Extreme Minimum Winter Temperatures in Ohio[1]

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ABSTRACT. **The Extreme Minimum Winter Temperature (EMWT) is the coldest temperature recorded each winter at a given weather station. This variable is a measure of winter temperature severity. EMWT influences the geographic distribution of plants, and is a prime control for the production of some fruit crops grown in Ohio. EMWT values are often used to map plant hardiness zones, but climatic variables rarely remain constant over time, and plant hardiness zones could shift significantly if the climate of Ohio changes and there is a change in EMWTs. EMWTs from 89 weather stations in Ohio were analyzed to determine spatial patterns and time trends. Summary statistics of EMWTs were tabulated and mean EMWT was mapped at a large scale. Linear and polynomial regression were utilized to examine the time series. EMWTs have not warmed during the climatic record of this variable. There does not appear to be a link between EMWTs in Ohio and the increasing levels of CO_2 in the atmosphere. The present study demonstrates the need for more research in applied climatology based on observed climate records, not obscured by the assumptions of the global warming paradigm.**

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INTRODUCTION

Ohio is located in the midlatitudes and experiences a generally temperate climate typical of the American Midwest. The position of the state near the middle of the North American continent produces a climate type suitable to support and maintain a large human population, extensive urban systems, and agricultural development. Average winter and summer temperatures are neither severely cold nor oppressively hot for most human activities. However, the midlatitude humid continental climate exhibits a wide range of extreme temperatures and significant intra-seasonal variability in temperature. Notable extremes of heat and cold have occurred in the past, and it is these extremes of temperature—especially cold winter temperatures—that determine the geographic ranges of many plants. In the study of regional climates, averages and normals are important statistical descriptions of climate, but in some circumstances extreme values are of greater importance.

The lowest temperature that occurs during winter at a given geographic location, known sometimes as the annual minimum temperature, or as the Extreme Minimum Winter Temperature (EMWT), is of considerable interest to climatologists. Perennial plants, such as tender fruit crops, ornamental species, and pest vines, are limited in range less by the annual average temperature than by the EMWT. Plant distributions are influenced by the coldest survivable temperature characteristic of a given environment. Extreme cold can hinder or even halt biochemical and other physiological actions, thus the magnitude of EMWT is a fundamental characteristic of the temperature climatology of any environment. For the cultivation of fruit crops, EMWT is a factor as critical as length of growing season, precipitation distribution, and edaphic conditions. Small scale maps of average EMWT have been published by the United States Department of Agriculture (1990). Knowledge of the magnitude, variability, and distribution of EMWT has applications in other fields as well. Designers take into account the coldest temperature which can occur at a given location, and the potential impact of this on structures and occupants (Rizzi 1980).

If the expected EMWT changes over time, or if EMWTs become more or less variable, then the geographic distribution of certain plant species could change as well. The subject of global warming and climate change associated with an enhanced "greenhouse effect" is of considerable scientific and popular interest (Jones and Henderson-Sellers 1990). It is well known that climate changes over time scales of thousands and millions of years, but significant climatic changes and trends on a "generational" time scale (a few decades) may also occur. The proponents of greenhouse warming warn that the earth's climate will warm several degrees in the next few decades, and also alert us that this warming is already under way, as exhibited by the known climate record (Jones and Wigley 1990). A wine and fruit industry more lucrative than the present would be one arguable benefit of "global warming" since the ranges of tender fruit could be extended further from Lake Erie. Conversely, pest vines such as Kudzu vine, which grows rampant in the southeastern states but is presently limited by cold northern winters, could extend its range northward into Ohio if EMWTs become warmer (Sasek and Strain 1990). The time series and trends of EMWT are thus an issue in Ohio climatology. A question remains as to whether EMWTs in Ohio have become warmer or cooler over recent decades. Even if climatic averages are not changing, an increase in the frequency of extreme events could be indicative of climate change.

The objective of the present study is to quantify the magnitude geographic variability of EMWT in Ohio, and to assess the overall time series trend of this variable. The present study provides a statistical analysis, climatic summary, and rationale for geographic explanation of extreme minimum winter temperatures in Ohio. Although extreme values in a local area may not match a global trend, the present study is one piece in the climate change puzzle.

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MATERIALS AND METHODS

Site Description

Ohio is a typical midwestern state and has grown parallel to the national trends of population growth, the removal of the climax vegetation, urban expansion and suburban sprawl, industrial growth, some agricultural abandonment, and a shift to a postindustrial society. Furthermore, Ohio has an extensive network of temperature recording stations with an accumulation of sufficient standardized data to determine temperature trends that have occurred in the past several decades. There are 89 stations with at least 30 years of continuous EMWT data (Fig. 1). These stations are well distributed throughout the state (Table 1), and should represent minimum temperatures as they occur in Ohio.

