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FREEZING AND THAWING DATES OF LAKES AND RIVERS AS PHENOLOGICAL INDICATORS

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[State College of Washington, Pullman, Wash., May 1942]

Phenology, the study of the progress of seasons, has an important place in investigations of wildlife, as in any other study of free-living organisms, but unfortunately, phenological data are few and rather fragmentary. During several years of study, I have gathered phenological material, such as the time of blooming of plants, freezing and thawing of lakes and rivers, and migration arrival and departure of birds. Scattered though it may be, there appears to be a wealth of such data and a concerted effort to gather it together would be desirable. Newspapers, for example, occasionally sponsor contests for guessing the moment when ice leaves rivers or harbors. Navigation records and travel journals, too, frequently contain valuable phenological information.

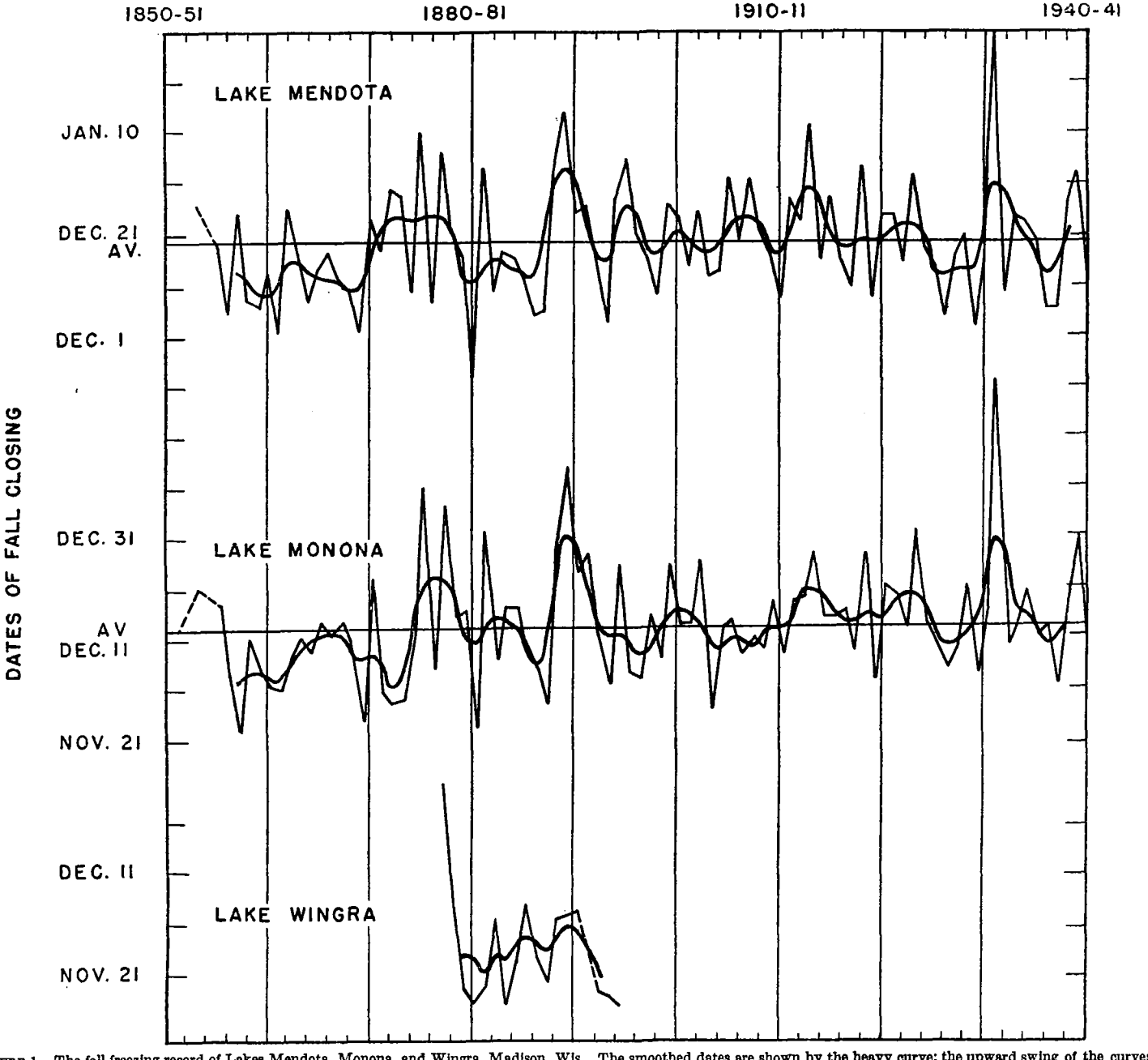

FIGURE 1.—The fall freezing record of Lakes Mendota, Monona, and Wingra, Madison, Wis. The smoothed dates are shown by the heavy curve; the upward swing of the curves indicates late freezing, and, therefore, a late fall.

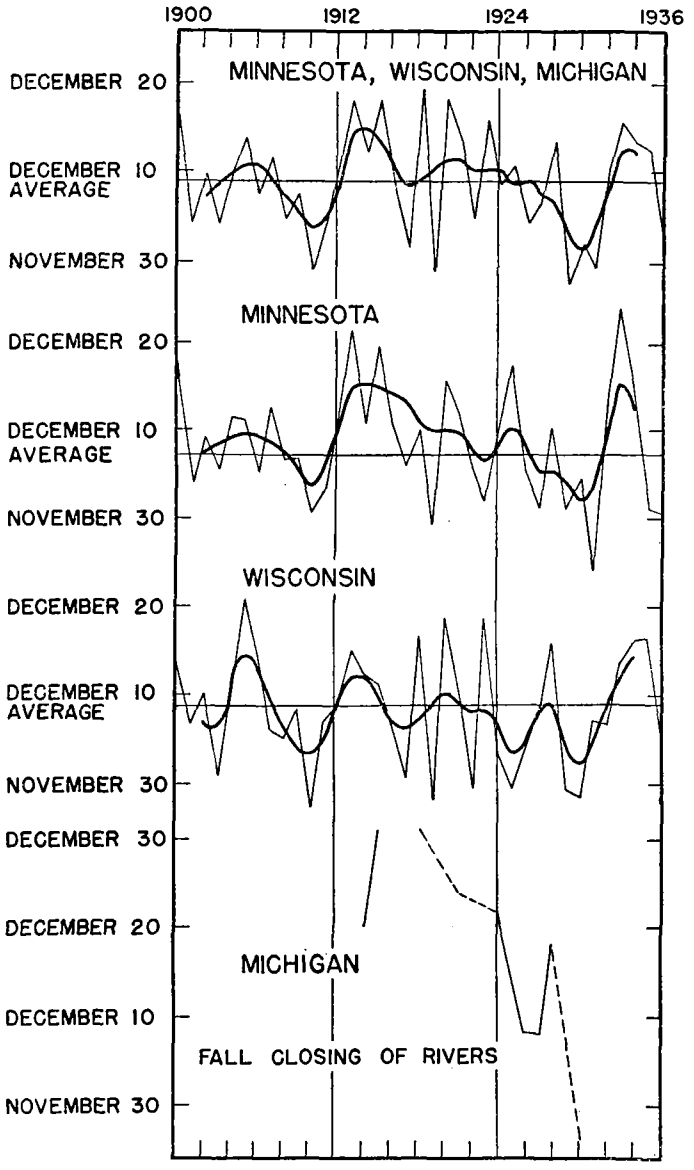

FIGURE 2.—The fall freezing record of rivers. The upper curve is the combined record of the rivers of Minnesota, Wisconsin, and Michigan

In many cases it appears that phenological data are better for some wildlife comparisons than temperature records themselves, as the influence of temperature is "integrated," so to speak. The effect of sudden cold spells is readily apparent and therefore well known. On the other hand, the effect of prolonged periods of adverse weather or even slightly unfavorable weather is less well known; yet it appears that prolonged periods of unfavorable weather may throw a considerable strain upon the physiology of animals.

Our literature is replete with comments on the effect of "early," "late," "cold," and "warm" falls and springs and of "open," "mild," "hard," and "long" winters. There appears to be no way of judging quantitatively what such terms mean, for the decision is generally bound up with human psychology. People are prone to remember times or temperatures that have been unfavorable or unpleasant.

Freezing and thawing dates of Lakes Monona and Mendota have been kept at the University of Wisconsin and the Madison weather station. The dates when ice left nearby Rock Lake at Lake Mills, were kept by Frank Foote from 1887 to 1915 and by Charles Kleist from 1916 to 1940. The thawing dates for Lake Geneva, Wis., were kept by Dr. Edwin Frost from 1900 to 1930. Records at Lake Wingra have been obtained from the Chase records.[1] The volumes of the DAILY RIVER STAGES have been combed for indications when rivers of Minnesota, Wisconsin and Michigan opened in the spring and closed in the fall. The data are not always usable because some observations began or ceased on fiscal or calendar dates, but these were generally recognizable as such. The data for the various river stations were averaged for each State (the number varying to 16 a year for any one State.)

