great Valley) coincide with vertically coupled flow. This sometimes results in a split-flow pattern, with winds southwest of Knoxville moving down valley and those east of Knoxville moving up valley. The causes of such a flow pattern may include the shape characteristics of the Great Valley (Kossman and Sturman 2002) but also may be associated with the specific location of the Cumberland and Smoky Mountains relative to upper-level wind flow (Eckman 1998). A northwest wind flow through the convex shape of the Great Valley may lead to a divergent wind flow pattern in the Knoxville area, resulting in downward air motion. Horizontal flow is also reduced by the windward Cumberland Mountains, which increase buoyancy and the apparent force caused by the earth's rotation, or the Coriolis effect (also known as Froude and Rossby ratios). Consequently, the leeward terrain of the Smoky Mountains becomes more effective at blocking or redirecting the winds.

Vertically coupled winds tend to occur when the atmosphere is unstably or neutrally buoyant. When a strong horizontal wind component is present, as in conditions behind a winter cold front or during strong regional cold-air advection, winds tend to override the terrain, flowing roughly in the same direction as the winds aloft. This is a consequence of the horizontal transport and momentum aloft being transferred to the surface. However, Coriolis effects may turn the winds to the left by up to 40° (Birdwell 1996).

In the Central Great Valley, vertically coupled winds dominate about 25–35 percent of each occurrence of broader-scale wind events; however, most vertically coupled winds are turned toward an up-valley or down-valley direction when small-scale ridge-and-valley terrain is factored in. Wintertime vertically coupled flow is typically dominated by strong, large-scale pressure forces, whereas summertime cases tend to be associated with a deep mixing depth (greater than 500 m). Most vertically coupled flows are associated with major wind shifts (90°–135°) when they begin or terminate (Birdwell 2011).

Pressure-driven channeling is the redirection of synoptically induced wind flow through a valley channel. The direction of wind flow through the valley is determined by the axis of the pressure gradient superimposed on the valley axis (Whiteman 2000). The process is affected by Coriolis forces, a leftward deflection of winds in the Northern Hemisphere. Eckman (1998) suggested that pressure-driven channeling plays a significant role in the Great Valley. Winds driven purely by pressure-driven channeling shift from up-valley to down-valley flow or in the opposite direction if large-scale pressure systems induce reversals in air pressure gradients across the axis of the Great Valley. Because the processes involved in pressure-driven flow primarily affect the horizontal motion of air, the presence of a temperature inversion enhances this pattern significantly. Weak vertical air motion and momentum associated with such inversions allow different layers of air to slide over one another with varied directions of movement (Monti et al. 2002).

Within the Central Great Valley, and especially within ORR, winds dominated by down-valley pressure-driven channeling range in frequency from 2 to 10 percent of cases, with the lowest values in summer and the highest in winter. Up-valley pressure-driven channeling usually does not dominate winds in the Central Great Valley but co-occurs with forced-channeled winds 50 percent of the time. Winds dominated by pressure-driven channeling often result in large wind shifts (90°–180°) before and after the occurrence of the wind pattern. These wind shifts occur about twice as frequently within and near ORR than in other parts of the Great Valley (Birdwell 2011). Most pressure-driven channeled winds occur in association with moderate (0.006–0.016 mb/km) synoptic pressure gradients.

Thermally driven winds are common in areas of complex terrain. These winds occur because of pressure and temperature differences caused by varied surface–air energy exchanges at similar altitudes along a valley's axis, sidewalls, or slopes. Conditions are ideal for the development of thermally driven winds when synoptic winds are light and when thermal differences are exacerbated by clear skies and low humidity (Whiteman 2000). Ridge-and-valley terrain may be responsible for enhancing or inhibiting such flow, depending on ambient weather conditions. Large-scale thermally driven winds are most frequent during summer and especially fall, when surface heating and low humidity help drive flow patterns (Birdwell 2011).

B.3. Temperature and Precipitation

Temperature and precipitation normals (1991–2020) and extremes (1948–2024) and their durations for the city of Oak Ridge and ORNL are summarized in Table B.1. Decadal temperature and precipitation averages for 5 decades (1970s–2010s) are provided in Table B.2. Hourly freeze data (1985–2024) are given in Table B.3. Overall, at ORNL, 2024 was 0.3°C warmer than normal compared with the 1991–2020 Oak Ridge base period, and precipitation was 15 percent below normal compared with the 1991–2020 mean.