Data Collection

The extreme minimum winter temperature (EMWT) is defined as the lowest daily minimum temperature (TMIN) observed for each winter at a given weather station. Daily minimum and daily maximum air temperatures are recorded at the seven National Weather Service (NWS) observing stations in Ohio, but the majority of data are collected by a network of volunteer observers at "cooperative" stations located throughout the state (Fig. 1). At cooperative

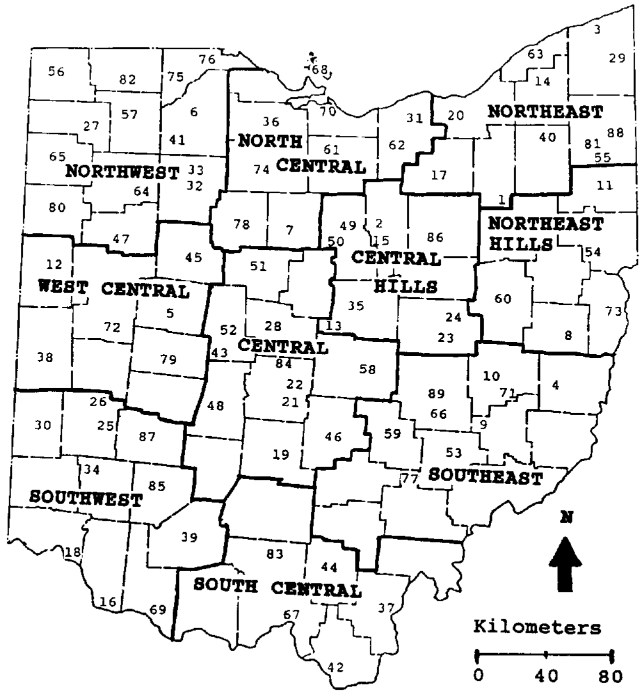

FIGURE 1. Locations of Ohio weather stations with at least 30 years of continuous extreme minimum winter temperature data. Dark lines indicate climatic division boundary. (See Table 1 for station number index.)

TABLE 1

Index of Ohio weather stations utilized for the analysis of extreme minimum winter temperatures in Ohio.

Map No.	Station Name*	Climate Division	County	Lat. ° 'N		Long. ° 'W		Elev. (m)
1	Akron-Canton WSO AP	Northeast	Summit	40	55	81	26	362
2	Ashland 2 SW	Central Hills	Ashland	40	50	82	21	380
3	Ashtabula	Northeast	Ashtabula	41	51	80	48	207
4	Barnesville	Southeast	Belmont	39	58	81	09	375
5	Bellefontaine	West Central	Logan	40	21	83	46	356
6	Bowling Green	Northwest	Wood	41	23	83	37	203
7	Bucyrus	North Central	Crawford	40	49	82	58	287
8	Cadiz	Northeast Hills	Harrison	40	16	81	0	378
9	Caldwell 6 NW	Southeast	Noble	39	49	81	36	294
10	Cambridge	Southeast	Guernsey	40	01	81	35	240
11	Canfield	Northeast Hills	Mahoning	41	01	80	46	342
12	Celina 3 NE	West Central	Mercer	40	34	84	32	257
13	Centerburg	Central Hills	Knox	40	18	82	39	362
14	Chardon	Northeast	Geauga	41	35	81	11	339
15	Charles Mill Lake	Central Hills	Ashland	40	44	82	22	308
16	Chilo Meldahl Lock	Southwest	Clermont	38	48	84	10	150
17	Chippewa Lake	Northeast	Medina	41	04	81	54	318
18	Cin Muni-Lunken Fld	Southwest	Hamilton	39	06	84	26	146
19	Circleville	Central	Pickaway	39	37	82	57	202
20	Cleveland WSFO AP	Northeast	Cuyahoga	41	25	81	52	231
21	Columbus Valley X-ing	Central	Franklin	39	54	82	54	225
22	Columbus WSO Ap	Central	Franklin	40	0	82	53	244
23	Coshocton 3 SSW	Central Hills	Coshocton	40	15	81	52	228
24	Coshocton Agr Rsch St	Central Hills	Coshocton	40	22	81	48	342
25	Dayton (City)	Southwest	Montgomery	39	46	84	11	224
26	Dayton WSO Ap	Southwest	Montgomery	39	54	84	12	299
27	Defiance	Northwest	Defiance	41	17	84	23	210

TABLE 1 *(Continued)*

Index of Ohio weather stations utilized for the analysis of extreme minimum winter temperatures in Ohio.

