Appendix C. Climate Overview for the Oak Ridge Area

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C.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 to the level of evapotranspiration that is normally experienced throughout the year. The "subtropical" nature of the local climate indicates that the region experiences a wide range of seasonal temperatures. Such areas typically experience significant changes in temperature between summer and winter.

Local winters are characterized by synoptic weather systems that often produce significant precipitation events 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 occur. Winter cloud cover tends to be enhanced by the regional terrain (cold air wedging).

Severe thunderstorms are the most frequent during spring but can occur at any time during the year. The Cumberland Mountains and the Cumberland Plateau often inhibit the intensity of severe systems that traverse the region (due to the downward momentum created as the storms move off of the 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 tornados). 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 adequate precipitation usually occurs during the fall, the months of August through October represent the driest period of the year. The occurrence of precipitation during the fall tends to be less cyclic than during other seasons but is occasionally enhanced by decaying tropical systems moving north from the Gulf of Mexico. During November, winter-type cyclones again begin to dominate the weather and continue to do so until May.

Decadal-scale climate change has recently affected the East Tennessee region. Most of these changes appear to be related to the hemispheric effects caused by the El Niño–Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO). The ENSO and PDO patterns, having cycles of 3 to 7 years and about 40 years, respectively, affect Pacific Ocean sea surface temperatures. The AMO affects Atlantic sea surface temperature (again, having a cycle of about 10–30 years. All of these patterns can collectively modulate regional temperature and precipitation trends with respect to East Tennessee (especially the AMO). The AMO shifted from a cold to warm sea surface temperature phase (mid-1990s) but may be shifting back to a cool phase as of 2009. The PDO appears to have entered a cool sea surface temperature phase since about 2000. Also, the ENSO pattern has more frequently brought about warmer Eastern Pacific sea surface temperatures in the last couple of decades. Additionally, some evidence exists that human-induced climate change may be producing some effects (via land cover change, soot and aerosols, and to a lesser extent, greenhouse gases). Largely due to the effects of the AMO and ENSO, Oak Ridge climate warmed about 1.2ºC (34ºF) during the 1990s but has stabilized near the 1990s values since then (little warming has occurred since 2000). The recent warming appears to have lengthened the growing season [i.e., the period with temperatures above 0ºC (32ºF)] by about 2 to 3 weeks over the last 30 years.

C.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 thermal circulations, and mountain-valley circulations. Pressure-driven channeling and vertically coupled flow (unstably stratified conditions) affect wind flow on scales comparable to that of the Great Valley (hundreds of kilometers). Forced channeling occurs on similar scales but is also quite important at smaller spatial scales, such as that of the local ridge-and-valley (Birdwell 1996). Along-valley and mountain-valley circulations are thermally driven and occur within a large range of spatial scales. Thermal flows are more prevalent under conditions of clear skies and low humidity.

Pressure-driven channeling, in its simplest essence, is the redirection of synoptically induced wind flow through a valley channel. The direction of wind flow through the valley is determined by the pressure gradient superimposed on the valley's 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 such a process shift from up-valley to down-valley flow or conversely as "weather"-induced flow shifts across the axis of the Great Valley. Since the processes involved in pressure-driven flow primarily affect the horizontal motion of air, the presence of a temperature inversion enhances flow significantly. Weak vertical air motion and momentum associated with such inversions allow different layers of air to slide over each other (Monti et al. 2002).

Forced channeling is defined as the direct deflection of wind by terrain. This form of channeling necessitates some degree of vertical motion transfer, implying that the mechanism is less pronounced during temperature-inversion conditions. Although forced channeling may result from interactions between large valleys and mountain ranges (such as the Great Valley and the surrounding mountains), the mechanism is especially important in narrow, small valleys such as those on the ORR (Kossman and Sturman 2002).