B.3.1. Recent Climate Change with Respect to Temperature and Precipitation

Table B.2 presents a decadal analysis of temperature patterns from 1970 to 2019. In general, temperatures in the Oak Ridge area rose from the 1970s to the 1990s and have nearly stabilized since the 1990s. Based on these average decadal temperatures, temperatures rose 1.2°C between the 1970s and the 1990s, from 13.8°C to 15.0°C (56.8°F to 59.0°F). The warmest decade of the past five was the 2000s at 15.2°C (59.4°F), although temperatures in the 2010s were virtually the same (15.1°C, or 59.2°F). More detailed analysis reveals that these temperature changes have been neither linear nor equal with respect to the seasons.

January and February average temperatures increased by about 2.5°C from the 1970s to the 1990s and have declined by just over 1°C since the 1990s. The peak in the 1990s may be associated with the effects of the AMO, other natural effects, and/or anthropogenic effects. The Arctic has seen the largest increase in temperatures anywhere in the Northern Hemisphere over the past 30 years, and this increase has had a corresponding effect on Oak Ridge temperatures in winter because of the influx of Arctic air masses.

During the winter months of January and February, much of the air entering eastern Tennessee comes from the Arctic. As a result, Oak Ridge temperatures have warmed more dramatically during these months. Changes to average temperatures in December have not been as dramatic as those in January and February. December averages were relatively warm in the 1970s (4.6°C), bottomed out in the 1980s (3.1°C), returned to approximately 1970s levels in the 1990s and 2000s, and finally warmed to about 6.0°C by the 2010s.

Compared with the 1970s, temperatures have warmed 1.0°C, 1.5°C, and 2.1°C during the climatological spring months of March, April, and May, respectively. However, most of the warming in March and April did not occur until the 2000s. The tendency toward warmer springs has slightly lengthened the growing season.

Summer months (June, July, and August) were 1.8°C, 1.3°C, and 0.9°C warmer on average, respectively, in the 2010s than in the 1970s; however, most observed warming during summer can be attributed to a rise in minimum temperatures. In fact, August maximum temperatures have declined about 1.0°C since the 2000s. Warming for June and July has virtually stopped since the 2000s.

Climatological fall months (September, October, and November) generally have had the smallest average temperature increases (0.9°C, 1.3°C, and 0.1°C, respectively) since the 1970s. In fact, average temperatures in September and October have remained fairly consistent since the 1990s, and November has not shown a clear trend across the decades since the 1970s.

The mean annual temperature increased by 1.4°C between the 1970s and the 2000s and then remained about the same in the 2010s (1.3°C warmer than the 1970s). About 90 percent of the increase occurred between the 1980s and 1990s. Mean annual decadal-averaged temperatures have varied by only 0.2°C since the 1990s. Since the 2020 ASER, a base period of 1991–2020 has been used to determine the mean annual temperature. The mean annual temperature increased by about 0.6°C, mainly because the cooler 1980s values were eliminated. Between 2022 and 2024, global temperatures were above average, perhaps in part because of an increase in water vapor within the stratosphere due to the eruption of Hunga Tonga in the South Pacific.

Decadal precipitation averages suggest some important changes in precipitation patterns in Oak Ridge from the 1970s to 2010s. Although overall decadal precipitation averages remained between about 48 and 60 in. annually, some decadal shifts were observed in monthly and seasonal patterns of rainfall. During winter (December, January, and February), precipitation remained fairly constant after the 1970s. However, February precipitation in the 2010s (and for winter overall after the 2000s) increased significantly. Spring precipitation (March, April, and May) declined about 20 percent after the 1970s. Summer (June, July, and August) precipitation changes are mixed.

June values changed little between the 1970s and the 2010s, but July values increased by about 20 percent, and August values declined by about 20 percent. Similar patterns were observed for the fall months. During the 2010s, September precipitation values increased by about 10 percent compared with the 1970s, whereas October values decreased by about 10 percent. Little change occurred in precipitation for November. Overall, annual average precipitation in the 2010s was about 3 percent less than it was in the 1970s (59.68 vs. 58.18 in.). Also, precipitation values in the 1980s and 2000s were 10 to 20 percent less than those in the 2010s, and precipitation levels in the 1990s were similar to levels observed in the 2010s.