Map No.	Station Name*	Climate Division	County	Lat. °	Lat. 'N	Long. °	Long. 'W	Elev. (m)
28	Delaware	Central	Delaware	40	17	83	04	260
29	Dorset	Northeast	Ashtabula	41	41	80	40	294
30	Eaton	Southwest	Preble	39	44	84	38	301
31	Elyria 3 E	North Central	Lorain	41	23	82	03	219
32	Findlay FAA Ap	Northwest	Hancock	41	01	83	40	239
33	Findlay WP	Northwest	Hancock	41	03	83	40	230
34	Franklin	Southwest	Warren	39	33	84	19	201
35	Fredericktown 4 S	Central Hills	Knox	40	25	82	32	315
36	Fremont	North Central	Sandusky	41	20	83	07	180
37	Gallipolis	South Central	Gallia	38	49	82	11	173
38	Greenville Water Plt	West Central	Darke	40	06	84	39	307
39	Hillsboro	Southwest	Highland	39	12	83	37	330
40	Hiram	Northeast	Portage	41	18	81	09	369
41	Hoytville	Northwest	Wood	41	13	83	46	210
42	Ironton	South Central	Lawrence	38	32	82	40	201
43	Irwin	Central	Union	40	07	83	29	303
44	Jackson 2 NW	South Central	Jackson	39	04	82	39	210
45	Kenton	West Central	Hardin	40	39	83	36	299
46	Lancaster 2 NW	Central	Fairfield	39	44	82	38	258
47	Lima Sewage Plant	Northwest	Allen	40	43	84	08	255
48	London Water Works	Central	Madison	39	53	83	27	306
49	Mansfield WSO Ap	Central Hills	Richland	40	49	82	31	389
50	Mansfield 5 W	Central Hills	Richland	40	46	82	37	405
51	Marion 2 N	Central	Marion	40	37	83	08	290
52	Marysville	Central	Union	40	14	83	22	301
53	McConnelsville Lock	Southeast	Morgan	39	39	81	51	198
54	Millport 2 NW	Northeast Hills	Columbia	40	43	80	54	344
55	Mineral Ridge Wtr Wks	Northeast	Trumbull	41	09	80	47	267
56	Montpelier	Northwest	Williams	41	35	84	36	258
57	Napoleon	Northwest	Henry	41	22	84	09	205
58	Newark Water Works	Central	Licking	40	05	82	25	251
59	New Lexington 2 NW	Southeast	Perry	39	44	82	13	267
60	New Philadelphia	Northeast Hills	Tuscarawas	40	30	81	27	270
61	Norwalk	North Central	Huron	41	16	82	37	201
62	Oberlin	North Central	Lorain	41	16	82	13	245
63	Painesville 4 NW	Northeast	Lake	41	45	81	18	180
64	Pandora	Northwest	Putnam	40	57	83	58	231
65	Paulding	Northwest	Paulding	41	07	84	36	218
66	Philo 3 SW	Southeast	Muskingum	39	50	81	55	306
67	Portsmouth	South Central	Scioto	38	45	82	53	162
68	Put-in-Bay Perry Mon	North Central	Ottawa	41	39	82	48	174
69	Ripley Exp Farm	Southwest	Brown	38	47	83	48	264
70	Sandusky	North Central	Erie	41	27	82	43	175
71	Senecaville Lake	Southeast	Guernsey	39	55	81	26	263
72	Sidney 1 S	West Central	Shelby	40	16	84	09	281
73	Steubenville	Northeast Hills	Jefferson	40	23	80	38	298
74	Tiffin	North Central	Seneca	41	07	83	10	221

TABLE 1 (*Continued*)

Index of Ohio weather stations utilized for the analysis of extreme minimum winter temperatures in Ohio.

Map No.	Station Name*	Climate Division	County	Lat. ° ' N		Long. ° ' W		Elev. (m)
75	Toledo Express WSO Ap	Northwest	Lucas	41	35	83	48	201
76	Toledo Blade	Northwest	Lucas	41	39	83	32	179
77	Tom Jenkins Lake	Southeast	Athens	39	33	82	04	228
78	Upper Sandusky	North Central	Wyandot	40	50	83	17	256
79	Urbana Sewage Plant	West Central	Champaign	40	06	83	47	300
80	Van Wert	Northwest	Van Wert	40	50	84	34	237
81	Warren 3 S	Northeast	Trumbull	41	12	80	49	270
82	Wauseon Water Plant	Northwest	Fulton	41	31	84	09	225
83	Waverly	South Central	Pike	39	07	82	59	168
84	Westerville	Central	Franklin	40	08	82	57	243
85	Wilmington 3 N	Southwest	Clinton	39	29	83	49	309
86	Wooster Exp Station	Central Hills	Wayne	40	47	81	55	306
87	Xenia 6 SSE	Southwest	Greene	39	37	83	54	290
88	Youngstown WSO Ap	Northeast	Trumbull	41	15	80	40	353
89	Zanesville FAA Ap	Southeast	Muskingum	39	57	81	54	264

*From Climatological Data—Ohio, National Climatic Data Center (1990).

stations, special "maximum-minimum thermometers" record the highest and lowest twenty-four hour temperatures, and the thermometers are reset daily. The EMWT value is that daily minimum temperature that is the lowest in the annual series from 1 July of one year to 30 June of the following year. Rather than analyzing the annual (calendar year) minimum of previous studies, this "fiscal year" approach better represents the continuum of winter conditions present through individual winters.

All temperature data were originally collected in degrees Fahrenheit, but these were converted to degrees Celsius, and rounded to the nearest tenth of a degree (Celsius) before statistical analysis, and the major findings of the study are reported in Celsius. The time period under investigation is from the winter 1870-71 to 1989-1990, but most stations used in this study do not have data before 1900. Stations with at least 30 years of EMWT data were considered for the analysis. The NWS TMIN values were obtained from computer data tapes supplied by the Kent State University Climatology Laboratory, and the Ohio Agricultural Research and Development Center. Additionally, published sources of daily TMIN values were utilized. These include *Climatological Data: Ohio* and the *Ohio Section of Climatological Data*, and from the tables originally published by Alexander (1923).

Statistical Methods

Descriptive statistics were calculated using the SAS 5.0 (1985) statistical analysis package. Formulae for the univariate statistical procedures (mean, standard deviation, etc.) are not listed in the SAS manual; however, the text for geographers by Clark and Hosking (1986) was useful for interpretation of statistical methods. The Shapiro-Wilk test was utilized to test all variables for normality ($P < 0.05$). Data plotting, linear regression, and polynomial regression over time were used to examine the time series. Formulae are clarified in Zar (1984). All significance tests were made at the 95% confidence level by convention (Clark and Hosking 1986).

A state isotherm map of EMWT "normals" was drawn. A climatic "normal" is a 30 year average; the most recent "normal period" being the winter 1960-61 to 1989-90.