Study of the various data indicates that the fall freeze-up is a good indicator of a late or early fall. The spring thaw, on the other hand, is a good indicator of late or early spring. In a like manner, the length of interval between a fall freeze and the following spring thaw indicates a long or short winter. The date of freezing and thawing is a function of temperature, not for any one day or even for several days, but for many days. Water has a high thermal capacity; hence, a protracted period is required in order to bring the water in condition for freezing or ice in condition for disappearing.

The data for freezing, thawing, and the number of days of closure for the several lakes and rivers used in this study are given in tables 1–8. Most of these data have not been published previously and, as far as I am aware, none in this form.

The fall closing data for Lakes Mendota, Monona, and Wingra at Madison, Wis., are graphed in figure 1. The three lakes differ greatly in size: Mendota covers 25 square miles, Monona is about a third the size of Mendota, and Wingra embraces some 400 acres. The fall closing of the rivers of Minnesota, Wisconsin, and Michigan is graphed in figure 2. It should be noted that the upward swing of the curves indicates warm falls. The early records of Mendota and Monona clearly show a long period much colder than the average which terminated in the early seventies. The years since have been characterized by warmer falls (later freezing) even though there is a definite sequence of fluctuation between cold and warm. A comparison between the temperature records themselves and the freezing dates shows a general similarity but a lesser tendency for the latter to pass suddenly from one extreme to another, probably because of the integrating effect of water.

The freezing and thawing dates indicate that winters at the beginning of the record were longer, by approximately 20 days than in recent years; the temperature records at Madison, however, do not show this so clearly. The number of days closed—and thus the length of winters—is indicated by the graphs for the lakes and rivers (figs. 3–4). It is clear that the winters have been shorter since the eighties, and we may think of these as "milder."

An examination of the opening of lakes and rivers in the spring shows again that the period since the eighties has been characterized by earlier springs (figs. 5 and 6), but the river records themselves are too short to show this (fig. 7).

As a matter of comparison I constructed a separate figure to indicate the early or late fall, long or short winters, and early or late springs. On this graph (fig. 8) the warmer years—that is, later falls, shorter winters, and earlier springs—than the average are indicated by the rise of the curve above the mean line and for colder years, the drop of the curve below the mean line. This curve is

[1] Leopold, Trans. Wis. Acad. Sci. Arts. & Letters. 30:69–76.

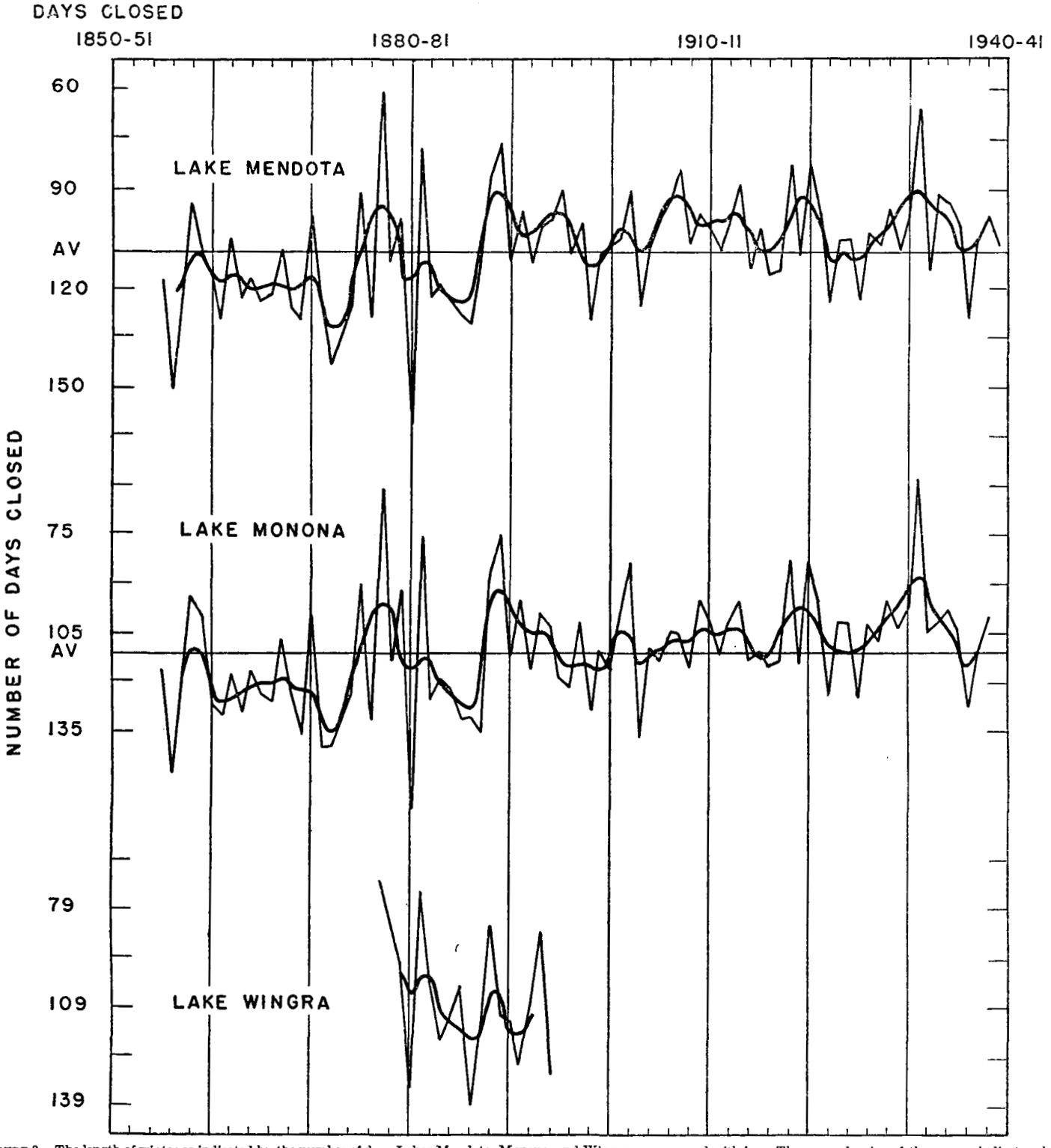

FIGURE 3.—The length of winter as indicated by the number of days Lakes Mendota, Monona, and Wingra were covered with ice. The upward swing of the curves indicates short winters.

not based upon the degree of warmness and coldness; it indicates only that the year is above or below average. The periods that are warmer or colder than average as shown by the smooth curve are indicated by heavy lines placed above or below, respectively. It is clear that the early years of records were distinctly colder than more recent ones.

In order to see if any systematic relation might exist between a series of years, I compared the springs, falls, and winters with each other on a moving three-year basis—that is, if one year were colder or warmer than the preceding, what was the possibility that the succeeding year would be colder or warmer? I also compared the years on the basis of one year colder or warmer than the average to determine the possibility that the succeeding year would be colder or warmer than the average itself. These compari-

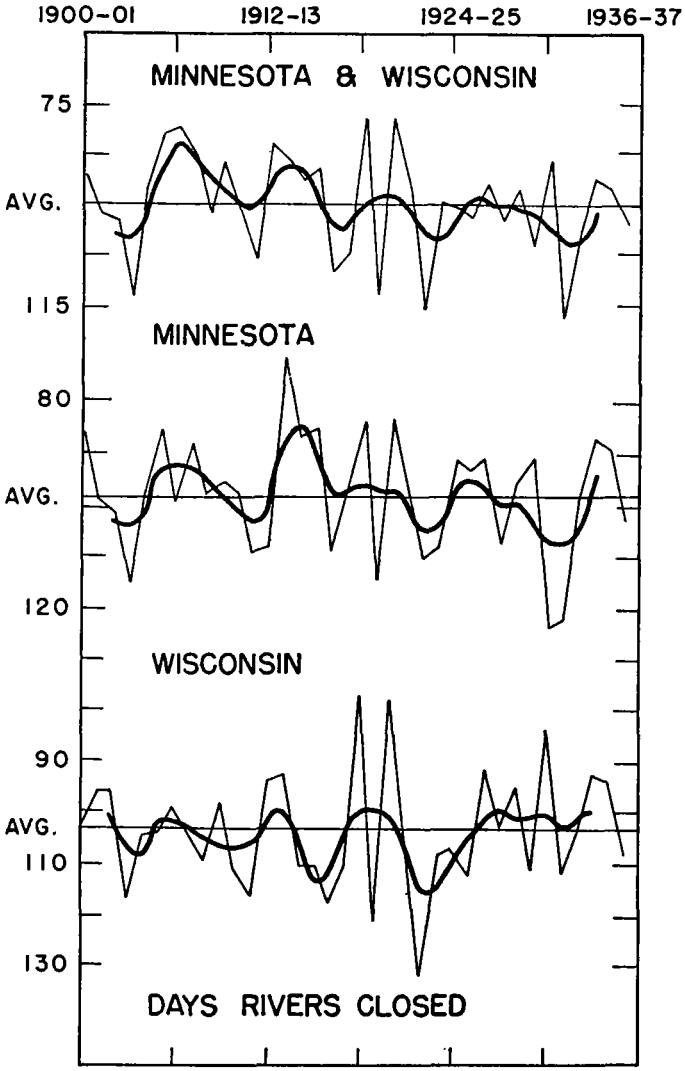

FIGURE 4.—The length of winter as indicated by the number of days Minnesota and Wisconsin rivers were closed.

sons gave results varying from nearly even to nearly 2 to 1 (table 9).