The increase in winter temperatures since the 1970s has affected monthly and annual snowfall amounts. During the 1970s and 1980s, snowfall averaged about 25.4 to 28 cm (10 to 11 in.) annually in Oak Ridge. However, during the most recent 2 decades (the 2000s and 2010s), snowfall averaged only 9.8 cm (3.9 in.) per year. This decrease seems to have occurred largely since the mid-1990s. January and February temperatures cooled slightly in the 2010s compared with the 2000s, which seems to have reversed the decrease in snowfall slightly, with annual averages of 13.2 cm (5.2 in.) during the 2010s. Concurrently with the overall decrease in snowfall, the annual number of hours of subfreezing weather generally declined after the 1980s (see Table B.3). However, the number of subfreezing hours during 2010 (1,123 h) was the highest recorded since 1988. January 2014 was the coldest January since 1985, with 371 subfreezing hours, and February 2015 was the coldest February since 1978, also with 371 subfreezing hours.

Table B.3 presents the number of hours of subfreezing temperatures in Oak Ridge for each year from 1985 to 2024. During the mid- to late 1980s, there were about 900 to 1,000 h of subfreezing temperatures during a typical year. In recent years, these values have fallen to about 600 to 700 h, although higher values have occurred relatively recently (e.g., 1,123 h in 2010). However, in some years in the 2010s, only 350 to 500 h of subfreezing weather were observed.

B.4. Moisture

ORR's humid environment results in frequent saturation of the surface layer, especially at night. Average annual relative humidity at ORNL for tower MT2, one of eight DOE-managed ORR meteorological towers, is 75.4 percent (2015–2021) at 2 m above ground level and 72.9 percent at 15 m above the ground. The average annual absolute humidity, a measure of the actual amount of water vapor (moisture) in the air regardless of the air's temperature, for MT2 is 10.3 g/m^3 at both 2 and 15 m above ground level. Absolute humidity varies greatly throughout the year, ranging from a monthly minimum of about 4.7 g/m^3 during winter to a maximum of about 16.9 g/m^3 during summer.

Table B.1. Climate normals (1991–2020) and extremes (1948–2024) for ORNL

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Temperature, °C													
30-year average max	8.8	11.4	16.5	21.9	26.2	29.8	31.4	31.2	28.1	22.2	15.4	10.3	21.1
2024 average max	5.5	14.1	17.3	20.4	24.5	29.3	30.3	30.3	27.2	23.2	17.7	10.4	20.9
77-year record max	25	27	30	33	35	41	41	39	39	35	28	26	41
30-year average min	-1.5	0.2	3.9	5.8	13.4	17.8	20.1	19.5	15.9	9.1	3.0	0.3	9.0
2024 average min	-3.7	1.3	5.2	9.6	14.6	18.8	21.0	19.0	17.3	10.1	7.8	1.4	10.2
77-year record min	-27	-25	-17	-7	-1	4	9	10	1	-6	-16	-22	-27
30-year average	3.5	5.8	10.2	13.2	19.7	23.7	25.6	25.2	21.8	15.5	9.1	5.2	14.9
2024 average	1.0	7.4	11.0	14.8	19.1	23.9	25.1	24.0	21.8	15.9	12.6	5.6	15.2
2024 departure from average	-2.5	1.6	0.8	1.6	-0.6	0.2	-0.5	-1.2	0	0.4	3.5	0.4	0.3
30-year average heating degree days, °C													
	451	351	252	110	31	1	0	0	9	101	270	399	1,974
30-year average cooling degree days, °C													
	0	0	7	18	80	170	235	221	120	22	1	0	874
Precipitation, mm													
30-year average	132.4	138.7	129.8	131.6	106.5	113.1	141.5	84.6	100.4	80.0	120.7	138.5	1,417.8
2024 totals	133.1	118.1	90.7	73.4	176	57.4	245.1	35.3	118.1	0.3	76.2	104.1	1,227.9
2024 departure from average	0.7	-20.6	-39.1	-58.2	69.5	-55.7	103.61	-49.3	17.71	-79.7	-44.5	-34.36	-189.9
77-year max monthly	337.2	384.7	311.0	356.5	271.9	283	489.6	265.8	257.6	203.8	310.5	321.2	1,939.4
77-year max 24 h	108.0	131.6	120.4	158.5	112.0	94.0	124.8	190.1	160.1	67.6	130.1	130.1	190.1
77-year min monthly	23.6	21.3	54.1	46.2	20.3	13.5	31.3	13.7	Trace	Trace	34.8	17.0	911.4
Snowfall, in.													
30-year average	4.6	5.1	2	0	0	0	0	0	0	0	2.5	2.5	14.5
2024 totals	8.10	0	0	0	0	0	0	0	0	0	Trace	Trace	8.1
77-year max monthly	24.4	43.7	53.4	15	Trace	0	0	0	0	Trace	16.5	53.4	105.2
77-year max 24 h	21.1	28.7	30.5	13.7	Trace	0	0	0	0	Trace	16.5	30.5	30.5