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. The phenomenon sometimes results in a split flow pattern (winds southwest of Knoxville moving down-valley and those to the 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 related to the specific location of the Cumberland and Smoky Mountains relative to upper level wind flow (Eckman 1998). The convex shape of the Great Valley with respect to a northwest wind flow may lead to a divergent wind flow pattern in the Knoxville area. This results in downward air motion. Additionally, horizontal flow is reduced by the windward mountain range (Cumberland Mountains), which increases buoyancy and Coriolis effects (Froude and Rossby ratios in the meteorological field). Consequently, the leeward mountain range (Smoky Mountains) becomes more effective at blocking or redirecting the winds.

Vertically coupled winds occur when the atmosphere is unstable (characterized by cooler temperatures aloft). When a strong horizontal wind component is also present (as in conditions behind a winter cold front or during strong cold air advection), winds "ignore" the terrain, flowing over it in roughly in the same direction as the winds aloft. This phenomenon is a consequence of the horizontal transport and momentum aloft being transferred to the surface. However, Coriolis effects may turn the winds by up to 25° to the left (Birdwell 1996).

Thermally driven winds are common in areas of significantly complex terrain. These winds occur as a result of pressure and temperature differences caused by varied surface-air energy exchange at similar altitudes along a valley's axis, sidewalls, and/or slopes. Thermal flows operate most effectively 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 air flow, depending on the ambient weather conditions. Eckman (1998) suggested that the presence of daytime up-valley winds and nighttime down-valley (drainage) flows between the ridge-and-valley terrain of the Oak Ridge area tended to reverse at about 9:00 to 11:00 a.m. and at about 5:00 to 7:00 p.m. local time, respectively. The terrain-following nature of drainage winds suggests that they would be more directly impacted by the presence of the ridge-and-valley than daytime flows, which tend to be accompanied by significant upward displacement.

Annual wind roses for each of the eight Oak Ridge Reservation meteorological towers during 2009 (Towers MT1, MT2, MT3, MT4, MT6, MT7, MT9, and MT10) have been compiled. These can be viewed online at http://www.ornl.gov/~das/web/RECWX7.HTM. The wind roses represent typical trends and should be used with caution.

A wind rose depicts the typical distribution of wind speed and direction for a given location. The winds are represented in terms of the direction from which they originate. The rays emanating from the center correspond to points of the compass. The length of each ray is related to the frequency that winds blow from that direction. The concentric circles represent increasing frequencies from the center outward, given in percent. Precipitation wind roses display similar information except that only hours during which precipitation fell were used. Precipitation events are defined as light [0.254 cm/h (< 0.10 in./h)], moderate [0.254–0.762 cm/h (0.10–0.30 in./h)], and heavy [0.762 cm/h (> 0.30 in./h)].

C.3 Temperature and Precipitation

Temperature and precipitation normals (1980–2009) and extremes (1948–2009) and their durations for the city of Oak Ridge are summarized in Table C.1. Decadal temperature and precipitation averages for the four decades from 1970 through 2009 are given in Table C.2. Hourly freeze data (1985–2009) are given in Table C.3.

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

Table C.2 presents a decadal analysis of temperature patterns over the last 40 years. In general, temperatures in Oak Ridge rose in the 1990s but have leveled off during the 2000s. Based on average decadal temperatures, temperatures have risen 2.5ºF or 1.4ºC between the decades of the 1970s and the 2000s from 13.7 to 15.2ºC (56.8 to 59.3ºF). More detailed analysis reveals that the temperature increases have been neither linear nor equal throughout the months or seasons.