A third comparison, that of one year colder or warmer than the average and the succeeding year colder or warmer than the year of comparison itself, gave rather consistent results. These varied between 3.3 to 1 and 2.4 to 1 (tables 10–12). The possibilities of predicting the general pattern of the future year in relation to the present year seems to be far better than guess work, especially if the lake and river date are used as indicators.

If the present fall is warmer than the average, the probabilities are 3.3 to 1 that the next will be colder than the present fall, but if the present fall is colder than the average the probabilities are 2.4 to 1 that the next will be warmer. If the present winter is warmer than the average, the probabilities are 2.6 to 1 that the next winter will be colder than the present winter, but if the present winter is colder than the average the probabilities are 2.4 to 1 that the next will be warmer. If the present spring is warmer than the average the probabilities are 2.8 to 1 that the next spring will be colder than the present spring, but if the present spring is colder than the average the probabilities are 2.6 to 1 that the next spring will be warmer

The ratio of comparison is higher with but one or two exceptions which are probably due to the data on the basis of freezing and thawing than on the basis of temperatures. Evidently the integrated effect of water is superior to direct averaging of the thermometer data themselves.

TABLE 1.—*The freezing and thawing record of Lake Monona, Madison, Wis. All dates smoothed by the formula* $\frac{a+4b+6c+4d+e}{16}$

Winter	Full freeze, days after Oct. 31	Smoothed date	Spring thaw, days after Feb. 28–29	Smoothed date	Length of frozen period in days	Smoothed length
1851–52	43		25		103	
1852–53						
1853–54	51					
1854–55						
1855–56	48		45		118	
1856–57	34		65		151	
1857–58	23	32.6	22	32.6	119	120.1
1858–59	41	34.2	15	24.2	94	110.2
1859–60	36	35.1	26	27.8	111	113.1
1860–61	32	33.6	41	36.0	129	122.6
1861–62	31	33.6	44	40.5	133	127.0
1862–63	37	36.3	36	42.0	119	126.0
1863–64	41	39.0	51	42.9	131	124.2
1864–65	39	40.8	36	43.8	117	123.3
1865–66	44	42.0	49	45.0	125	123.0
1866–67	42	42.6	50	43.8	128	122.4
1867–68	44	41.2	31	41.3	108	120.4
1868–69	40	37.8	46	40.6	126	123.0
1869–70	24	36.6	42	40.3	138	123.8
1870–71	52	37.2	32	41.1	100	124.1
1871–72	30	34.5	51	44.8	142	130.6
1872–73	28	31.1	49	47.1	141	136.3
1873–74	29	34.6	45	46.1	136	131.5
1874–75	42	44.6	45	44.3	123	119.9
1875–76	71	51.8	41	41.7	91	110.2
1876–77	35	53.1	47	35.5	132	102.6
1877–78	67	52.6	9	29.0	62	96.5
1878–79	46	49.0	41	28.9	115	100.1
1879–80	46	42.3	18	34.2	93	112.3
1880–81	22	40.4	62	37.8	160	117.6
1881–82	62	43.8	19	37.6	77	113.9
1882–83	37	45.4	44	39.6	127	114.4
1883–84	47	44.8	46	44.4	120	120.0
1884–85	47	43.1	48	47.1	121	124.2
1885–86	37	39.0	48	47.1	131	128.1
1886–87	35	36.0	46	44.8	131	129.1
1887–88	28	41.0	44	39.3	137	118.6
1888–89	59	53.4	26	37.4	87	100.6
1889–90	75	61.6	29	33.8	74	92.3
1890–91	54	59.5	47	36.8	113	97.6
1891–92	57	51.8	32	35.7	96	104.3
1892–93	41	44.4	38	30.3	117	106.1
1893–94	32	41.6	11	27.3	99	105.8
1894–95	55	41.7	39	30.0	104	108.5
1895–96	34	39.5	32	33.0	119	113.8
1896–97	33	37.8	36	33.3	123	115.6
1897–98	45	39.9	26	35.1	101	115.3
1898–99	37	43.6	46	40.3	129	116.6
1899–1900	55	46.4	47	42.9	112	116.5
1900–1901	44	47.0	42	38.4	118	111.3
1901–2	44	46.6	27	31.6	103	105.1
1902–3	56	44.1	21	30.8	85	106.9
1903–4	27	40.3	46	35.1	140	115.1
1904–5	43	39.7	34	36.8	111	117.3
1905–6	44	41.0	39	33.6	115	112.7
1906–7	38	40.6	24	29.6	106	107.0
1907–8	41	40.3	26	28.9	106	108.6
1908–9	39	41.6	37	29.1	118	107.8
1909–10	48	42.8	24	27.6	96	104.9
1910–11	38	43.7	21	28.2	103	104.7
1911–12	48	46.3	40	32.0	113	106.1
1912–13	49	49.8	33	34.4	104	104.8
1913–14	57	50.6	33	35.3	96	104.7
1914–15	45	48.3	40	36.6	115	108.6
1915–16	45	45.5	35	38.4	111	112.6
1916–17	46	44.3	42	39.2	116	112.6
1917–18	38	44.8	44	35.9	116	107.4
1918–19	57	45.1	20	29.1	83	101.6
1919–20	33	44.8	28	23.8	116	98.7
1920–21	51	45.8	16	23.6	85	98.0
1921–22	49	47.8	25	30.3	96	102.6
1922–23	43	49.8	50	38.6	127	109.1
1923–24	62	50.5	44	40.1	103	110.0
1924–25	44	46.8	27	36.8	103	110.1
1925–26	40	41.0	46	32.6	126	111.6
1926–27	35	38.8	17	27.7	102	109.1
1927–28	39	40.6	26	24.6	108	104.3
1928–29	51	42.1	27	23.4	96	101.5
1929–30	33	44.8	17	22.6	104	98.0
1930–31	46	53.9	24	24.1	98	90.4
1931–32	91	60.3	30	26.6	60	86.6
1932–33	40	54.5	27	27.3	107	93.1
1933–34	43	46.9	26	27.1	103	100.3
1934–35	50	44.9	28	28.1	98	104.1
1935–36	41	43.2	27	30.9	107	110.5
1936–37	43	40.3	43	32.1	130	115.8
1937–38	31	41.0	22	31.1	111	112.7
1938–39	49	46.8	31		102	
1939–40	61		43		102	
1940–41	33					
Average	43.4 Dec. 13		35.2 Apr. 4		111.6	