RESULTS

Descriptive Statistics

All data for each station fit the normal frequency distribution. The univariate statistics were surprisingly uniform throughout Ohio. A pooled standard deviation of 3.99° C was characteristic of Ohio EMWT. The coldest EMWT in the entire data set was -36.7° C for Sidney (West Central Division), recorded during January 1884, and the warmest was -9.4° C at Portsmouth (South Central), recorded 11 February 1937. Generally, the Northeast Division stations were coldest (Table 2), so it is noteworthy that the record coldest EMWT was found in west central Ohio. It was not surprising that the warmest EMWT was recorded at one of the most southerly locations. As expected, stations along the lakeshore or along the southern boundary had the warmest mean EMWT. Over much of Ohio, the mean EMWT was between -22° C and -24° C. A general latitudinal gradation was seen, especially in the South Central Division, where the isotherm

TABLE 2

Descriptive statistics for extreme minimum winter temperatures in Ohio.

	N	$\bar{x}$	s	Record Low	Record High	10th prctl	30 year Normal $\bar{x}$ (1961-90)
NORTH WEST DIVISION							
Bowling Green Swg Pl	96	-22.49	3.5	-30.0	-15.6	-27.8	-22.58
Defiance	77	-22.96	3.5	-32.2	-15.0	-27.8	-24.05
Findlay FAA AP	42	-21.89	3.6	-28.3	-15.0	-27.7	-22.70
Findlay Sewage Plant	93	-22.24	3.6	-29.4	-15.0	-28.1	-22.94
Hoytville	38	-23.48	3.2	-30.0	-17.8	-28.9	-23.84
Lima Sewage Plant	89	-21.98	3.4	-29.4	-15.0	-27.2	-23.33
Montpelier	88	-23.33	3.7	-31.7	-15.0	-27.9	-24.44
Napoleon	52	-23.43	3.6	-31.1	-16.1	-28.8	-23.02
Pandora	41	-23.24	3.3	-30.6	-15.6	-27.8	-23.83
Paulding	55	-23.35	3.5	-31.7	-16.7	-28.5	-24.06
Toledo Express WSO Ap	36	-23.25	3.2	-28.9	-16.1	-27.2	-23.83
Toledo Blade	91	-19.96	3.8	-26.7	-12.2	-25.6	-20.44
Van Wert	71	-22.47	3.5	-30.0	-15.0	-27.8	-23.02
Wauseon Water Plant	120	-23.98	4.2	-35.6	-14.4	-29.4	-24.43
NORTH CENTRAL DIVISION							
Bucyrus	96	-22.97	3.6	-33.3	-13.9	-27.8	-23.29
Elyria	41	-22.10	3.3	-28.3	-14.4	-26.1	-22.50
Fremont	38	-21.95	3.1	-27.8	-15.0	-27.2	-22.45
Norwalk	64	-23.18	4.2	-31.7	-15.0	-29.4	—
Oberlin	106	-22.54	3.8	-30.6	-14.4	-27.8	-23.72
Put-In-Bay Perry Mon	63	-19.65	4.1	-27.2	-11.1	-25.6	-20.35
Sandusky	107	-19.76	3.6	-27.2	-11.1	-25.1	-20.95
Tiffin	104	-21.39	3.5	-28.9	-14.4	-26.7	-22.42
Upper Sandusky	108	-22.06	3.6	-30.0	-15.6	-27.2	-22.68
NORTH EAST DIVISION							
Akron-Canton WSO AP	42	-21.68	3.9	-31.1	-15.6	-28.2	-22.37
Ashtabula	39	-20.24	3.3	-27.2	-13.3	-25.4	-21.20
Chardon	45	-23.67	4.0	-32.2	-16.1	-30.0	-25.40
Chippewa Lake	55	-22.98	3.3	-29.4	-15.0	-27.1	-24.03
Cleveland WSO AP	42	-20.88	3.7	-28.3	-14.4	-27.2	-21.71
Dorset	34	-26.22	2.7	-33.3	-21.7	-29.7	-26.68
Hiram	97	-21.82	3.7	-30.6	-15.0	-26.7	-22.41
Mineral Ridge Wtr Wks	51	-22.18	3.6	-28.9	-13.3	-27.2	-23.01
Painesville 4 NW	41	-19.02	3.5	-26.1	-12.2	-24.9	-19.66
Warren 3 S	98	-22.55	4.0	-32.2	-13.9	-27.8	-24.52
Youngstown WSO AP	42	-21.62	3.5	-28.9	-15.0	-26.5	-22.53
WEST CENTRAL DIVISION							
Bellefontaine Sewage	91	-23.22	3.7	-30.6	-15.0	-28.9	-24.01
Celina 3 NE	34	-23.30	3.6	-30.6	-16.7	-28.6	-23.46
Greenville Water Plt	97	-22.62	3.8	-32.2	-15.0	-27.9	-24.44
Kenton	100	-22.87	3.6	-31.1	-16.1	-27.8	-23.35
Sidney 1 S	44	-23.63	4.7	-36.7	-17.2	-30.6	—
Urbana Sewage Plant	95	-22.93	3.9	-32.2	-13.3	-28.3	-23.80
CENTRAL DIVISION							
Circleville	74	-21.00	4.1	-30.6	-12.8	-27.5	-21.66
Columbus Valley X-ing	42	-21.41	4.4	-30.0	-13.9	-28.9	-22.05
Columbus WSO AP	42	-21.01	4.0	-28.3	-14.4	-26.7	-21.62
Delaware Lake	68	-22.16	3.9	-32.8	-13.9	-27.3	-23.53
Irwin	49	-23.39	3.6	-31.1	-15.6	-28.9	-23.96
Lancaster	89	-22.16	4.4	-31.1	-12.8	-28.9	-22.86
London Water Works	54	-22.47	3.8	-30.6	-15.6	-27.8	-22.97
Marion 2 N	80	-22.54	3.6	-30.6	-13.3	-27.2	-23.71
Marysville	55	-22.44	4.0	-30.6	-13.9	-28.5	-23.07
Newark Water Works	55	-22.26	4.3	-32.2	-13.3	-28.5	-22.30
Westerville	37	-24.06	4.7	-32.8	-15.6	-31.7	-24.81

TABLE 2 (*Continued*)

Descriptive statistics for extreme minimum winter temperatures in Ohio.