January and February average temperatures have seen increases of 2.1ºC (3.8ºF) and 1.9ºC (3.5ºF), respectively. This significant increase is probably dominated by the effects of the Atlantic Multidecadal Oscillation (AMO). Also, the Arctic has seen the largest increase in temperatures of anywhere in the Northern Hemisphere over the last 30 years. During the months of January and February, much of the air entering eastern Tennessee comes from the Arctic. As a result of these factors, Oak Ridge temperatures have warmed more dramatically during these months. Spring temperatures (March–April) have risen by about 1.4ºC (2.5ºF). Summer and fall temperatures exhibit temperature rises of 1.6ºC (2.8ºF) and 1.4ºC (2.5ºF), respectively. December temperatures changed the least +0.1ºC (+0.2ºF). Most of these average increases were driven by significant increases in minimum daily temperatures. Overall, annual minimum temperatures seem to have increased more dramatically by 1.7ºC (3.1ºF) than maximum temperatures (by 1ºC (1.9ºF). For the most recent decade (2000s), August average temperatures are now warmer than those of July.

Decadal precipitation averages suggest some important changes in precipitation patterns in Oak Ridge over the period of the 1970s to 2000s. Although overall precipitation has remained within a window of about 48 to 56 in. annually, there have been some recent decadal shifts in the patterns of rainfall on a monthly or seasonal scale. In particular, precipitation has tended to increase during the late winter and early spring (February through April) by about 2.54 cm/month (1 in./month). Conversely, the late summer and early fall months (August through October) have seen slight decreases in precipitation [about 1.27 cm/month (0.50 in./month)]. However, 2009 has been a notable exception to this trend. Overall, annual precipitation during the 2000s is consistent with the 30-year average [around 132 cm (52 in.)]. The year 2007 was the driest year on record in Oak Ridge [91.1 cm (35.87 in.)], which was the heart of a 4-year period of below average precipitation (2005–2008). The year 2009 had precipitation that was more than 17% above normal. These statistics encompass the period from 1948 to 2009.

The previously discussed increase in winter temperatures apparently affected monthly and annual snowfall amounts until recently. During the 1970s and 1980s, snowfall averaged about 25.4–28 cm (10–11 in.) annually in Oak Ridge. However, during the most recent decade (2000s), snowfall has averaged only 6.6 cm (2.6 in). This decrease seems to have occurred largely since the mid-1990s. Snowfall during 2008 totaled only 2.0 cm (0.8 in). However, snowfall during 2009 began to increase again with a total of 10.2 cm (4.0 in.).

Wind roses for Tower MT2 (“C”) during light, moderate, heavy, and all precipitation events (during the decade of 1998 to 2007) have been compiled. These may be viewed online at http://www.ornl.gov/~das/web/RECWX7.HTM. The precipitation classes are defined by the National Weather Service as follows:

- light: trace to 0.254 cm/h (0.10 in./h)
- moderate: 0.28 to 0.762 cm/h (0.11 to 0.30 in./h)
- heavy: more than 0.762 cm/h (0.30 in./h)

Table C.1. Climate normals (1980–2009) and extremes (1948–2009) for Oak Ridge, Tennessee (Town Site), with 2009 comparisons