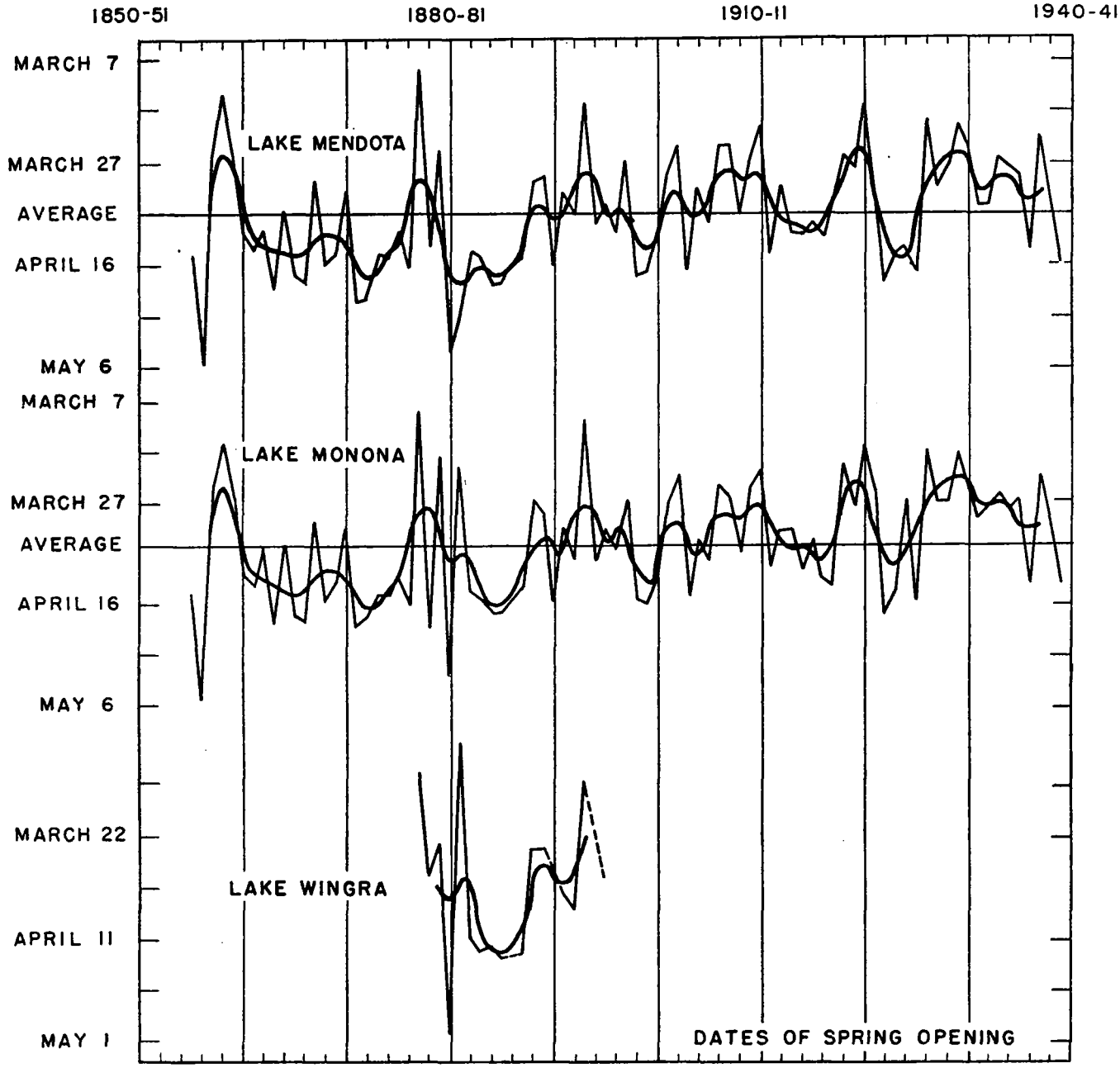

FIGURE 5.—The spring-thawing records of Lakes Mendota, Monona, and Wingra. The upward swing of the curves indicates early thawing and, therefore, early spring.

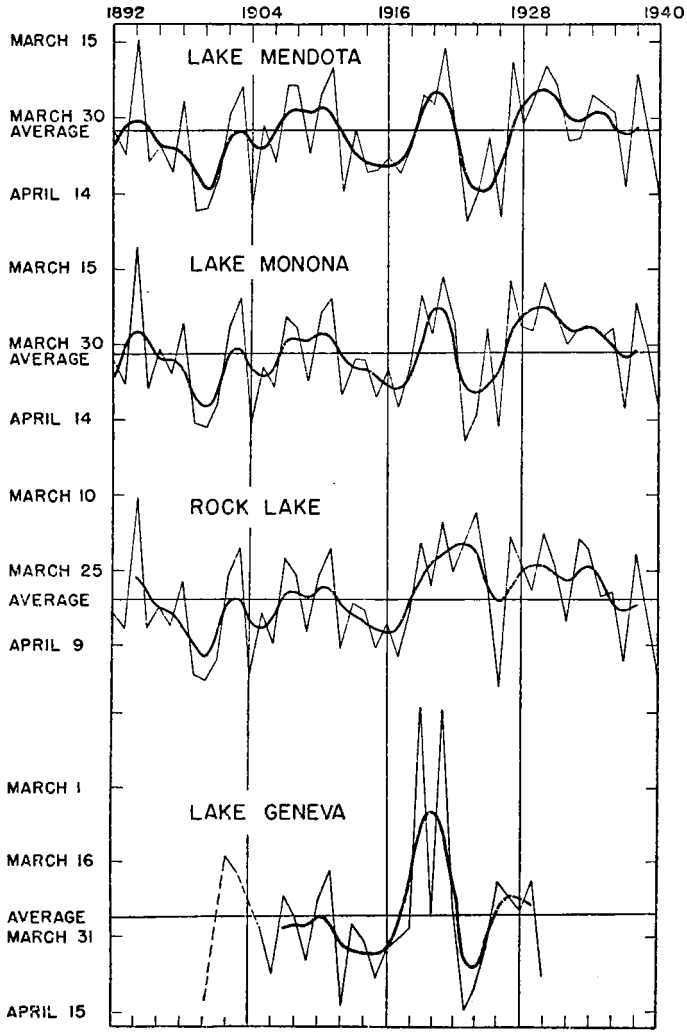

FIGURE 6.—The spring thaw of Rock Lake and Lake Geneva compared with Lakes Mendota and Monona.

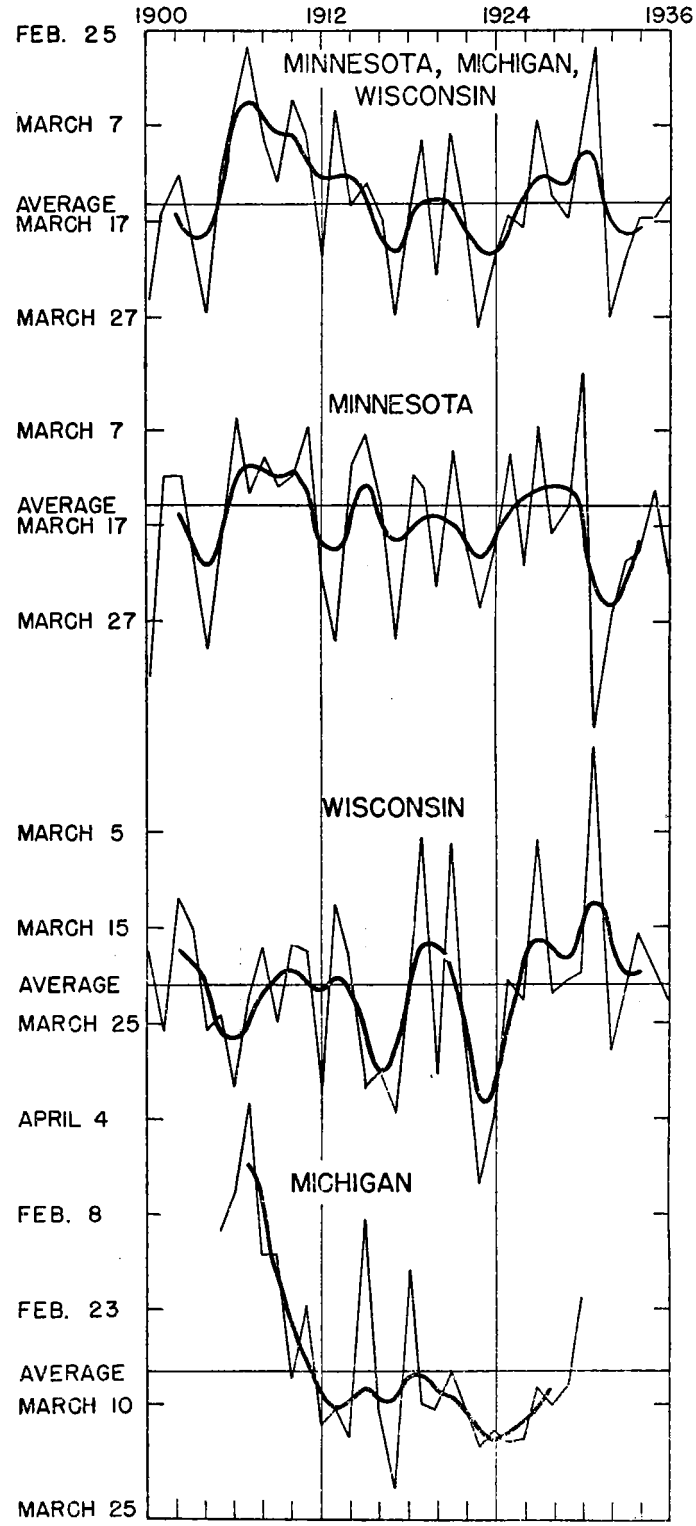

FIGURE 7.—The spring-thawing record of rivers of Minnesota, Wisconsin, and Michigan. The top curve is the combined thawing record for all rivers.

