Appendix B. Climate Overview for the Oak Ridge Area

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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 Oak Ridge Reservation (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), 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 night time 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. 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 vertical motions.

Figures B.1, B.2, and B.3 are wind roses for data obtained during 2005 at ORNL Meteorological Tower C, at 10, 30, and 100 m above ground level, respectively. 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.

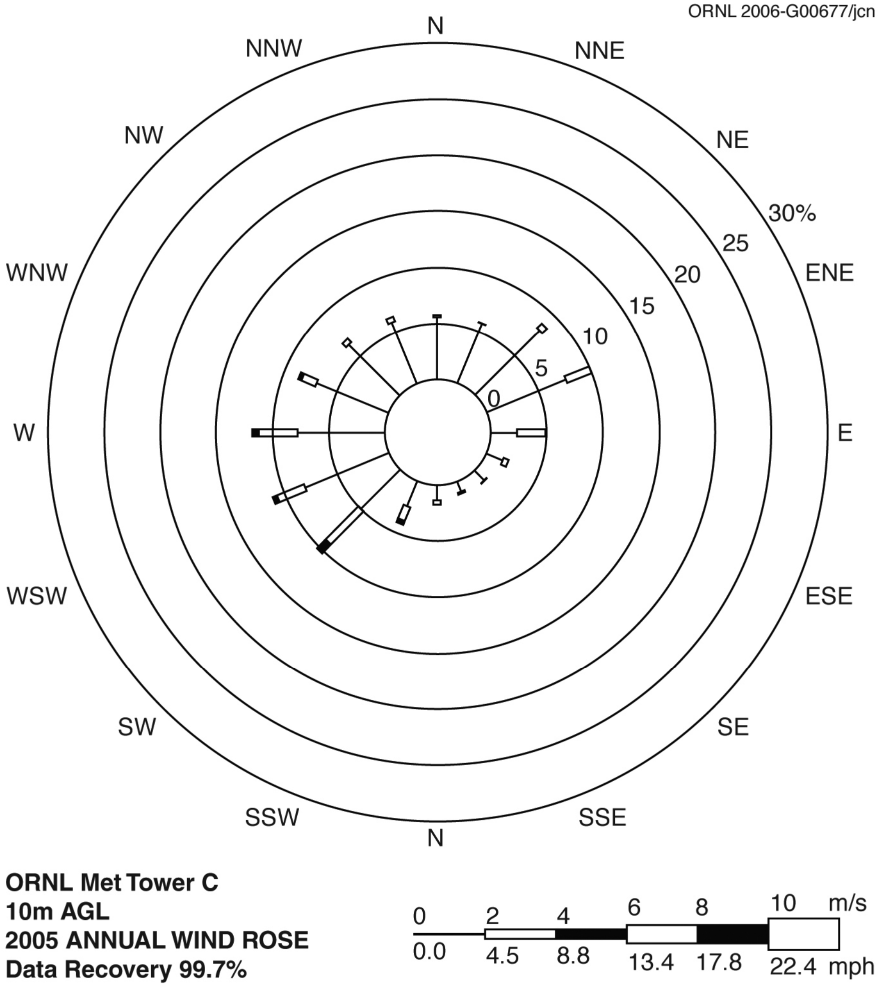

Fig. B.1. Wind rose for ORNL Meteorological Tower C for data taken at 10 m above ground level, 2005.