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Temperature, °C (°F)													
30-Year Average Max	8.3 (47.0)	11.2 (52.2)	16.4 (61.5)	21.4 (70.6)	25.8 (78.5)	29.8 (85.6)	31.5 (88.7)	31.2 (88.1)	27.7 (81.9)	21.9 (71.4)	15.6 (60.1)	9.6 (49.3)	20.9 (69.6)
2009 Average Max	7.4 (45.3)	11.2 (52.1)	16.4 (61.6)	21.4 (70.6)	25.1 (77.1)	30.7 (87.2)	29.3 (84.8)	30.0 (86.0)	26.2 (79.2)	19.2 (66.6)	16.7 (62.0)	8.4 (47.2)	20.2 (68.3)
62-Year Record Max	25 (77)	26 (79)	30 (86)	33 (92)	34 (93)	38 (101)	41 (105)	39 (103)	39 (102)	32 (90)	28 (83)	26 (78)	41 (105)
30-Year Average Min	-2.2 (28.1)	-0.7 (30.8)	3.0 (37.4)	6.7 (44.1)	12.5 (54.5)	17.1 (62.8)	19.6 (67.3)	19.1 (66.4)	15.2 (59.4)	8.4 (47.1)	3.1 (37.5)	-0.9 (30.4)	8.4 (47.2)
2009 Average Min	-2.7 (27.1)	0.0 (32.0)	4.8 (40.6)	7.9 (46.3)	14.3 (57.8)	18.9 (66.1)	18.5 (65.3)	19.3 (66.8)	17.9 (64.3)	9.2 (48.5)	4.3 (39.7)	0.0 (32.0)	9.4 (48.9)
62-Year Record Min	-27 (-17)	-25 (-13)	-17 (1)	-7 (20)	-1 (30)	4 (39)	9 (49)	10 (50)	1 (33)	-6 (21)	-18 (0)	-22 (-7)	-27 (-17)
30-Year Average	3.1 (37.6)	5.3 (41.5)	9.7 (49.5)	14.4 (58.0)	19.2 (66.5)	23.5 (74.3)	25.6 (78.0)	25.2 (77.3)	21.5 (70.7)	15.2 (59.3)	9.3 (48.8)	4.4 (39.9)	14.7 (58.5)
2009 Average	2.9 (37.2)	6.2 (43.1)	10.6 (51.1)	14.9 (58.8)	19.7 (67.5)	24.9 (76.9)	23.9 (75.1)	24.7 (76.4)	22.1 (71.8)	14.2 (57.6)	10.5 (50.9)	4.2 (39.6)	14.9 (58.8)
2009Dep from Average	-0.2 (-0.4)	0.9 (1.6)	0.9 (1.6)	0.4 (0.8)	0.6 (1.0)	1.4 (2.6)	-1.6 (-2.9)	-0.5 (-0.9)	0.6 (1.1)	-0.9 (-1.7)	1.2 (2.1)	-0.2 (-0.3)	0.2 (0.4)
30-year average heating degree days, °C (°F)[a]													
	468 (842)	366 (659)	267 (480)	128 (231)	36 (65)	2 (3)	0	0	14 (25)	113 (204)	268 (482)	429 (773)	2091 (3763)
30-year average cooling degree days, °C (°F)[a]													
	0	0	2 (4)	15 (28)	66 (118)	161 (290)	228 (410)	215 (387)	108 (195)	18 (32)	1 (2)	0	815 (1466)
Precipitation, mm (in.)													
30-Year Average	119.7 (4.71)	122.5 (4.82)	115.6 (4.55)	113.1 (4.45)	114.1 (4.49)	96.3 (3.79)	131.4 (5.17)	81.6 (3.21)	96.6 (3.80)	71.1 (2.80)	119.7 (4.71)	131.1 (5.16)	1313 (51.66)