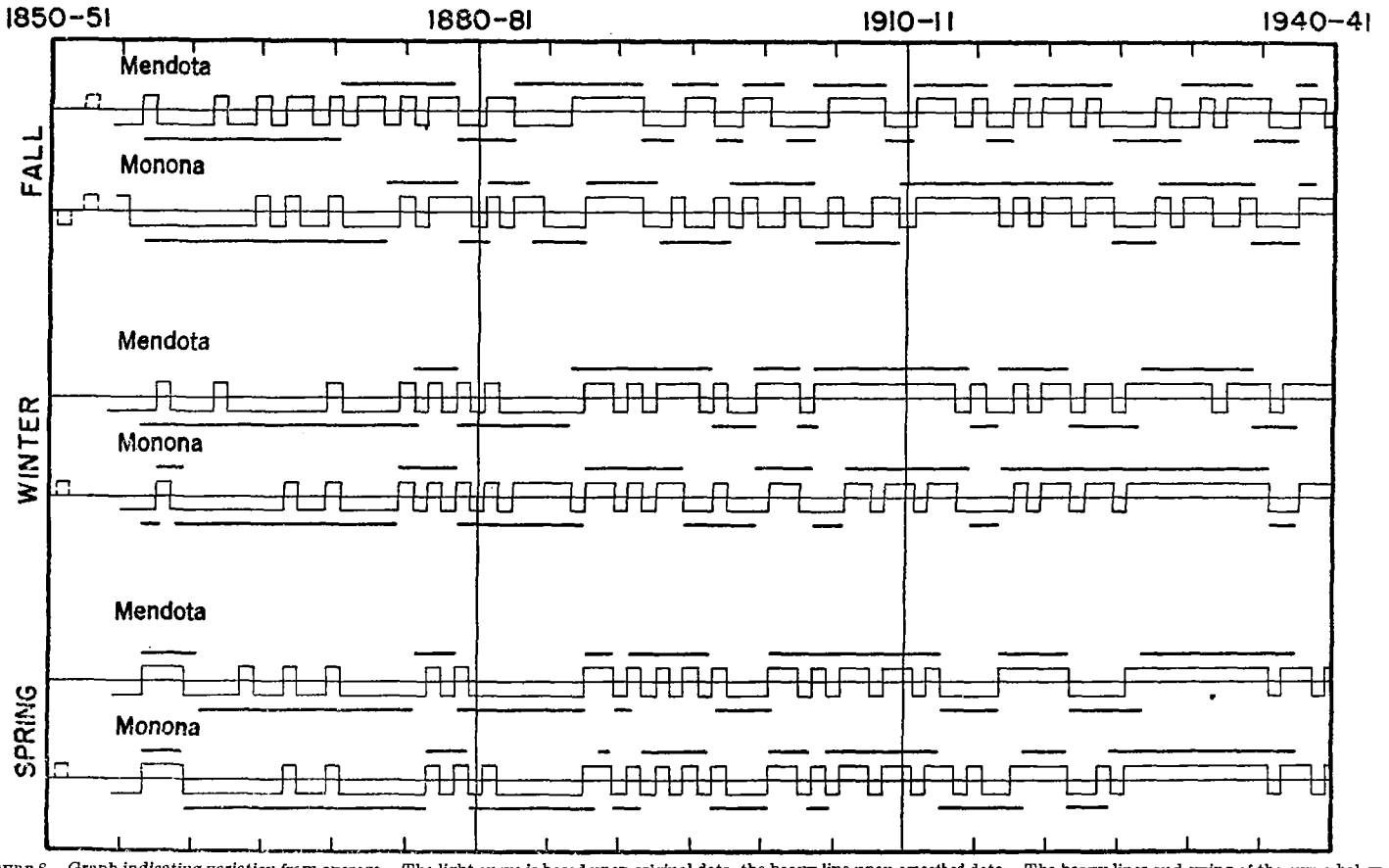

FIGURE 8.—Graph indicating variation from average. The light curve is based upon original data, the heavy line upon *smoothed* data. The heavy lines and swing of the curve below the median line indicate falls, winters, or springs *colder* than average.

TABLE 2.—*The freezing and thawing record of Lake Mendota, Madison, Wis.*

Winter	Full freeze days after Nov. 30	Smoothed date	Spring thaw days after Feb. 28–29	Smoothed date	Length of frozen period in days	Smoothed length
1853–54	27					
1854–55						
1855–56	18		45		118	
1856–57	6		67		151	
1857–58	25	14.4	26	34.4	121	121.4
1858–59	8	12.2	14	25.0	96	110.5
1859–60	7	9.8	26	27.9	110	110.3
1860–61	14	9.6	41	36.2	117	116.9
1861–62	2	12.3	44	41.6	132	119.4
1862–63	26	16.1	40	43.8	104	117.9
1863–64	18	16.2	52	44.3	125	118.4
1864–65	8	13.8	36	44.4	118	120.9
1865–66	14	13.6	49	45.3	125	121.8
1866–67	18	12.5	51	44.3	123	120.8
1867–68	12	12.5	31	41.9	110	119.8
1868–69	10	9.9	47	41.4	127	121.8
1869–70	2	11.3	43	41.4	131	120.4
1870–71	24	17.3	33	42.9	99	118.3
1871–72	19	22.6	54	47.5	126	124.7
1872–73	30	25.4	54	49.9	144	133.6
1873–74	29	24.6	45	47.8	136	132.1
1874–75	10	23.6	46	45.1	126	121.1
1875–76	41	24.0	41	42.2	91	110.5
1876–77	8	24.4	48	36.1	130	101.9
1877–78	37	24.8	9	30.2	62	95.6
1878–79	21	21.4	43	31.6	112	100.4
1879–80	17	14.1	25	39.9	99	114.1
1880–81	7	11.8	64	48.7	161	119.4
1881–82	33	15.3	52	50.9	78	114.1
1882–83	10	17.1	44	48.2	124	113.6
1883–84	18	16.3	46	47.4	119	119.5
1884–85	17	14.8	51	48.8	124	124.2
1885–86	12	12.6	50	48.8	128	126.2
1886–87	5	14.0	46	96.4	131	122.6
1887–88	24	22.1	46	41.5	113	109.8
1888–89	33	31.6	31	36.4	88	95.1
1889–90	45	34.8	30	35.7	75	91.0
1890–91	26	30.8	47	37.7	111	97.1
1891–92	27	23.7	33	36.4	97	103.1
1892–93	16	17.1	38	31.6	112	104.8
1893–94	4	16.4	15	29.2	101	103.2
1894–95	28	22.8	39	32.3	101	99.8
1895–96	36	27.1	36	36.1	91	99.4
1896–97	21	23.4	41	36.6	110	103.4
1897–98	17	17.8	27	37.9	100	110.1
1898–99	9	17.3	49	42.3	130	115.1

TABLE 2.—*The freezing and thawing record of Lake Mendota, Madison, Wis.*—Continued

Winter	Full freeze days after Nov. 30	Smoothed date	Spring thaw days after Feb. 28–29	Smoothed date	Length of frozen period in days	Smoothed length
1899–1900	27	20.1	48	44.3	111	113.7
1900–1901	25	22.0	42	39.8	107	107.8
1901–1902	15	20.1	30	33.8	105	103.2
1902–1903	25	18.8	24	33.1	89	104.6
1903–1904	13	17.6	48	36.3	126	109.1
1904–1905	14	19.3	32	36.8	108	107.7
1905–1906	32	23.3	39	33.1	97	99.9
1906–1907	20	25.8	24	29.1	94	93.6
1907–1908	32	25.6	24	28.6	83	93.3
1908–1909	22	22.6	38	29.5	106	97.2
1909–1910	18	18.2	26	28.6	98	100.4
1910–1911	9	17.8	20	29.6	101	102.2
1911–1912	28	22.6	45	34.1	108	102.1
1912–1913	24	28.3	32	37.3	99	99.6
1913–1914	43	30.0	41	38.9	88	99.6
1914–1915	16	26.2	41	40.0	115	104.1
1915–1916	28	21.9	39	40.2	102	108.7
1916–1917	16	18.9	42	38.7	116	110.1
1917–1918	11	18.9	36	34.7	115	105.9
1918–1919	34	20.2	26	29.4	82	99.3
1919–1920	9	20.4	28	25.2	110	95.2
1920–1921	25	21.0	16	25.5	81	94.8
1921–1922	25	22.2	31	32.7	96	100.9
1922–1923	16	23.0	50	41.5	125	108.5
1923–1924	32	23.3	45	45.4	104	110.2
1924–1925	19	20.5	44	44.6	105	110.6
1925–1926	16	15.3	50	59.3	124	111.6
1926–1927	6	13.0	19	32.1	103	108.7
1927–1928	17	14.3	32	27.9	106	103.9
1928–1929	21	14.2	27	25.8	96	101.8
1929–1930	3	15.2	20	24.4	107	99.3
1930–1931	16	23.9	24	26.6	98	92.9
1931–1932	61	31.1	35	30.8	65	90.0
1932–1933	10	27.8	35	31.0	115	94.1
1933–1934	25	22.9	26	29.6	91	96.6
1934–1935	24	21.3	28	29.4	94	98.4
1935–1936	20	17.2	30	32.2	101	105.6
1936–1937	7	12.6	44	33.4	128	111.4
1937–1938	7	14.7	22	32.8	105	108.5
1938–1939	28	21.8	35		97	
1939–1940	33		47		105	
1940–1941	14					
Average	19.7 Dec. 20		37.3 Apr. 6		108.6	