Table B.1. Climate normals (1991–2020) and extremes (1948–2024) for ORNL (continued)

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Days w/temperature													
30-year max ≥ 32°C	0	0	0	0.1	1.5	7.7	14.4	12.7	4.9	0.1	0	0	41.4
2024 max ≥ 32°C	0	0	0	0	0	5	9	9	2	0	0	0	8
30-year min ≤ 0°C	19.8	15.4	8.7	1.8	0.1	0	0	0	0	0.9	10.3	16.5	73.5
2024 min ≤ 0°C	22	16	4	0	0	0	0	0	0	0	2	16	60
30-year max ≤ 0°C	2.6	0.8	0.1	0	0	0	0	0	0	0	0	0.8	4.3
2024 max ≤ 0°C	6	0	0	0	0	0	0	0	0	0	0	0	6
Days w/precipitation													
30-year avg ≥ 0.01 in.	11.8	11.6	12.4	11.1	11.5	11.4	12.3	9.8	8.1	8.3	9.2	12.2	129.7
2024 days ≥ 0.01 in.	13	9	10	13	17	11	13	2	9	1	11	10	119
30-year avg ≥ 1.00 in.	1.7	1.4	1.4	1.5	1.1	1.2	1.6	0.9	1.2	1	1.7	1.7	16.4
2024 days ≥ 1.00 in.	1	1	1	0	3	0	3	0	2	0	1	0	12

Table B.2. Decadal climate change (1970–2019) for city of Oak Ridge/ORNL, with 2024 comparisons

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Temperature, °C													
1970–1979 avg max	6.6	9.7	15.6	21.4	24.8	28.5	30.0	29.7	26.8	20.8	14.5	10.0	19.9
1980–1989 avg max	6.9	10.2	15.9	21.0	25.6	29.8	31.6	30.7	27.1	21.3	15.6	8.6	20.3
1990–1999 avg max	9.4	12.3	16.2	21.9	26.2	29.7	32.1	31.4	28.4	22.6	15.2	10.4	21.3
2000–2009 avg max	8.8	11.2	17.0	21.4	25.8	29.8	30.8	31.4	27.6	21.8	15.9	9.8	21.0
2010–2019 avg max	8.1	11.2	16.3	22.6	26.8	30.2	31.2	30.8	28.5	22.3	15.1	11.4	21.2
1980s vs. 2010s	1.2	1.0	0.3	1.6	1.2	0.4	-0.2	0.0	1.4	1.0	-0.5	2.3	0.8
2000s vs. 2010s	-0.7	0.0	-0.8	1.2	1.0	0.4	0.5	-0.6	0.9	0.5	-0.8	1.1	0.2
2024 avg max	5.5	14.1	17.3	20.4	24.5	29.3	30.3	30.3	27.2	23.2	17.7	10.4	20.9
1970–1979 avg min	-3.4	-2.4	3.0	6.7	11.6	15.7	18.3	18.1	15.5	7.5	2.6	-0.8	7.7
1980–1989 avg min	-4.1	-2.1	1.7	6.0	11.4	16.2	19.0	18.4	14.4	7.5	3.1	-2.3	7.4
1990–1999 avg min	-0.9	0.0	2.9	7.2	12.5	17.2	20.0	18.9	15.1	8.2	2.2	0.1	8.6
2000–2009 avg min	-1.4	0.0	4.4	8.6	13.6	18.0	20.0	20.0	16.1	9.5	3.9	-0.4	9.4
2010–2019 avg min	-2.0	0.6	4.2	8.8	14.1	18.2	20.3	19.5	16.4	9.4	2.7	1.2	9.5
1980s vs. 2010s	2.0	2.6	2.5	2.7	2.7	2.1	1.3	1.1	2.0	2.0	-0.4	3.6	2.1

Table B.2. Decadal climate change (1970–2019) for city of Oak Ridge/ORNL, with 2024 comparisons (continued)