2009	148.4 (5.48)	87.1 (3.43)	110.3 (4.34)	96.0 (3.78)	147.6 (5.81)	149.1 (5.87)	150.4 (5.92)	116.1 (4.57)	139.2 (5.48)	146.9 (5.78)	66.6 (2.62)	207.6 (8.17)	1565.4 (61.61)
2009 Dep from Average	28.7 (1.13)	-35.3 (-1.39)	-5.3 (-0.21)	-17.0 (-0.67)	33.5 (1.32)	52.8 (2.08)	19.1 (0.75)	34.6 (1.36)	42.7 (1.68)	75.7 (2.98)	-53.1 (-2.09)	76.5 (3.01)	252.8 (9.95)
62-Year Max Monthly	337.2 (13.27)	324.7 (12.78)	311.0 (12.24)	356.5 (14.03)	271.9 (10.70)	283.0 (11.14)	489.6 (19.27)	265.8 (10.46)	176.6 (6.95)	176.6 (6.95)	310.5 (12.22)	321.2 (12.64)	1939 (76.33)
62-Year Max 24-hr	108.0 (4.25)	131.6 (5.18)	120.4 (4.74)	158.5 (6.24)	112.0 (4.41)	94.0 (3.70)	124.8 (4.91)	190.1 (7.48)	129.8 (5.11)	67.6 (2.66)	130.1 (5.12)	130.1 (5.12)	190.1 (7.48)
62-Year Min Monthly	23.6 (0.93)	21.3 (0.84)	54.1 (2.13)	22.4 (0.88)	20.3 (0.80)	13.5 (0.53)	31.3 (1.23)	13.7 (0.54)	Trace	Trace	34.8 (1.37)	17.0 (0.67)	911.4 (35.87)
Snowfall, mm (in.)													
30-Year Average	68.6 (2.7)	71.1 (2.8)	27.9 (1.1)	7.6 (0.3)	0	0	0	0	0	0	Trace	38.1 (1.5)	213.4 (8.4)
2009 Totals	25.4 (1.0)	25.4 (1.0)	0	Trace	0	0	0	0	0	0	0	50.8 (2.0)	101.6 (4.0)
62-Year Max Monthly	243.9 (9.6)	437.0 (17.2)	533.6 (21.0)	149.9 (5.9)	Trace	0	0	0	0	Trace	165.2 (6.5)	533.6 (21.0)	1052 (41.4)
62-Year Max 24-hr	210.9 (8.3)	287.1 (11.3)	304.9 (12.0)	137.2 (5.4)	Trace	0	0	0	0	Trace	165.2 (6.5)	304.9 (12.0)	304.9 (12.0)
Days w/Temp													
30-Year Max ≥ 32C	0	0	0	0.2	0.8	7.7	14.7	13.3	4.2	0	0	0	40.9
2009 Max ≥ 32 C	0	0	0	0	0	7	1	7	0	0	0	0	15
30-Year Min ≤ 0C	21.5	16.7	10.9	2.8	0	0	0	0	0	1.8	10.5	18.8	83.0
2009 Min ≤ 0C	21	16	7	1	0	0	0	0	0	0	3	9	64
30-Year Max ≤ C	2.6	0.9	0.2	0	0	0	0	0	0	0	0	1.5	5.2
2009 Max ≤ 0C	2	1	0	0	0	0	0	0	0	0	0	0	3
Days w/Precipitation													
30-Year Avg ≥ 0.01 in.	11.5	11.0	11.9	10.6	11.7	10.9	12.3	9.6	8.5	8.4	9.6	11.7	127.7
2009 Days ≥ 0.01 in.	12	10	12	12	18	12	13	12	17	14	6	11	149
30-Year Avg ≥ 1.00 in.	1.3	1.4	1.2	1.2	1.2	1.0	1.4	0.8	1.3	0.9	1.5	1.6	14.8
2009 Days ≥ 1.00 in.	1	1	1	2	1	1	1	1	1	1	1	3	15