TABLE 3.—*The freezing and thawing record of Lake Wingra, Madison, Wis.*

Winter	Fall freeze, days after Oct. 31	Smoothed date	Spring thaw, days after Feb. 28-29	Smoothed date	Length of frozen period in days	Smoothed length
1877-78	59		9		70	
1878-79	36		29		85	
1879-80	19	25.1	23	31.6	96	100.2
1880-81	16	25.1	60	33.1	136	105.1
1881-82	20	21.6	2	30.2	74	100.6
1882-83	32	23.3	41	33.4	101	102.1
1883-84	15	23.1	44	40.7	121	109.6
1884-85	24	25.0	44	44.1	112	112.9
1885-86	35	27.3	45	44.6	102	116.3
1886-87	24	26.3	*45	*43.4		*119.6
1887-88	20	25.8	44	37.8	116	113.1
1888-89	32	28.9	24	30.1	84	104.2
1889-90		*31.8	24	26.8		*106.4
1890-91	34	30.1	*28	*28.5		*114.6
1891-92		*25.9	33	30.6		*116.2
1892-93	18	20.6	36	27.2	110	109.8
1893-94	17		10	*21.7	85	
1894-95	15		*20			
1895-96			30			

* Interpolated.

TABLE 4.—*The thawing records of Rock Lake and Lake Geneva, Wis. Frab Frank Foote kept the record from 1887 to 1916, and Charles Kliest from 1916 to 1940. Dr. Edwin Trast kept the Lake Geneva record*

Winter	Rock Lake thaw, days after Feb. 28-29	Smoothed date	Lake Geneva thaw, days after Dec. 31	Smoothed date
1887-88	45			
1888-89				
1889-90	29			
1890-91				
1891-92				
1892-93	34			
1893-94	37			
1894-95	11	26.6		
1895-96	36	29.1		
1896-97	33	32.8		
1897-98	36	33.6		
1898-99	27	37.4		
1899-1900	46	40.7		
1900-1901	47	43.2	104	
1901-02	43	38.6		
1902-3	26	31.6	74	
1903-4	21	30.7	77	
1904-5	46	35.1		
1905-6	34	37.0	88	
1906-7	40	33.8	98	
1907-8	23	29.6	82	88.1
1908-9	26	29.1	86	87.8
1909-10	38	30.0	95	87.8
1910-11	26	28.7	83	86.0
1911-12	21	29.0	77	87.0
1912-13	41	32.3	104	91.1
1913-14	32	34.4	88	92.6
1914-15	33	35.4	91	92.9
1915-16	41	37.2	98	93.8
1916-17	36	38.4	93	93.1
1917-18	42	36.8	90	88.1
1918-19	33	31.9	89	78.1
1919-20	20	26.4	44	68.6
1920-21	28	23.1	86	65.1
1921-22	16	21.8	44	68.3
1922-23	25	21.0	84	80.4
1923-24	20	20.0	105	93.9
1924-25	14	21.6	100	96.9
1925-26	27	28.1	93	91.8
1926-27	48	31.9	79	84.9
1927-28	19	28.6		*82.5
1928-29	24	25.1	85	83.2
1929-30	29	24.1	79	
1930-31	18	23.9	98	
1931-32	25	25.6		
1932-33	35	26.6		
1933-34	19	24.7		
1934-35	21	24.1		
1935-36	30	27.4		
1936-37	29	31.8		
1937-38	43	33.0		
1938-39	22	32.4		
1939-40	35			
1940-41	46			
Average	30.9 Mar. 31		85.2 Mar. 26	

*Interpolated.

TABLE 5.—*Fall freezing records of Wisconsin, Minnesota, and Michigan rivers—days after Oct. 31*

Winter	Wisconsin	Smoothed date	Minnesota	Smoothed date	Michigan
1900-01	13.5		17.3		
1901-02	7.0		4.0		
1902-3	10.0	7.3	9.0	7.6	
1903-4	1.0	7.1	5.6	8.2	
1904-5	10.0	10.8	11.5	9.4	
1905-6	21.0	14.4	11.3	9.6	
1906-7	14.5	13.2	5.3	9.1	
1907-8	6.0	9.1	12.6	8.8	
1908-9	5.5	6.4	6.5	7.6	
1909-10	8.5	4.7	6.5	5.1	
1910-11	2.8	3.7	.3	3.7	
1911-12	7.0	5.6	3.3	6.1	
1912-13	9.0	9.5	12.0	11.4	
1913-14	15.0	12.0	21.3	15.2	
1914-15	12.2	12.1	11.2	15.8	20.0
1915-16	11.2	9.9	13.4	14.4	31.0
1916-17	6.6	7.2	10.5	12.2	
1917-18	.5	6.7	6.0	11.1	
1918-19	16.8	7.7	20.0	10.6	31.0
1919-20	−1.2	9.1	−.4	10.0	
1920-21	18.8	10.1	16.0	10.5	
1921-22	9.5	9.2	12.0	10.0	24.0
1922-23	−.5	8.2	5.8	7.3	
1923-24	18.6	8.3	2.0	6.3	
1924-25	3.6	6.2	9.5	9.1	21.3
1925-26	−.4	3.6	17.5	10.5	16.2
1926-27	4.8	5.0	5.5	8.0	8.0
1927-28	8.3	8.2	1.3	5.6	7.7
1928-29	16.0	8.8	10.4	5.2	13.0
1929-30	−.6	4.4	1.6	4.0	
1930-31	−1.1	2.1	4.4	2.0	−4.0
1931-32	7.0	4.9	−6.0	3.8	
1932-33	7.0	8.1	13.5	10.2	
1933-34	13.5	12.3	24.0	15.8	
1934-35	16.0	14.3	15.0	12.7	
1935-36	16.5		.8		
1936-37	5.4		.5		
Average	8.2 Dec. 8		6.8 Dec. 7		13.4 Dec. 13

TABLE 6.—*Spring-thawing record of Wisconsin, Minnesota, and Michigan rivers*

Winter	Minnesota rivers, days after Jan. 31	Smoothed date	Wisconsin rivers, days after Feb. 28-29	Smoothed date	Michigan rivers, days after Feb. 28-29	Smoothed date
1900-1901	61.0		17.5			
1901-2	40.3		26.0			
1902-3	40.3	44.4	12.0	17.6		
1903-4	47.0	47.5	15.5	18.4		
1904-5	58.0	49.3	25.7	22.4		
1905-6	44.8	45.2	24.3	26.1	−17.0	
1906-7	33.5	40.1	32.7	26.8	−23.3	
1907-8	41.5	38.7	23.0	24.1	−38.0	−25.3
1908-9	37.7	39.3	17.0	21.4	−13.5	−19.0
1909-10	40.8	39.4	25.0	20.0	−13.5	−9.6
1910-11	39.7	39.2	15.5	19.4	6.3	−2.4
1911-12	34.5	41.5	17.3	20.7	−5.5	2.6
1912-13	50.0	46.5	31.8	21.5	12.7	7.5
1913-14	57.0	47.9	12.7	20.1	11.3	10.6
1914-15	38.7	43.3	17.5	21.4	14.8	9.3
1915-16	35.1	40.6	31.2	26.5	−2.2	7.8
1916-17	42.5	43.9	30.0	30.0	11.1	9.6
1917-18	57.0	46.7	34.3	27.6	23.2	9.2
1918-19	39.8	45.3	20.4	21.0	−11.0	5.5
1919-20	41.0	44.0	3.8	16.8	10.0	5.4
1920-21	51.2	44.2	30.8	17.0	10.7	7.8
1921-22	37.3	44.6	6.3	19.4	5.3	8.9
1922-23	47.5	46.6	25.8	25.9	10.4	11.0
1923-24	53.5	48.3	42.0	32.6	16.8	13.8
1924-25	46.8	46.3	35.0	31.7	14.4	15.1
1925-26	37.4	43.5	20.3	24.9	15.5	14.8
1926-27	49.1	42.1	22.3	18.5	15.4	13.0
1927-28	34.4	41.6	6.0	15.8	7.1	10.5
1928-29	45.4	41.2	21.8	17.5	10.1	7.8
1929-30	43.0	41.0	20.5	18.2	7.0	
1930-31	28.8	44.3	20.3	14.3	−7.0	
1931-32	66.0	51.4	−6.3	12.3		
1932-33	54.7	54.0	27.7	16.5		
1933-34	48.8	50.6	21.8	19.9		
1934-35	47.8	47.1	15.7	19.4		
1935-36	41.4		19.6			
1936-37	40.8		22.3			
Average	*42.8 Mar. 15		*21.2 Mar. 21		*4.5 Mar. 5	

* Based on original data.