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2000s vs. 2010s	-0.6	0.6	-0.2	0.1	0.5	0.4	0.3	-0.5	0.3	-0.1	-1.2	1.6	0.1
2024 avg min	-3.7	1.3	5.2	9.6	14.6	18.8	21.0	19.0	17.3	10.1	7.8	1.4	10.2
1970–1979 avg	1.6	3.7	9.3	14.1	18.1	22.1	24.1	23.9	21.1	14.2	8.6	4.6	13.8
1980–1989 avg	1.4	4.1	8.8	13.5	18.5	23.0	25.3	24.6	20.8	14.4	9.4	3.1	13.9
1990–1999 avg	4.2	6.2	9.6	14.5	19.4	23.5	26.0	25.2	21.9	15.5	8.8	5.3	15.0
2000–2009 avg	3.7	5.6	10.7	15.3	19.7	23.9	25.4	25.7	21.9	15.6	9.9	4.7	15.2
2010–2019 avg	3.0	5.3	10.3	15.7	20.3	24.0	25.4	24.6	21.9	15.4	8.7	6.4	15.1
1980s vs. 2010s	1.5	1.8	1.5	2.1	1.8	0.9	0.1	0.2	1.2	1.1	-0.7	2.8	1.2
2000s vs. 2010s	-0.7	0.2	-0.4	0.3	0.6	0.0	0.0	-1.0	0.1	-0.2	-1.2	1.2	-0.1
2024 avg	1.0	7.4	11.0	14.8	19.1	23.9	25.1	24.0	21.8	15.9	12.6	5.6	15.2
						Precipitation, mm							
1970–1979 avg	143.4	94.6	169.4	118.3	149.8	120.5	130.4	109.8	107.2	99.8	129.6	145.3	1,516.4
1980–1989 avg	100.4	109.1	112.6	88.8	110.6	84.1	120.4	82.6	108.9	79.8	128.0	107.6	1,236.2
1990–1999 avg	141.4	136.5	149.0	126.3	113.4	110.0	134.8	83.6	71.9	67.3	109.8	161.0	1,429.4
2000–2009 avg	116.9	121.8	115.6	125.0	117.8	95.2	138.9	78.4	108.8	74.0	121.4	124.4	1,333.4
2010–2019 avg	130.1	146.6	117.4	131.9	93.8	132.4	156.8	92.5	114.1	91.0	128.0	151.7	1,478.2
1980s vs. 2010s	29.5	37.6	4.6	42.9	-16.8	15.2	36.3	9.9	5.3	11.2	0.0	44.3	239.3
2000s vs. 2010s	13.2	24.9	1.7	6.9	24.1	13.5	17.8	14.0	5.3	17.0	6.7	27.2	146.9
2024 totals	133.1	118.1	90.7	73.4	176	57.4	245.1	35.3	118.1	0.3	76.2	104.1	1,227.9
						Snowfall, cm							
1970–1979 avg	11.1	12.5	4.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.4	35.1
1980–1989 avg	11.4	8.8	2.2	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	32.8
1990–1999 avg	6.9	7.8	8.1	Trace	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.1	10.9
2000–2009 avg	2.1	4.5	Trace	Trace	0.0	0.0	0.0	0.0	0.0	0.0	Trace	1.7	8.3
2010–2019 avg	5.3	6.4	0.3	Trace	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.4	13.2
1980s vs. 2010s	5.2	1.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.8	12.4
2000s vs. 2010s	3.6	2.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	6.6
2024 totals	20.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Trace	Trace	20.6

Table B.3. Hourly subfreezing temperature data for Oak Ridge, Tennessee, 1985–2024[a] (Hours at or below 0°C, −5°C, −10°C, and −15°C)