Table C.2. Decadal climate change (1970–2009) for Oak Ridge, Tennessee (Town Site) with 2009 comparisons

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Temperature, °C (°F)													
1970-1979 Avg Max	6.6 (43.8)	9.7 (49.5)	15.6 (60.1)	21.4 (70.6)	24.8 (76.7)	28.5 (83.3)	30.0 (85.9)	29.7 (85.5)	26.8 (80.2)	20.8 (69.4)	14.5 (58.2)	10.0 (49.9)	19.9 (67.8)
1980-1989 Avg Max	6.9 (44.4)	10.2 (50.3)	15.9 (60.7)	21.0 (69.8)	25.6 (78.1)	29.8 (85.7)	31.6 (88.8)	30.7 (87.3)	27.1 (80.8)	21.3 (70.3)	15.6 (60.2)	8.6 (47.5)	20.3 (68.6)
1990-1999 Avg Max	9.4 (48.8)	12.3 (54.1)	16.2 (61.2)	21.9 (71.3)	26.2 (79.1)	29.7 (85.5)	32.1 (89.8)	31.4 (88.6)	28.4 (83.2)	22.6 (72.8)	15.2 (59.4)	10.4 (50.8)	21.3 (70.4)
2000-2009 Avg Max	8.8 (47.9)	11.2 (52.1)	17.0 (62.7)	21.4 (70.6)	25.8 (78.4)	29.8 (85.6)	30.8 (87.5)	31.4 (88.5)	27.6 (81.8)	21.8 (71.2)	15.9 (60.6)	9.8 (49.6)	21.0 (69.7)
Change (70s vs. 00s)	2.2 (5.1)	1.5 (2.6)	1.4 (2.6)	0.0 (0.0)	1.0 (1.7)	1.3 (2.3)	0.8 (1.6)	1.4 (2.5)	0.8 (1.6)	1.0 (1.8)	1.4 (2.4)	-0.2 (-0.3)	1.1 (1.9)
2009 Avg Max	7.4 (45.3)	12.4 (54.4)	16.4 (61.6)	21.4 (70.6)	25.1 (77.1)	30.7 (87.2)	29.3 (84.8)	30.0 (86.0)	26.2 (79.2)	19.2 (66.6)	16.7 (62.0)	8.4 (47.2)	20.2 (68.3)
1970-1979 Avg Min	-3.4 (25.8)	-2.4 (27.6)	3.0 (37.4)	6.7 (44.1)	11.6 (52.8)	15.7 (60.2)	18.3 (64.9)	18.1 (64.6)	15.5 (59.9)	7.5 (45.5)	2.6 (36.8)	-0.8 (30.5)	7.7 (45.8)
1980-1989 Avg Min	-4.1 (24.7)	-2.1 (28.3)	1.7 (35.0)	6.0 (42.9)	11.4 (52.4)	16.2 (61.2)	19.0 (66.2)	18.4 (65.1)	14.4 (57.9)	7.5 (45.4)	3.1 (37.5)	-2.3 (27.8)	7.4 (45.3)
1990-1999 Avg Min	-0.9 (30.3)	0.0 (32.0)	2.9 (37.1)	7.2 (45.0)	12.5 (54.5)	17.2 (63.0)	20.0 (67.9)	18.9 (66.1)	15.1 (59.2)	8.2 (46.8)	2.2 (36.0)	0.1 (32.2)	8.6 (47.6)
2000-2009 Avg Min	-1.4 (29.5)	0.0 (32.0)	4.4 (39.9)	8.6 (47.5)	13.6 (56.4)	18.0 (64.3)	20.0 (67.9)	20.0 (68.0)	16.1 (61.0)	9.5 (49.0)	3.9 (39.0)	-0.4 (31.4)	9.4 (48.9)
Change (70s vs. 00s)	2.0 (3.7)	2.4 (4.4)	1.4 (2.5)	1.9 (3.4)	2.0 (3.6)	2.3 (4.1)	1.7 (3.0)	1.9 (3.4)	0.6 (1.1)	2.0 (3.5)	1.3 (2.2)	0.4 (0.9)	1.7 (3.1)
2009 Avg Min	-2.7 (27.1)	-0.4 (31.3)	4.8 (40.6)	7.9 (46.3)	14.3 (57.8)	18.9 (66.1)	18.5 (65.3)	19.3 (66.8)	17.9 (64.3)	9.2 (48.5)	4.3 (39.7)	0.0 (32.0)	9.7 (49.5)
1970-1979 Avg	1.6 (34.9)	3.7 (38.6)	9.3 (48.8)	14.1 (57.4)	18.1 (64.7)	22.1 (71.8)	24.1 (75.4)	23.9 (75.0)	21.1 (70.0)	14.2 (57.5)	8.6 (47.5)	4.6 (40.3)	13.8 (56.8)
1980-1989 Avg	1.4 (34.6)	4.1 (39.3)	8.8 (47.9)	13.5 (56.4)	18.5 (65.3)	23.0 (73.4)	25.3 (77.5)	24.6 (76.2)	20.8 (69.4)	14.4 (57.9)	9.4 (48.8)	3.1 (37.7)	13.9 (57.0)