TABLE 7.—*Average freezing and thawing dates for Wisconsin, Minnesota, and Michigan rivers combined*

Winter	Freezing dates, days after Jan. 31	Smoothed date	Thawing date, days after Nov. 30	Smoothed date
1900-1901	53.2		15.8	
1901-2	43.8		4.8	
1902-3	40.2	44.2	9.3	7.3
1903-4	45.6	46.1	4.3	8.5
1904-5	54.8	46.5	10.0	9.3
1905-6	40.0	41.3	13.7	10.5
1906-7	32.5	34.2	7.6	10.1
1907-8	26.3	31.7	11.5	8.8
1908-9	36.4	34.1	5.2	7.1
1909-10	40.5	35.6	7.3	4.8
1910-11	32.0	36.3	−.9	3.6
1911-12	35.5	38.0	4.5	4.9
1912-13	48.4	40.0	11.2	10.6
1913-14	33.2	40.0	18.1	14.2
1914-15	42.8	40.4	12.7	15.0
1915-16	40.8	42.7	17.8	13.2
1916-17	44.8	46.2	8.4	10.1
1917-28	55.1	47.6	1.9	8.8
1918-19	43.8	45.2	19.5	9.3
1919-20	36.2	42.8	−.6	10.2
1920-21	50.5	42.4	18.2	11.4
1921-22	35.5	42.8	13.6	11.2
1922-23	44.5	45.8	2.5	10.0
1923-24	56.3	48.9	15.9	10.2
1924-25	48.7	48.7	8.6	10.2
1925-26	43.5	45.6	10.2	8.4
1926-27	45.4	42.1	4.2	9.1
1927-28	34.1	40.1	6.3	7.3
1928-29	42.5	40.8	13.4	6.4
1929-30	44.4	40.7	−2.3	3.4
1930-31	38.7	38.3	2.1	1.6
1931-32	20.5	39.2	−.5	3.9
1932-33	55.0	44.9	10.7	8.5
1933-34	49.2	48.2	15.6	
1934-35	44.3	46.1	13.3	
1935-36	44.5		6.8	
1936-37	42.6		2.7	
Average	42.5 Mar. 15		8.9 Dec. 9	

TABLE 8.—*Length of closed period, Wisconsin, Minnesota, and Michigan rivers*

Winter	Minnesota	Smoothed length	Wisconsin	Smoothed length	Combined average length	Smoothed average length	Michigan
1900-1901	85.0		102.5		90.0		
1901-2	98.3		95.0		97.4		
1902-3	100.1	101.9	95.5	101.4	98.3	101.0	
1903-4	114.4	103.1	115.7	105.6	113.5	101.5	
1904-5	95.3	97.8	104.3	105.6	92.8	94.5	
1905-6	84.2	92.5	101.7	102.4	80.8	90.0	
1906-7	98.2	91.7	98.5	101.2	79.7	83.7	
1907-8	87.1	92.5	102.0	102.7	86.9	87.3	
1908-9	96.3	93.8	109.5	103.9	97.3	90.9	
1909-10	95.2	96.1	97.0	104.9	86.7	93.0	
1910-11	96.2	99.8	110.1	107.2	96.6	95.7	
1911-12	108.7	101.9	115.8	106.2	105.9	95.7	
1912-13	107.0	96.0	93.7	100.9	94.0	91.3	
1913-14	69.4	86.4	92.5	99.5	86.6	88.2	
1914-15	85.9	84.3	109.0	104.6	90.1	89.7	48.0
1915-16	85.1	90.8	109.8	110.5	89.0	95.0	71.1
1916-17	108.5	96.5	117.7	110.7	108.7	99.5	69.0
1917-18	95.8	96.2	109.9	104.4	103.9	98.4	
1918-19	83.0	95.4	77.0	99.3	78.7	95.5	69.0
1919-20	113.6	96.3	123.0	98.3	113.1	94.2	
1920-21	83.3	96.1	77.5	99.5	79.3	93.4	
1921-22	97.5	98.6	106.3	106.8	92.9	96.6	76.4

TABLE 8.—*Length of closed period, Wisconsin, Minnesota, and Michigan rivers*—Continued

Winter	Minnesota	Smoothed length	Wisconsin	Smoothed length	Combined average length	Smoothed average length	Michigan
1922-23	109.7	103.0	132.5	114.6	115.8	101.4	
1923-24	106.8	101.9	107.4	113.8	94.8	100.6	
1924-25	89.9	96.4	106.7	109.0	96.9	97.3	84.2
1925-26	93.6	93.6	112.7	105.0	97.2	95.7	89.3
1926-27	90.9	95.5	91.2	101.1	91.9	95.2	89.1
1927-28	106.1	97.6	104.5	99.5	98.2	95.4	93.4
1928-29	94.6	97.7	94.5	100.3	93.0	96.3	79.0
1929-30	89.2	102.3	110.9	99.9	103.0	97.0	
1930-31	123.6	105.1	84.4	99.9	86.4	99.6	
1931-32	122.7	105.9	111.7	102.0	117.5	102.9	
1932-33	97.3	101.9	104.8	101.4	100.5	101.0	
1933-34	85.8	92.6	92.2		90.7	95.9	
1934-35	88.4		93.2		93.2		
1935-36	102.0		97.8		97.8		
Average	96.9		103.0		95.3		77.7

TABLE 9.—*Comparison of years on basis of colder or warmer than the average or previous year and following year colder or warmer than the average or previous year*

Comparison of—	Basis	Average			
		Warmer		Colder	
		Colder	Warmer	Colder	Warmer
Fall and following fall	Previous year				
	Succeeding year	68.73	31.27	37.24	62.76
Do	Average				
	Average	52.40	47.60	53.84	46.16
Fall and following spring	Previous year				
	Succeeding year	48.32	51.68	50.49	49.51
Do	Average				
	Average	47.86	52.14	52.32	47.62
Spring and following spring	Previous year				
	Succeeding year	64.04	35.96	30.78	69.22
Spring and following fall	Previous year				
	Succeeding year	57.20	42.80	47.50	52.50
Do	Average				
	Average	53.38	46.62	50.25	49.75
Winter and following winter	Previous year				
	Succeeding year	60.66	39.34	35.10	64.90
Do	Average				
	Average	46.59	53.41	49.74	50.26

TABLE 10.—*Comparison of falls on basis of colder or warmer than the average and the next year colder or warmer than the previous year*

	Wisconsin temperature	Madison temperature	Lake Mendota	Lake Monona	Wisconsin rivers	Minnesota rivers	Average
Number of years	47	73	80	79	34	36	
Warmer falls than average	22	36	36	36	19	19	
Next fall colder than previous	77.27	75.00	80.56	75.00	73.68	78.95	76.74
Next fall warmer than previous	22.73	25.00	19.44	25.00	26.32	21.05	23.26
Colder falls than average	25	37	44	43	15	17	
Next falls colder than previous	28.00	24.32	36.36	30.23	26.67	29.41	29.16
Next fall warmer than previous	72.00	75.68	63.64	60.77	73.33	70.59	70.84

TABLE 11.—*Comparison of winters on the basis of colder or warmer than the average and the next colder or warmer than the previous year*

	Wisconsin temperatures	Madison temperatures	Lake Mendota	Lake Monona	Wisconsin Rivers	Minnesota Rivers	Average
Years	1891-1939	1853-1939	1853-1940	1851-1940	1900-1936	1900-1936	
Number of years	46	78	83	79	35	35	
Average	20.6°	22.9°	[1] 108.6	[1] 111.6	[1] 103.0	[1] 96.9	
Warmer winters than average	25	49	43	38	16	18	
Next winter colder than previous	84.00	61.22	67.44	71.05	81.25	66.67	71.94
Next winter warmer than previous	16.00	38.78	32.56	28.95	18.75	33.33	28.06
Colder winters than average	21	29	40	41	19	17	
Next winter colder than previous	38.10	20.69	37.50	29.27	26.32	23.53	29.24
Next winter warmer than previous	61.90	79.31	62.50	70.73	73.68	76.47	70.76

[1] Days.