Year	January				February				March			April		May		October		November			December				Annual			
	≤0	<-5	<-10	<-15	≤0	<-5	<-10	<-15	≤0	<-5	<-10	≤0	<-5	≤0	<-5	≤0	<-5	≤0	<-5	<-10	≤0	<-5	<-10	<-15	≤0	<-5	<-10	<-15
1985	467	195	103	39	331	127	26	0	105	6	0	43	3	0	0	0	0	22	0	0	431	201	66	2	1,399	532	195	41
1986	308	125	38	10	161	29	3	0	124	28	0	17	0	0	0	0	0	32	10	0	232	34	0	0	874	226	41	10
1987	302	53	7	0	111	19	3	0	95	0	0	55	4	0	0	36	0	103	18	0	151	16	0	0	853	110	10	0
1988	385	182	43	0	294	102	19	0	97	9	0	6	0	0	0	45	0	62	3	0	301	55	0	0	1,190	351	62	0
1989	163	27	0	0	190	66	10	0	35	0	0	18	0	3	0	7	0	125	14	0	421	188	71	30	962	295	81	30
1990	142	13	0	0	115	5	0	0	35	0	0	35	0	0	0	19	0	62	1	0	172	43	5	0	580	62	5	0
1991	186	44	0	0	158	47	15	0	49	0	0	0	0	0	0	4	0	148	16	0	192	38	0	0	737	145	15	0
1992	230	65	8	0	116	22	0	0	116	4	0	27	2	0	0	7	0	100	0	0	166	9	0	0	762	102	8	0
1993	125	11	0	0	245	47	8	0	124	32	9	3	0	0	0	0	0	152	2	0	223	44	0	0	872	136	17	0
1994	337	191	85	26	196	46	3	0	66	0	0	18	0	0	0	0	0	53	1	0	142	0	0	0	812	238	88	26
1995	240	45	6	0	217	84	18	0	37	0	0	0	0	0	0	0	0	142	3	0	288	84	10	0	924	216	34	0
1996	301	91	0	0	225	110	62	27	182	49	6	23	0	0	0	3	0	101	0	0	194	40	4	0	1,029	290	72	27
1997	254	101	24	0	67	0	0	0	25	0	0	6	0	0	0	6	0	96	10	0	232	14	0	0	686	125	24	0
1998	97	10	7	0	25	0	0	0	74	20	0	0	0	0	0	0	0	38	0	0	132	4	0	0	366	34	7	0
1999	181	68	0	0	113	14	0	0	62	0	0	0	0	0	0	4	0	41	0	0	177	23	0	0	578	105	0	0
2000	273	62	5	0	127	30	0	0	18	0	0	8	0	0	0	11	0	94	11	0	345	124	7	0	876	227	12	0
2001	281	60	5	0	79	9	0	0	53	0	0	2	0	0	0	18	0	28	0	0	137	35	0	0	598	104	5	0
2002	185	28	0	0	121	16	0	0	91	17	0	2	0	0	0	0	0	41	0	0	82	6	0	0	522	67	0	0
2003	345	123	26	0	117	12	0	0	19	0	0	0	0	0	0	0	0	37	0	0	102	9	0	0	620	144	26	0
2004	285	50	2	0	76	0	0	0	18	0	0	0	0	0	0	0	0	9	0	0	247	41	4	0	635	91	6	0
2005	151	65	6	0	52	1	0	0	81	1	0	0	0	0	0	1	0	55	0	0	176	28	0	0	516	95	6	0
2006	70	0	0	0	169	19	0	0	44	0	0	0	0	0	0	15	0	37	0	0	126	41	1	0	461	60	1	0
2007	189	30	5	0	283	70	0	0	29	0	0	32	0	0	0	0	0	60	0	0	83	8	0	0	673	111	5	0
2008	242	86	11	0	114	7	0	0	69	6	0	0	0	0	0	15	0	89	18	0	157	34	5	0	686	151	16	0
2009	238	93	29	0	178	64	5	0	55	15	0	5	0	0	0	0	0	8	0	0	178	22	0	0	662	194	34	0
2010	384	181	14	0	289	32	0	0	40	2	0	0	0	0	0	0	0	46	0	0	364	109	11	0	1,123	324	25	0
2011	300	61	0	0	108	14	0	0	2	0	0	0	0	0	0	5	0	29	0	0	91	0	0	0	535	75	0	0
2012	169	27	0	0	78	19	0	0	9	0	0	1	0	0	0	0	0	46	0	0	76	0	0	0	379	46	0	0
2013	245	49	0	0	120	12	0	0	95	7	0	0	0	0	0	11	0	121	0	0	173	6	0	0	765	74	0	0
2014	371	208	76	12	109	5	0	0	68	0	0	5	0	0	0	0	0	122	10	0	94	1	0	0	769	224	76	12

Table B.3. Hourly subfreezing temperature data for Oak Ridge, Tennessee, 1985–2024[a] (continued) (Hours at or below 0°C, −5°C, −10°C, and −15°C)