1990-1999 Avg	4.2 (39.6)	6.2 (43.1)	9.6 (49.2)	14.5 (58.2)	19.4 (66.8)	23.5 (74.3)	26.0 (78.9)	25.2 (77.4)	21.9 (71.4)	15.5 (59.8)	8.8 (47.8)	5.3 (41.5)	15.0 (59.0)
2000-2009 Avg	3.7 (38.7)	5.6 (42.1)	10.7 (51.3)	15.3 (59.6)	19.7 (67.5)	23.9 (75.1)	25.4 (77.7)	25.7 (78.3)	21.9 (71.4)	15.6 (60.1)	9.9 (49.8)	4.7 (40.5)	15.2 (59.3)
Change (70s vs. 00s)	2.1 (3.8)	1.9 (3.5)	1.4 (2.5)	1.2 (2.2)	1.6 (2.8)	1.8 (3.3)	1.3 (2.3)	1.8 (3.3)	0.8 (1.4)	1.4 (2.6)	1.3 (2.3)	0.1 (0.2)	1.4 (2.5)
2009 Avg	1.2 (34.1)	6.1 (42.9)	10.6 (51.1)	14.9 (58.8)	19.7 (67.5)	24.9 (76.9)	23.9 (75.1)	24.7 (76.4)	22.1 (71.8)	14.2 (57.6)	10.5 (50.9)	4.2 (39.6)	14.8 (58.6)
Precipitation, mm (in.)													
1970-1979 Avg	143.4 (5.65)	94.6 (3.72)	169.4 (6.67)	118.3 (4.66)	149.8 (5.89)	120.5 (4.74)	130.4 (5.13)	109.8 (4.32)	107.2 (4.22)	99.8 (3.93)	129.6 (5.10)	145.3 (5.72)	1516.4 (59.68)
1980-1989 Avg	100.4 (3.95)	109.1 (4.29)	112.6 (4.43)	88.8 (3.49)	110.6 (4.35)	84.1 (3.31)	120.4 (4.74)	82.6 (3.25)	108.9 (4.29)	79.8 (3.14)	128.0 (5.04)	107.6 (4.23)	1236.2 (48.66)
1990-1999 Avg	141.4 (5.57)	136.5 (5.37)	149.0 (5.86)	126.3 (4.97)	113.4 (4.47)	110.0 (4.33)	134.8 (5.31)	83.6 (3.29)	71.9 (2.83)	67.3 (2.65)	109.8 (4.32)	161.0 (6.34)	1429.4 (56.26)
2000-2009 Avg	116.9 (4.60)	121.8 (4.80)	115.6 (4.55)	125.0 (4.92)	117.8 (4.64)	95.2 (3.75)	138.9 (5.47)	78.4 (3.09)	108.8 (4.28)	74.0 (2.91)	121.4 (4.78)	124.4 (4.90)	1333.4 (52.48)
Change (70s vs. 00s)	-26.5 (-1.04)	27.2 (1.07)	-43.8 (-1.72)	6.7 (0.26)	-32.0 (-1.26)	-25.3 (-1.00)	8.5 (0.33)	-31.4 (-1.24)	1.6 (0.06)	-25.8 (-1.02)	-8.2 (-0.32)	-20.9 (-0.82)	-183.0 (-7.20)
2009 Totals	148.4 (5.84)	87.1 (3.43)	110.3 (4.34)	96.0 (3.78)	147.6 (5.81)	149.1 (5.87)	150.4 (5.92)	116.1 (4.57)	139.2 (5.48)	146.9 (5.78)	66.6 (2.62)	207.6 (8.17)	1565.4 (61.61)
Snowfall, cm (in.)													
1970-1979 Avg	11.1 (4.4)	12.5 (4.9)	4.2 (1.7)	0.2 (0.1)	0	0	0	0	0	0	0.5 (0.2)	4.4 (1.8)	351 (13.8)
1980-1989 Avg	11.3 (4.5)	8.8 (3.5)	2.2 (0.9)	2.2 (0.9)	0	0	0	0	0	0	0	7.5 (3.0)	328 (12.9)
1990-1999 Avg	6.8 (2.7)	7.8 (3.1)	8.1 (3.2)	Trace	0	0	0	0	0	0	0.3 (0.1)	3.1 (1.2)	109 (4.3)
2000-2009 Avg	2.1 (0.8)	4.5 (1.8)	Trace	Trace	0	0	0	0	0	0	Trace	1.7 (0.7)	-242 (-9.5)
Change (70s vs. 00s)	-9.0 (-3.6)	-8.0 (-3.1)	-4.2 (-1.7)	-0.2 (-0.1)	0	0	0	0	0	0	-0.5 (-0.2)	-2.7 (-1.1)	
2009 Totals	2.5 (1.0)	1.0 (0.4)	0	Trace	0	0	0	0	0	0	0	5.1 (2.0)	20.3 (0.8)