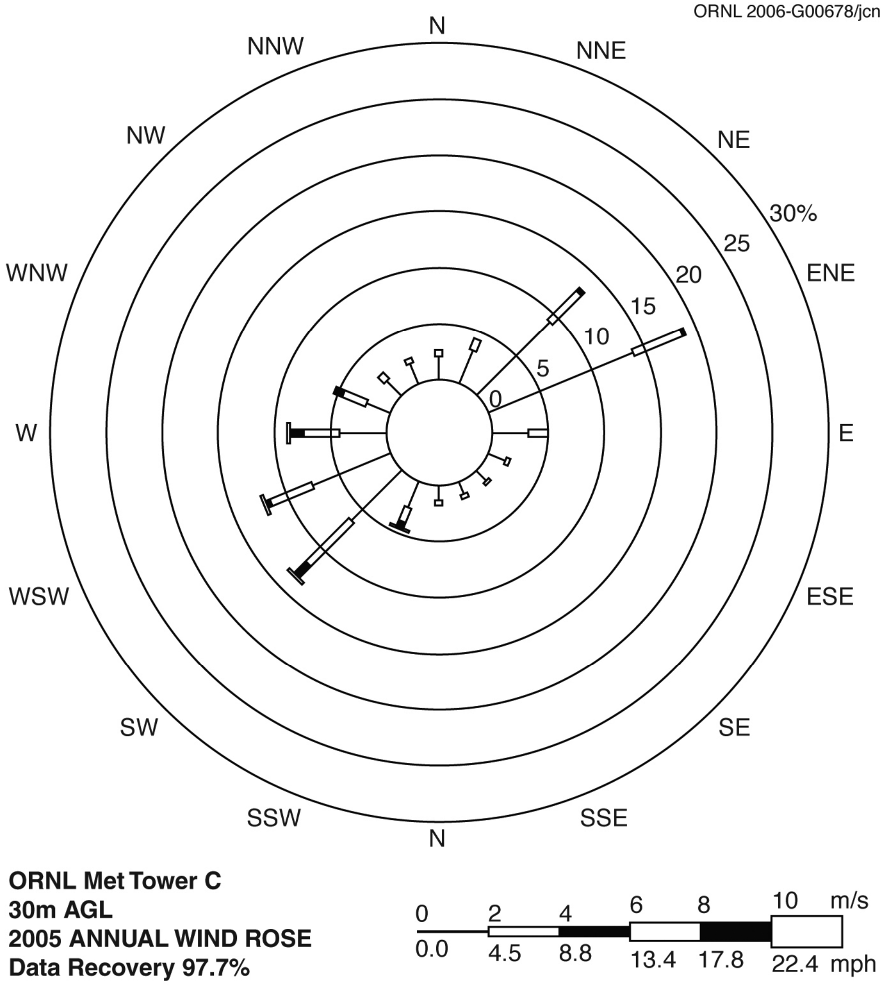

Fig. B.2. Wind rose for ORNL Meteorological Tower C for data taken at 30 m above ground level, 2005.

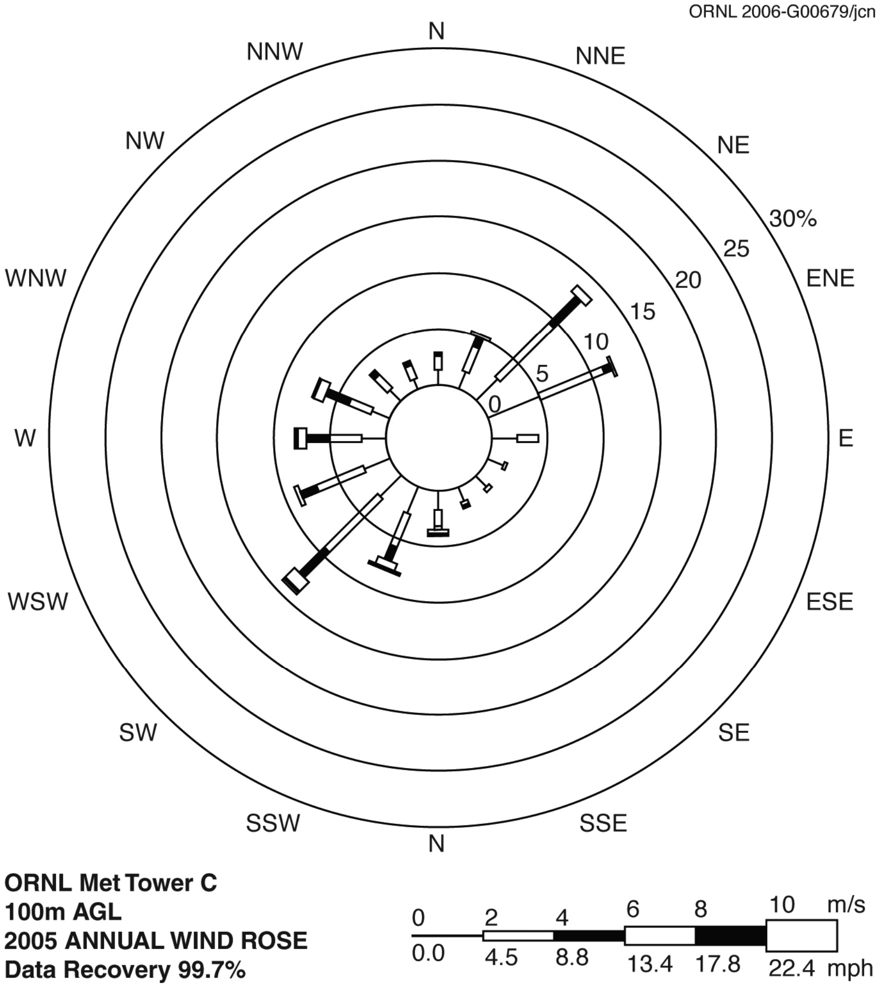

Fig. B.3. Wind rose for ORNL Meteorological Tower C for data taken at 100 m above ground level, 2005.