TABLE 12.—*Comparison of springs on the basis of colder or warmer than the average and the next colder or warmer than the previous year*

	Wisconsin temperatures	Madison temperatures	Lake Mendota	Lake Monona	Wisconsin rivers	Minnesota rivers	Michigan rivers	Lake Geneva	Rock Lake	Average of all
Years	1891–1939	1853–1939	1853–1940	1851–1940	1900–1936	1900–1936	1905–30	1900–1930	1887–1940	----
Number of years	47	81	79	81	36	35	23	24	48	----
Average	29.7	31.30	Apr. 6	Apr. 4	Mar. 21	Apr. 7	Mar. 5	Mar. 26	Mar. 31	----
Warmer springs than average	22	44	37	40	18	17	7	9	25	----
Next spring colder than previous	72.73	54.55	75.68	80.00	83.33	70.59	71.43	77.78	80.00	74.01
Next spring warmer than previous	27.27	45.45	24.32	20.00	16.67	29.41	28.57	22.22	20.00	25.99
Colder than average	25	37	42	41	18	18	11	15	23	----
Next spring colder than previous	24.00	37.84	23.81	24.39	16.67	16.67	43.75	26.67	34.78	27.62
Next spring warmer than previous	76.00	62.16	76.19	75.61	83.33	83.33	56.25	73.33	65.22	72.38

METEOROLOGICAL AND CLIMATOLOGICAL DATA FOR SEPTEMBER 1943

[Climate and Crop Weather Division, J. B. KINCER, in charge]

AEROLOGICAL OBSERVATIONS

NOTICE.—Effective with the December 1942 issue, the publication of table 1 (RAOB summaries) was discontinued indefinitely.—EDITOR.

TABLE 2.—*Free-air resultant winds based on pilot-balloon observations made near 5 p. m. (75th meridian time) during September 1943. Directions given in degrees from North (N=360°, E=90°, S=180°, W=270°). Velocities in meters per second*

Altitude (meters) m. s. l.	Abilene, Tex. (538 m.)			Albuquerque, N.Mex. (1,630 m.)			Atlanta, Ga. (299 m.)			Billings, Mont. (1,095 m.)			Bismarck, N. Dak. (512 m.)			Boise, Idaho (870 m.)			Brownsville, Tex. (7 m.)			Buffalo, N. Y. (220 m.)			Burlington, Vt. (132 m.)			Charleston, S. C. (17 m.)			Cincinnati, Ohio (152 m.)			Denver, Colo. (1,627 m.)			El Paso, Tex. (1,196 m.)		
	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity
Surface	30	135	1.5	30	216	1.7	28	27	1.1	30	303	2.2	30	272	3.5	30	314	4.0	29	79	4.1	30	256	2.2	30	250	0.8	30	88	1.2	30	258	0.6	30	52	1.6	30	145	0.6
500	---	---	---	---	---	---	28	42	0.7	---	---	---	---	---	---	---	---	---	28	72	3.9	30	242	4.1	30	232	1.8	30	92	2.2	30	230	1.6	---	---	---	---	---	---
1,000	30	131	2.5	---	---	---	28	70	0.9	---	---	---	30	262	3.2	30	308	3.3	27	104	2.1	28	239	4.9	29	237	3.5	29	78	1.8	29	240	1.8	---	---	---	---	---	---
1,500	26	127	2.5	---	---	---	27	97	1.5	30	269	2.1	30	274	4.9	30	301	2.7	27	106	1.3	27	252	6.3	28	263	4.9	26	18	1.5	28	254	2.6	---	---	---	30	149	1.3
2,000	25	108	2.5	30	209	2.1	26	97	1.0	30	281	3.0	27	277	6.4	30	308	1.4	23	112	1.4	25	262	6.3	26	256	6.2	22	318	1.3	26	267	3.6	30	51	2.0	29	130	1.3
2,500	24	114	1.4	30	226	1.3	26	323	.3	29	283	6.0	26	285	8.5	30	277	2.0	21	108	1.0	16	257	4.8	22	258	8.6	19	320	1.6	24	274	5.1	30	43	1.2	27	119	.6
3,000	22	101	1.1	29	254	1.4	25	301	1.7	28	287	8.0	26	287	10.0	30	272	3.4	19	99	1.5	14	263	4.5	17	269	7.5	18	297	2.1	22	266	8.0	30	309	1.8	26	173	.4
4,000	20	25	1.5	27	276	2.6	22	282	4.7	28	290	11.8	22	287	12.1	30	280	5.8	16	127	1.0	---	---	---	11	266	10.0	16	302	2.2	19	271	8.6	29	294	6.3	24	16	1.1
5,000	19	322	2.1	22	299	4.6	19	286	7.5	26	288	14.0	21	296	12.4	29	277	6.4	15	28	.8	---	---	---	---	---	---	14	281	4.5	13	293	7.1	28	295	8.4	24	328	1.5
6,000	17	304	3.4	19	297	4.8	18	286	8.4	22	293	13.8	16	299	15.2	27	278	7.6	13	285	.7	---	---	---	---	---	---	13	293	5.8	---	---	---	28	291	8.9	21	290	2.5
8,000	14	285	7.9	14	292	7.4	13	286	13.3	19	294	15.1	13	297	15.9	22	279	9.3	10	334	1.1	---	---	---	---	---	---	11	295	6.7	---	---	---	20	293	10.2	16	282	8.8
10,000	10	281	10.3	---	---	---	10	285	18.6	18	303	14.4	10	274	16.9	17	276	6.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	18	291	13.6	---	---	---
12,000	---	---	---	---	---	---	---	---	---	15	308	16.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	14	288	15.1	---	---	---
14,000	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	12	282	13.2	---	---	---

Altitude (meters) m. s. l.	Ely, Nev. (1,910 m.)			Grand Junction, Colo. (1,413 m.)			Greensboro, N. C. (271 m.)			Havre, Mont. (767 m.)			Jacksonville, Fla. (16 m.)			Joliet, Ill. (178 m.)			Las Vegas, Nev. (573 m.)			Little Rock, Ark. (88 m.)			Medford, Oreg. (410 m.)			Miami, Fla. (15 m.)			Mobile, Ala. (66 m.)			Nashville, Tenn. (194 m.)			New York, N. Y. (15 m.)		
	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity	Observations	Direction	Velocity
Surface	30	222	1.1	30	306	1.5	28	68	0.7	29	286	2.3	29	74	4.5	29	235	1.3	30	164	1.4	30	98	0.9	30	309	1.1	29	104	2.5	28	57	1.6	29	56	0.7	30	24	1.7
500	---	---	---	---	---	---	28	44	.9	---	---	---	29	75	5.4	29	252	1.9	---	---	---	30	111	1.6	30	319	1.4	29	97	4.8	28	74	1.7	29	117	.7	29	330	1.0
1,000	---	---	---	---	---	---	28	10	.8	29	288	4.0	27	76	4.1	29	248	3.5	30	172	1.7	27	81	1.6	30	332	1.3	28	90	3.1	27	66	1.9	27	187	.6	26	301	2.2
1,500	---	---	---	30	295	2.6	28	328	.9	29	282	4.4	25	72	1.9	27	251	4.7	30	175	1.8	26	59	1.2	30	227	.1	26	86	1.6	25	66	2.5	26	43	.4	23	301	3.6
2,000	30	232	1.3	30	290	3.3	28	329	1.7	29	281	4.9	22	349	.7	23	266	5.9	30	202	2.1	24	338	1.5	30	153	1.4	25	83	.9	21	58	1.9	26	292	1.2	22	299	4.2
2,500	30	224	1.6	30	279	3.5	28	314	3.0	28	284	6.8	17	289	1.0	22	271	6.9	30	221	2.6	20	329	3.1	29	148	1.1	20	104	.6	19	16	.5	26	301	3.7	21	292	4.3
3,000	30	230	2.0	30	275	3.7	26	301	3.7	25	278	8.2	16	291	2.1	20	271	7.0	30	230	3.3	18	305	3.9	29	134	1.0	18	147	.8	17	334	1.0	25	290	5.3	18	286	7.3
4,000	30	247	3.1	29	268	4.5	22	285	5.2	22	285	10.6	14	273	2.5	13	266	6.7	28	240	3.7	14	307	6.0	29	198	.9	16	57	1.0	11	360	2.6	25	294	7.1	12	288	7.0
5,000	26	265	4.5	26	275	5.7	19	273	7.3	18	290	12.3	12	262	3.6	---	---	---	28	243	3.2	13	306	5.8	28	211	1.7	14	29	1.6	---	---	---	17	299	7.7	---	---	---
6,000	26	270	5.7	23	284	7.8	17	285	5.1	15	286	12.6	---	---	---	---	---	---	27	261	3.1	11	303	8.2	25	302	1.2	10	50	2.0	---	---	---	14	293	12.0	---	---	---
8,000	21	275	7.9	---	---	---	12	263	7.8	---	---	---	---	---	---	---	---	---	22	270	4.2	---	---	---	21	270	2.1	---	---	---	---	---	---	11	293	16.3	---	---	---
10,000	18	281	9.3	---	---	---	12	279	11.6	---	---	---	---	---	---	---	---	---	18	279	5.7	---	---	---	17	297	4.1	---	---	---	---	---	---	10	280	23.2	---	---	---
12,000	15	276	12.1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	14	269	14.0	---	---	---	13	304	8.2	---	---	---	---	---	---	---	---	---	---	---	---
14,000	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	11	265	17.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---