	N	$\bar{x}$	s	Record Low	Record High	10th prctl	30 year Normal $\bar{x}$ (1961-90)
CENTRAL HILLS DIVISION							
Ashland 2 W	84	-22.17	3.4	-29.4	-14.4	-27.2	-23.52
Centerburg 2 SE	39	-23.57	3.9	-30.6	-17.2	-30.0	-23.83
Charles Mill Lake	49	-24.14	4.0	-33.3	-15.6	-28.9	-25.62
Coshocton Sewage Plt	55	-21.53	4.4	-28.9	-12.2	-28.3	-22.49
Coshocton Agri Rsch	34	-21.92	3.6	-29.4	-15.6	-28.3	-22.02
Fredericktown 4 S	41	-24.27	4.1	-32.2	-16.7	-30.5	-24.98
Mansfield WSO AP	39	-21.96	3.7	-30.0	-16.1	-28.9	-22.76
Mansfield 5 W	42	-25.48	3.6	-33.9	-18.9	-30.0	-25.83
Wooster Exp Station	107	-22.52	3.6	-31.1	-13.9	-27.8	-23.11
NORTH EAST HILLS DIVISION							
Cadiz	87	-20.90	3.9	-32.2	-12.2	-27.2	-21.91
Canfield 1 S	73	-23.21	3.9	-31.1	-14.4	-29.2	-25.77
Millport 2 NW	69	-24.49	3.9	-31.7	-17.2	-30.0	-25.84
New Philadelphia	30	-22.11	3.6	-28.3	-15.6	-27.2	-22.11
Steubenville	49	-20.22	3.7	-30.0	-13.9	-25.6	-20.98
SOUTH WEST DIVISION							
Chilo-Meldahl Lock Dam	53	-20.00	4.3	-29.4	-12.2	-26.7	-20.66
Cin Muni-Lunken Fld	35	-19.20	4.4	-28.9	-12.2	-26.0	-19.72
Dayton	106	-20.19	4.1	-33.3	-11.7	-26.3	-20.45
Dayton WSO AP	40	-22.22	4.0	-31.1	-15.6	-28.9	-22.65
Eaton	35	-23.69	4.7	-34.4	-16.7	-31.1	-23.95
Franklin	36	-21.82	4.3	-31.7	-15.6	-29.1	-22.00
Hillsboro	97	-21.29	4.0	-30.6	-12.2	-27.8	-21.61
Ripley Exp Farm	31	-21.71	4.6	-30.6	-13.9	-28.8	-21.80
Wilmington 3 N	69	-22.03	4.3	-31.7	-15.6	-29.4	-22.91
Xenia 6 SSE	55	-22.08	4.7	-33.3	-12.2	-28.5	-23.07
SOUTH CENTRAL DIVISION							
Gallipolis	55	-20.04	4.4	-29.4	-10.6	-26.7	-20.75
Ironton 1 NE	100	-18.85	4.4	-32.8	-10.0	-25.0	-19.44
Jackson 2 NW	55	-23.32	5.1	-35.0	-12.8	-30.4	-24.69
Portsmouth	100	-18.21	4.1	-28.9	-9.4	-24.2	-19.80
Waverly	55	-21.80	4.8	-31.7	-11.7	-29.4	-22.68
SOUTH EAST DIVISION							
Barnesville-Frds Sch	50	-24.07	4.2	-31.7	-14.4	-28.9	-24.54
Caldwell 6 NW	48	-22.30	4.3	-30.6	-12.2	-28.9	-23.50
Cambridge Water Plant	68	-22.81	4.7	-36.1	-12.8	-28.4	—
McConnelsville Lock 7	97	-21.50	4.4	-33.9	-11.1	-27.8	-22.60
New Lexington 2 NW	49	-23.73	4.6	-32.2	-15.0	-31.1	-24.37
Philo 3 SW	42	-20.92	3.9	-28.3	-13.9	-27.6	-21.63
Senecaville Lake	48	-23.07	4.7	-34.4	-15.0	-29.5	—
Tom Jenkins Lake	34	-24.92	3.9	-32.8	-15.6	-30.0	—
Zanesville FAA AP	45	-21.40	3.7	-28.3	-15.6	-27.5	-21.99

N = Number of winters in station climate record.
$\bar{x}$ = Mean extreme minimum winter temperature in degrees Celsius.
s = Standard deviation of extreme minimum winter temperatures in degrees Celsius.
10th prctl = The tenth percentile of the entire extreme minimum winter temperature data for that station.
Normal $\bar{x}$ = Thirty year mean for the time period 1961 to 1990.

gradient was steep. Portsmouth and Ironton (South Central Division) had the warmest mean EMWTs in Ohio. After latitudinal location, proximity to Lake Erie was the most important spatial control of EMWT. The lakeshore stations were relatively mild, and there was a steep decrease in mean EMWT inland, especially in the Northeastern Division where the mean EMWT dropped from -19.02° C at Painesville to -26.22° C at Dorset. There was more geographic variability of mean EMWT in the Northeastern Division than in other portions of the state from the effects of Lake Erie and the high terrain inland.