Table C.3. Hourly Sub-freezing Temperature Data for Oak Ridge, Tennessee, 1985–2009

Number of hours at or below 0, -5, -10, and -15 (°C)[a]

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	1399	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	1190	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	1029	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
Avg.	239	73	16	3	155	38	7	1	68	7	1	12	0	0	0	8	0	69	4	0	203	46	7	1	755	168	31	5

[a]Source: 1985–2009 National Oceanic and Atmospheric Administration Atmospheric Turbulence and Diffusion Division KOQT Station, Automated Surface Observing System.

The meteorological record from Tower C was used because it is centrally located within the ORR.

Hourly values of subfreezing temperatures in Oak Ridge are presented in Table C.3 for the years 1985 through 2009. During the mid-to-late 1980s, a typical year experienced about 900 to 1000 h of subfreezing temperatures. In recent years, the value has fallen to approximately 500–700 h.

C.4 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 air flow. Although ridge-and-valley terrain creates identifiable patterns of association during unstable conditions as well, strong vertical mixing and momentum tend to significantly reduce these effects. "Stability" describes the tendency of the atmosphere to mix 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 local terrain's effect 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 true with respect to mountain waves. Deep stable layers of air tend to reduce the vertical space available for oscillating vertical air motions caused by local mountain ranges (Smith et al. 2002). This effect on mountain wave formation may be important with regard the impact that the nearby Cumberland Mountains may have on local air flow.

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 due to direct insolation on the cloud tops. Warming may also occur within the clouds as latent energy (which is released due to the condensation of moisture). Surface air underlying the clouds may remain relatively cool (as it is 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 cooling of fog decks has also been observed to help modify stability in the surface layer (Whiteman et al. 2001).

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 is in turn influenced by the synoptic-scale "weather"-related pressure gradient). Ridge-and-valley terrain may have a significant ability to block such winds and their associated mechanical energy (Carlson and Stull 1986). Consequently, enhanced radiational cooling at the surface results since there is less wind energy available to remove chilled air.

Stable boundary layers also exhibit intermittent turbulence that has been associated with a number of the above factors. The process results from "give-and-take" between the effects of friction and radiational cooling. As a stable surface layer intensifies via a radiation 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 results in an increase in 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 winds 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 (7.2ºF) may result from these processes. Since these intermittent processes are driven primarily by large-scale horizontal wind flow and radiational cooling of the surface, ridge-and-valley terrain significantly affects these oscillations.

Wind roses for ORNL Tower MT2 at 30 m (98.4 ft) with respect to Stability A through G during 2009 have been compiled and may be viewed at http://www.ornl.gov/~das/web/RECWX7.HTM. Stability A (unstable) conditions show a strong preference for winds from the south half of the compass. Stability D conditions (neutral), which also tend to correspond to higher wind speed, show a significant preference for winds from the west and west-northwest. During very stable conditions (F and G stability), winds shows a preference for east north east directions (likely down valley "cold air" drainage flow).

C.5 References

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