Temperature and Precipitation

Temperature and precipitation normals (1975–2005) and extremes (1948–2005), and their durations are summarized for the city of Oak Ridge in Table B.1. Hourly freeze data (1985–2005) are given in Table B.2.

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. (see Table B.3). 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). The “D” stability class represents a neutral state. (see Table B.4).

The suppression of vertical motions during stable conditions increases the frequency with which air motion is impacted by the local terrain. 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 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 a 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 large-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 a “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 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.

Table B.1. Climate normals (1776–2005) and extremes (1948–2005) for Oak Ridge, Tennessee (Town Site) with 2005 comparisons

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Temperature, °C (°F)													
30-year average max	7.5 (45.5)	11.0 (51.8)	16.3 (61.4)	21.7 (71.0)	25.7 (78.2)	29.5 (85.1)	31.3 (88.4)	30.9 (87.6)	27.5 (81.5)	22.7 (72.9)	15.4 (59.7)	9.3 (48.7)	20.7 (69.3)
2005 average max	10.6 (51.1)	11.9 (53.4)	15.4 (59.7)	20.9 (69.7)	24.7 (76.4)	29.4 (84.9)	30.3 (86.6)	31.7 (89.1)	30.5 (86.9)	22.4 (72.3)	16.8 (62.2)	7.7 (45.9)	21.0 (69.9)
58-year record max	24 (76)	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	-2.9 (26.7)	-1.1 (30.1)	2.9 (37.2)	6.9 (44.5)	12.1 (53.8)	16.8 (62.3)	19.4 (66.9)	18.9 (66.0)	14.9 (58.9)	8.1 (46.5)	3.1 (37.6)	-1.4 (29.4)	8.1 (46.7)
2005 average min	0.8 (33.5)	1.7 (35.1)	2.6 (36.7)	8.2 (46.8)	10.9 (51.6)	18.6 (65.4)	21.2 (70.1)	20.9 (69.6)	16.1 (61.0)	9.7 (49.5)	3.6 (38.5)	-1.6 (29.1)	9.4 (48.9)
58-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	1.4 (34.6)	4.0 (39.2)	9.0 (48.2)	14.8 (58.6)	18.5 (65.3)	22.7 (72.8)	24.6 (76.2)	24.8 (76.6)	21.2 (70.2)	14.8 (58.7)	8.8 (47.9)	3.9 (39.0)	14.0 (57.3)
2005 average	5.7 (42.3)	6.8 (44.3)	9.0 (48.2)	14.8 (58.7)	17.8 (64.0)	24.0 (75.2)	25.8 (78.4)	26.3 (79.4)	23.3 (74.0)	16.1 (60.9)	10.2 (50.4)	3.1 (37.5)	15.2 (59.4)
2005 departure from average	4.3 (7.7)	2.8 (5.1)	0	0.1 (0.1)	-0.7 (-1.3)	1.3 (2.4)	1.2 (2.2)	1.6 (2.8)	2.1 (3.8)	1.2 (2.2)	1.4 (2.5)	-0.8 (-1.5)	1.2 (2.2)
30-year average heating degree days, °C (°F)[a]													
	497 (895)	378 (681)	279 (502)	133 (239)	43 (77)	3 (5)	0	0	16 (28)	126 (226)	278 (500)	442 (796)	2194 (3949)
30-year average cooling degree days, °C (°F)[a]													
	0	0	1 (2)	12 (22)	58 (105)	147 (264)	218 (393)	200 (360)	103 (185)	14 (26)	1 (2)	0	755 (1359)
Precipitation, mm (in.)													
30-year average	122.2 (4.81)	121.7 (4.79)	129.8 (5.11)	111.5 (4.39)	122.5 (4.82)	118.1 (4.65)	138.0 (5.43)	86.1 (3.39)	99.6 (3.92)	71.9 (2.83)	125.3 (4.93)	127.5 (5.02)	1374.3 (54.09)
2005	125.5(4.94)	102.9 (4.05)	75.2 (2.96)	159.6 (6.28)	81.1 (3.19)	101.9 (4.01)	193.1 (7.60)	35.6 (1.40)	47.3 (1.86)	46.0 (1.81)	104.4 (4.11)	73.7 (2.90)	1146.2 (45.11)
2005 departure from average	3.3 (0.13)	-18.8 (-0.74)	-54.6 (-2.15)	48.0 (1.89)	-41.4 (-1.63)	-16.3 (-0.64)	55.1 (2.17)	-50.6 (-1.99)	-52.3 (-2.06)	-25.9 (-1.02)	-20.8 (-0.82)	-53.9 (-2.12)	-228.2 (-8.98)
58-year record 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)	489.6 (19.27)
58-year record max 24-h	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)
58-year record 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)	13.5 (0.53)
Snowfall, mm (in.)													
30-year average	99.1 (3.9)	101.6 (4.0)	12.7 (0.5)	5.1 (0.2)	0	0	0	0	0	0	2.5 (0.1)	53.4 (2.1)	274.4 (10.8)
2005	25.4 (1.0)	Trace	Trace	Trace	0	0	0	0	0	0	0	0	25.4 (1.0)
58-year record 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)	533.6 (21.0)
58-year record 24-h	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)