Over most of the flat western half of Ohio, the mean EMWT was between -22° C and -24° C, and the gradient was gentle. The mean EMWT pattern in eastern Ohio was more complex because of the hilly topography, Lake Erie, and the Ohio River. Surprisingly, some relatively cold spots were located in southern Ohio. For example, Tom Jenkins Lake (Southeast Division) was located in a region broadly characterized by generally mild EMWTs, but the station site was prone to cold air drainage. Despite its southerly latitude, this station exhibited some of the coldest EMWTs in the state, quite different from the surrounding stations.

Urban effects also had some influence on EMWT. In the Northwest Division, a 3.4° C temperature difference was observed between the warmer urban Toledo station (Toledo Blade) and the cooler rural Toledo station (Express Airport NWS Office). The proximity of the Toledo Blade station to Lake Erie also contributed to the contrast. A 2.2° C urban heat island effect was observed between the two Dayton sites (Southwest Division). The urban heat island effect on mean EMWT may help certain horticultural plants to survive through cooler periods—an arguable beneficial aspect of heat islands.

Site micro-characteristics influenced the EMWT in any location. Although the map (Fig. 2) was less generalized than the similar map produced by the U.S.D.A. (1990), further specificity at individual locations is possible only if site characteristics are known. Cold, dense air descends downslope on cold nights, therefore low spots are prone to colder EMWTs than the map indicates. This map (Fig. 2) still represents a broad generalization of EMWT in Ohio and should be viewed with caution.

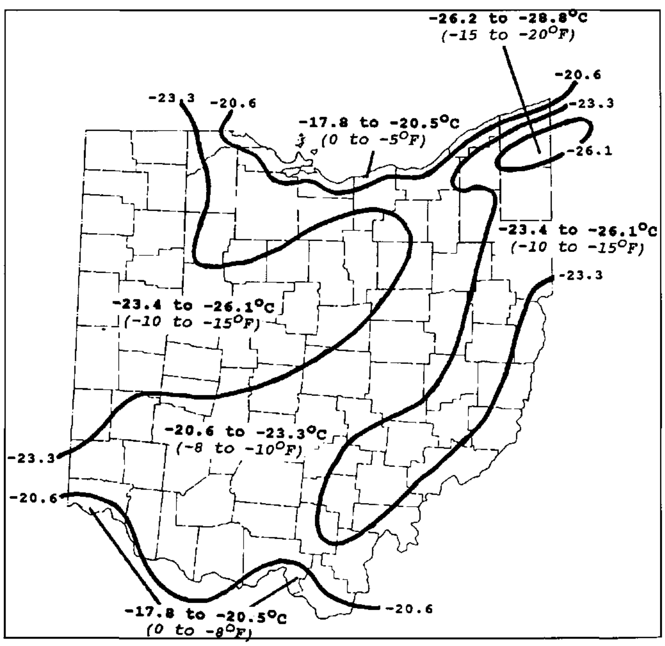

FIGURE 2. Map of mean extreme minimum winter temperature in Ohio (1960-61 to 1989-90 normal period). Isotherm categories are the plant hardiness zones defined by the U.S.D.A. Isotherms are shown here in degrees Celsius.

The record low EMWT for each station was an interesting comparative statistic; however, the magnitude of the record low EMWT was dependent on the length of station record. The longer a station records temperature, the greater the chance that a new, lower EMWT would have been recorded. A station with a long record had sampled more outbreaks of Arctic air than a station with a short record. Therefore, the record low EMWT was lower at stations with longer records, if all other factors were equal. The 10th percentile was the EMWT exceeded in 10% of winters. Few Ohio stations could have expected to have 10% of their EMWTs below -30° C, but 71% of Ohio stations have recorded a temperature below -30° C at least once in their climate record.

Time Series Analysis

The time series analysis revealed that Ohio EMWTs were not serially correlated. Some trends were observable through data plotting. Generally, the early portions of this century had cooler EMWTs, the 1930s had the warmest EMWTs, and there has been an overall cooling trend since mid-century. The data plots (Fig. 3) for Sandusky (North Central Division) and Hiram (Northeast Division) reflected the overall pattern. The wide variability of EMWT on any given winter complicated the pattern, but all stations showed the general trend. At Sandusky, the plot shows that although there were some mild years during the 1980s, the 1980s also had two winters when the EMWT