Year	*January*				*February*				*March*			*April*		*May*		*October*		*November*			*December*				*Annual*			
	≤0	*<-5*	*<-10*	*<-15*	*≤0*	*<-5*	*<-10*	*<-15*	*≤0*	*<-5*	*<-10*	*≤0*	*<-5*	*≤0*	*<-5*	*≤0*	*<-5*	*≤0*	*<-5*	*<-10*	*≤0*	*<-5*	*<-10*	*<-15*	*≤0*	*<-5*	*<-10*	*<-15*
2015	228	52	16	0	371	120	31	6	52	16	0	0	0	0	0	0	0	11	0	0	41	0	0	0	703	188	47	6
2016	333	82	12	0	211	17	0	0	35	0	0	9	0	0	0	0	0	44	3	0	163	32	0	0	795	134	12	0
2017	130	47	11	1	64	5	0	0	82	8	0	0	0	0	0	8	0	67	0	0	252	20	0	0	603	44	10	0
2018	362	199	86	4	67	7	0	0	49	2	0	11	0	0	0	0	0	89	6	0	102	11	0	0	680	225	86	4
2019	146	46	1	0	46	0	0	0	80	9	0	5	0	0	0	0	0	93	11	0	90	0	0	0	466	66	1	0
2020	124	14	0	0	102	11	0	0	20	1	0	12	0	4	0	0	0	30	0	0	210	49	11	0	502	75	11	0
2021	151	1	0	0	144	33	0	0	34	0	0	31	0	0	0	0	0	121	0	0	70	0	0	0	551	34	0	0
2022	271	45	0	0	126	3	0	0	37	11	0	3	0	0	0	8	0	59	3	0	170	75	36	13	674	137	36	13
2023	67	0	0	0	31	3	0	0	53	5	0	0	0	0	0	0	0	77	10	0	130	1	0	0	358	19	0	0
2024	312	118	65	13	114	9	0	0	25	0	0	0	0	0	0	0	0	12	0	0	157	25	0	0	620	152	65	13
Avg	239	74	17	3	147	31	5	1	58	6	0	9	0	0	0	6	0	68	4	0	182	37	6	1	710	151	28	5

[a] *Source: 1985–2014 National Oceanic and Atmospheric Administration, Atmospheric Turbulence and Diffusion Division, KOQT Station, Automated Surface Observing System; 2015–2024 ORNL, Tower "D."*

B.5. Severe Weather

On average, thunderstorms and associated lightning occur in the Oak Ridge area at a rate of 48 days per year, with a monthly maximum of about 11 days occurring in July. About 40 of these thunderstorm days occur during the 7-month period from April through October, with the remainder spread evenly throughout late fall and winter. The highest number of thunderstorm days at ORNL (65) was observed during 2012; the lowest (34) was observed during 2007. A total of 40 thunderstorm days occurred in 2024.

Hailstorms are infrequent on ORR and typically occur in association with severe thunderstorms. Hailstorms are usually caused by high-altitude thunderstorm updrafts, which propel water droplets above the freezing level. Some hail events have been known to occur in association with nonthunder rain showers and low freezing levels (particularly during winter or spring). Most hailstorm occurrences (77 percent) do not produce hailstones larger than 2 cm (about 0.75 in.). From 1961 through 1990, about six hail events (with hailstones larger than about 2 cm) were documented at locations within 40 km (25 miles) of ORNL. Nearly all of these events occurred during the summer and fall seasons. During the 2011 significant tornado outbreak in East Tennessee, large hail (greater than 2 cm) was observed in Farragut, Tennessee, about 15 km (9 miles) southeast of ORNL.

A tornado outbreak occurs in East Tennessee about once every 3 to 6 years on average. The Fujita Tornado Scale, usually referred to as the F-Scale, was developed in 1973 to classify tornadoes based on the resulting damage. The scale ranges from F0 (minimal damage) to F5 (incredible damage). The version used today—the Enhanced Fujita Scale—went into effect in 2007 and ranges from EF0 tornadoes with winds of 65 to 85 mph to EF5 tornadoes with winds exceeding 200 mph. Tornado indices from the National Weather Service in Morristown, Tennessee, show that since 1950, three tornadoes have been documented within 10 km (6 miles) of ORNL: two F0 tornadoes and one F3 (severe damage) tornado. The F3 tornado occurred in February 1993 and moved through Bear Creek Valley near the Y-12 National Security Complex, with winds damaging the roofs of several buildings along Union Valley Road. To date, the February 1993 tornado is the only documented tornado that has occurred within ORR.