Table B.1 (continued)

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Days, average, maximum, and minimum temperature													
30-year average max ≥ 32°C	0	0	0	0.1	0.9	5.1	14.5	11.7	3.8	0	0	0	36.1
2005 average max ≥ 32°c	0	0	0	0	0	4	10	18	6	0	0	0	38
30-year average min ≤ 0°C	22.7	17.2	12.1	2.8	0.1	0	0	0	0	2.2	11.4	20.3	88.8
2005 min ≤ 0°C	14	11	12	0	0	0	0	0	0	1	9	20	67
30-year average max ≤ 0°C	3.4	1.3	0.2	0	0	0	0	0	0	0	0.1	1.8	6.8
2005 max ≤ 0°C	3	0	0	0	0	0	0	0	0	0	0	0	3
Days, average, maximum, and minimum precipitation													
30-year average ≥ 0.01 in.	11.6	10.6	12.0	10.2	11.6	11.6	12.3	9.7	9.3	8.1	10	11.1	128.1
2005 ≥ 0.01 in.	12	13	11	13	6	12	18	9	4	5	10	11	124
30-year average ≥ 1.00 in.	1.3	1.2	1.5	0.8	1.5	1.4	1.5	0.8	1.3	0.8	1.4	1.4	14.9
2005 ≥ 1.00 in.	2	1	0	2	1	1	2	2	1	1	2	0	15

[a] Unit degrees, not absolute degrees.

Table B.2. Hourly freeze data for Oak Ridge, Tennessee, 1985–2005

Number of hours at or below a given temperature (°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
Avg.	249	77	17	4	149	37	8	1	72	8	1	13	0	0	0	8	0	73	4	0	216	49	8	2	781	176	34	6

[a] Source: 1985–2000 National Oceanic and Atmospheric Administration Atmospheric Turbulence and Diffusion Division KOQT Station, Automated Surface Observing System.

Table B.3. Hourly mixing height statistics for the Oak Ridge Reservation during 2005 (eastern standard time)

Hour	Average height (m)				
	Annual	Dec–Feb	Mar–May	Jun–Aug	Sep–Nov
0100	329	395	384	253	286
0200	324	374	369	262	290
0300	319	367	350	265	297
0400	323	355	363	284	289
0500	329	378	359	279	303
0600	336	390	366	289	299
0700	319	357	360	287	271
0800	344	365	416	295	299
0900	412	396	532	376	343
1000	595	482	786	675	435
1100	876	560	1113	1109	711
1200	1093	642	1338	1388	994
1300	1219	752	1533	1495	1085
1400	1366	820	1575	1816	1243
1500	1402	902	1667	1729	1297
1600	1420	933	1723	1696	1314
1700	1397	898	1789	1607	1283
1800	1155	669	1668	1419	849
1900	688	486	1128	830	299
2000	362	443	412	301	292
2100	332	418	383	238	290
2200	337	437	386	251	275
2300	337	398	365	275	262
2400	318	412	332	236	295
All	663.3	526.2	820.7	735.3	566.7

Table B.4. Stability distribution by hour of the day measured at ORNL Tower C, 2005 (local time)

Hour	Stability class[a]						
	A	B	C	D	E	F	G
1	0	0	0	28	45	187	105
2	0	0	0	24	54	192	95
3	0	0	0	21	55	202	87
4	0	0	0	21	56	207	81
5	0	0	0	19	55	214	77
6	0	0	0	23	47	218	77
7	0	0	0	24	49	229	63
8	0	0	0	365	0	0	0
9	0	108	9	248	0	0	0
10	0	191	55	119	0	0	0
11	19	168	103	75	0	0	0
12	75	134	91	65	0	0	0
13	96	134	82	53	0	0	0
14	91	137	85	52	0	0	0
15	71	137	101	56	0	0	0
16	47	134	99	85	0	0	0
17	0	0	0	175	182	8	0
18	0	0	0	121	209	35	0
19	0	0	0	78	184	99	4
20	0	0	0	39	121	191	14
21	0	0	0	36	73	210	46
22	0	0	0	32	55	187	91
23	0	0	0	29	57	173	106
24	0	0	0	23	53	186	103

[a] Stability classes range from “A” (very unstable) to “G” (very stable). The “D” stability class represents a neutral state.