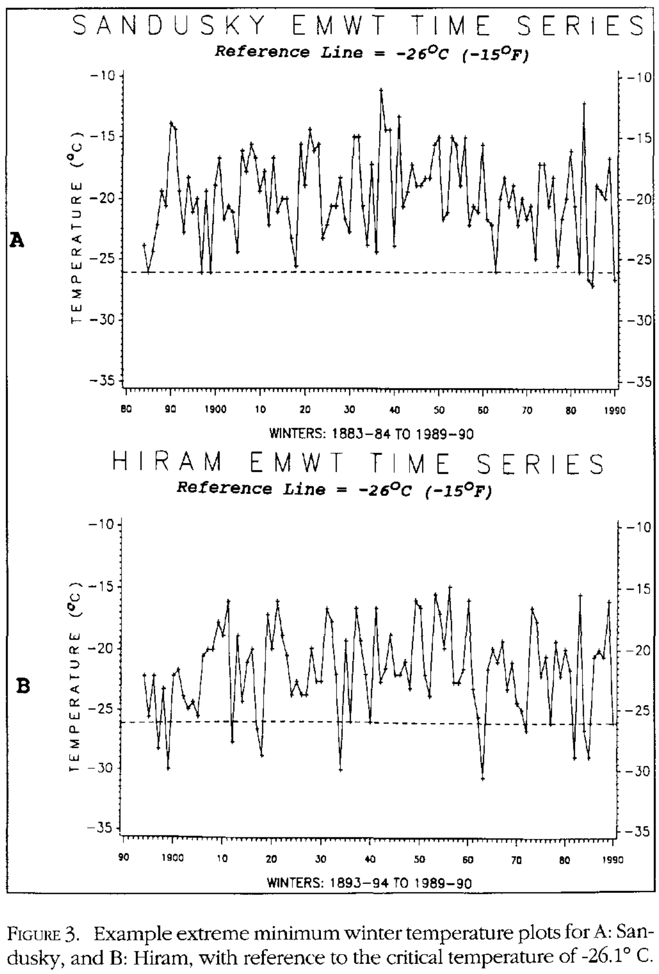

FIGURE 3. Example extreme minimum winter temperature plots for A: Sandusky, and B: Hiram, with reference to the critical temperature of -26.1° C.

dipped below -26.1° C (the critical temperature for some grapes, peaches, etc.), although in previous years it had never attained that degree of coldness.

The linear correlation and regression tests (Table 3) showed that Ohio EMWTs did not have a positive linear trend; in fact, the Northeast Division had several stations with cooling trends since mid-century (see Chippewa Lake graph, Fig. 4). Stations with a test for the slope beta (B) that were greater than 1.96 or less than -1.96 were significant. Ten stations had a century of EMWT data, however, only the Dayton city station had a significant positive (i.e., warming) linear slope (Fig. 5) and this might have been partially explained by the influence of urban warming. The linear tests for the recent normal period also did not show a warming of EMWT over time for most stations (Table 3).

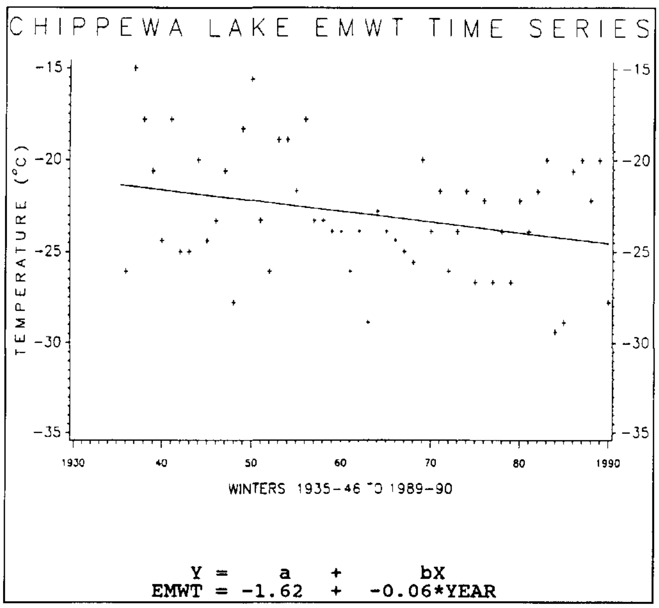

FIGURE 4. Significant linear cooling trend for the Chippewa Lake station (Northeast Division).

The polynomial regression tests (Table 4) also indicated that the most recent decades have been cooling. A negative (i.e., cooling) quadratic polynomial equation commonly had the best fit for those stations with a long period of record. In Table 4, *t*-test statistics greater than 1.96 or less than -1.96 were significant slopes (B) at the 95% confidence level (P <0.05). The best fit polynomial was partly a function of the length of the time series. However, the negative quadratic was the most common significant relationship considering all stations that have about a century of EMWT data. Significant polynomial curves were shown for Wauseon, Canfield, Wooster, and Oberlin (Fig. 6) as examples.

DISCUSSION

Descriptive Statistics

The EMWT statistics presented here deviate from the previous EMWT averages published by Rizzi (1980) and the handbook of the American Society of Heating, Refrigeration and Air Conditioning Engineers (A.S.R.A.E. 1985) which had only presented 27 Ohio stations for previous normal periods 1941-1970 and 1951-1980, respectively. The average EMWT was approximately 0.5° C to 1.5° C colder for most of these stations if the entire climate record is considered. A difference of up to 3.2° colder than the published value (Rizzi 1980) was found for some stations if only the recent normal period was considered. The differences were due to the differences in the normal period. This demonstrates the need for updated climatic normals, and closer scrutiny of previously published normals, particularity for extreme values.

For local expectations of EMWT, planners should be aware of the EMWT statistics of the cooperative station located nearest them. Planners are urged to familiarize themselves with the bias of the cooperative station located nearest them to compensate for local variability in EMWT. Planners who wish to use plant hardiness zone maps should be apprised of: 1) the mean EMWT at the stations nearest them, 2) variations resulting from changes in topography over short horizontal differences, and 3) any urban bias. Temperatures will tend to be a few degrees warmer on clear calm nights on ridges, compared to the valleys where cold air often accumulates.