Eleven additional tornadoes have been documented since 1950 within 20 km (12 miles) of ORNL, ranging in intensity from F0/EF0 to F2/EF2. The most recent of these was an EF2 that occurred during the afternoon of August 7, 2023, and touched down just west of Pellissippi Parkway before crossing the road and traversing east for a track totaling 6.1 km (3.8 miles). Just days prior, a brief EF0 tornado spun up along Highway 70 in Oral, Tennessee, in Roane County. Both tornadoes formed within passing squall lines, which produced widespread high winds and associated damage across the local area. The remaining tornadoes within 20 km (12 miles) of ORNL affected eastern Roane County to the south and the Edgemoor Road area to the northeast of ORR. Another 10 tornadoes, ranging from F0/EF0 to F3/EF3 in intensity, have occurred within 35 km (22 miles) of ORNL since 1950. Most of them occurred to the east and south of ORR in Knox and Roane Counties; however, a few occurred in the Rocky Top and Norris areas.

The annual probability that a tornado will strike any location in a grid square can be estimated by multiplying the number of tornadoes per year per square kilometer in that particular grid square by the path area of a tornado. The result of this calculation is greatly affected by the assumed path area of a tornado. In total, about 24 tornadoes have been documented within 35 km (22 miles) of ORNL since 1950.

B.6. Stability

The local ridge-and-valley terrain plays a role in the development of stable surface air under certain conditions and influences the dynamics of airflow. Although ridge-and-valley terrain creates identifiable patterns during times of unstable conditions as well, strong vertical mixing and momentum tend to reduce these effects. *Stability* describes the tendency of the atmosphere to mix (especially vertically) or overturn. Consequently, dispersion parameters are influenced by the stability characteristics of the atmosphere. Stability classes range from A (very unstable) to G (very stable), with D being a neutral state.

The suppression of vertical motions during stable conditions increases the effect of local terrain on air motion. Conversely, stable conditions isolate wind flows within the ridge-and-valley terrain from the effects of more distant terrain features and from winds aloft. These effects are particularly significant with respect to mountain waves, which are downwind oscillations that result from terrain-induced disruption within the horizontal flow. Like water flowing over a boulder, when air is perpendicular to a stationary boundary (e.g., the Cumberland or Smoky Mountains), it tends to stay at the same altitude or sink in a stable air mass. This causes a “ripple” or “wave” on the lee side of the terrain. This effect on mountain-wave formation may be important to the impact that the nearby Cumberland Mountains could have on local airflow.

A second factor that may decouple large-scale wind flow effects from local ones (and thus produce stable surface layers) occurs with overcast sky conditions. Clouds overlying the Great Valley may warm because of direct insolation (i.e., exposure to the sun’s rays) on the cloud tops. Warming may also occur within the clouds as latent energy, which is released because of the condensation of moisture. Surface air underlying the clouds may remain relatively cool because the layer remains cut off from direct exposure to the sun. Consequently, the vertical temperature gradient associated with the air mass becomes more stable (Lewellen and Lewellen 2002). Long-wave radiational cooling of fog or low stratus decks has also been observed to help modify stability in the surface layer (Whiteman et al. 2001). This occurs because the emittance of long-wave radiation further cools the surface layer and thus strengthens the associated inversion.

Stable boundary layers typically form as a result of radiational cooling processes near the ground (Van De Weil et al. 2002); however, they are also influenced by the mechanical energy supplied by horizontal wind motion, which in turn is influenced by the large-scale weather-related pressure differences from one location to another (gradient). Ridge-and-valley terrain may significantly block such winds and their associated mechanical energy (Carlson and Stull 1986). Consequently, radiational cooling at the surface is enhanced because less wind energy is available to remove chilled air.

Stable boundary layers also exhibit intermittent turbulence, which is associated with the aforementioned factors. The process results from interactions between the effects of friction and radiational cooling. As a stable surface layer intensifies via a radiational cooling process, it tends to decouple from air aloft, thereby reducing the effects of surface friction. The upper air layer responds with an acceleration in wind speed. Increased wind speed aloft increases mechanical turbulence and wind shear at the boundary with the stable surface layer. Eventually, the turbulence works into the surface layer and weakens it. As the inversion weakens, friction again increases, reducing wind speeds aloft. The reduced wind speeds aloft allow enhanced radiation cooling at the surface, which reintensifies the inversion and allows the process to start again. Van De Weil et al. (2002) have shown that cyclical temperature oscillations up to 4°C (7°F) may result from these processes. Because these intermittent processes are driven primarily by large-scale horizontal wind flow and radiational cooling of the surface, ridge-and-valley terrain significantly affects the intensity of these oscillations.

B.7. References

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