The mean EMWT map (Fig. 2) here also varies a few degrees Celsius from the Department of Agriculture plant hardiness zone map (U.S.D.A. 1990), which used data

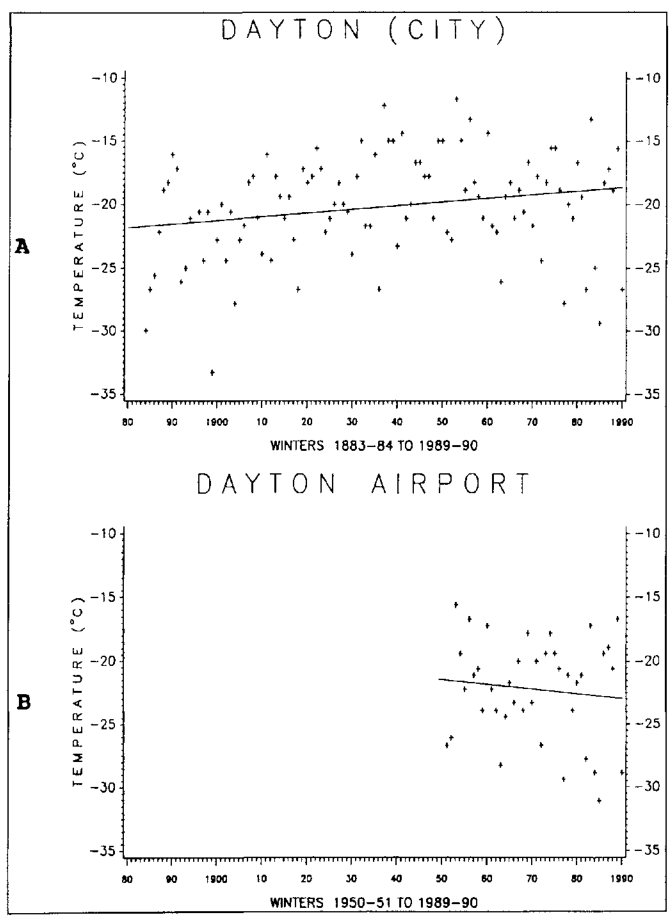

FIGURE 5. Comparison of the time series and linear regression at the A: Dayton city urban site, and the B: Dayton airport rural site (Southwest Division).

TABLE 3

Linear relationship of extreme minimum winter temperature over time.

	Test for Entire Time Series					Test for Normal Period 1960-61 to 1989-90		
	Time Series	*N*	r^2	Beta	Test H_o B = 0	r^2	Beta	Test H_o B = 0
NORTHWEST DIVISION								
Bowling Green Swg Pl	1894-95	96	0.140	0.018	1.373	-0.068	-0.026	-0.363
Defiance	m1894-95	77	-0.028	-0.003	-0.240	0.150	0.059	0.801
Findlay FAA AP	1948-49	42	-0.243	-0.044	-1.566	0.122	0.046	0.648
Findlay Sewage Plant	1894-95	93	0.020	0.014	0.191	0.127	0.049	0.678
Hoytville	1952-53	38	-0.216	-0.062	-1.329	0.013	0.005	0.068
Lima Sewage Plant	1901-02	89	-0.103	-0.014	-0.969	0.219	0.087	0.074
Montpelier	m1891-92	88	0.039	0.013	0.331	-0.005	-0.002	-0.028
Napoleon	m1893-94	52	0.120	0.016	0.848	-0.063	-0.025	-0.332
Pandora	1949-50	41	-0.163	-0.044	-1.029	0.147	0.056	0.784
Paulding	1935-36	55	-0.300*	-0.066	-2.288*	0.070	0.028	0.369
Toledo Express AP	1954-55	36	-0.231	-0.062	-1.222	0.089	0.031	0.472
Toledo Blade	m1870-71	91	0.112	0.011	1.288	0.071	0.030	0.377
Van Wert	m1894-95	71	0.059	0.008	0.486	0.111	0.043	0.593
Wauseon Water Plant	1870-71	120	0.163	0.020	1.795	0.031	0.013	0.166
NORTH CENTRAL DIVISION								
Bucyrus	1894-95	96	0.030	0.004	0.295	0.100	0.038	0.529
Elyria	1949-50	41	-0.186	-0.051	-1.182	-0.021	-0.007	-0.109
Fremont	1952-54	38	-0.206	-0.058	-1.262	0.060	0.021	0.314
Norwalk	m1894-95	64	0.236	0.041	1.914	—	—	—
Oberlin	1884-85	106	0.040	0.005	0.405	0.075	0.029	0.400
Put-In-Bay Perry Mon	m1921-22	63	-0.039	-0.008	-0.303	-0.016	-0.007	-0.085
Sandusky	1883-84	107	-0.021	-0.002	-0.210	0.007	0.003	0.035
Tiffin	1886-87	104	-0.101	-0.012	-1.022	0.017	0.006	0.088
Upper Sandusky	1882-83	108	0.096	0.011	0.996	0.009	0.003	0.048
NORTHEAST DIVISION								
Akron-Canton WSO AP	1948-49	42	-0.222	-0.071	-1.445	0.028	0.013	0.146
Ashtabula	1951-52	39	-0.373*	-0.115	-2.443*	-0.151	-0.058	-0.810
Chardon	1945-47	45	-0.646*	-0.198	-5.551*	-0.428*	-0.172	-2.503*
Chippewa Lake	1935-36	55	-0.282*	-0.058	-2.141*	0.167	0.053	0.897
Cleveland WSO AP	1948-49	42	-0.296*	-0.088	-1.958*	0.016	0.076	0.082
Dorset	1956-57	34	-0.421*	-0.114	-2.628*	-0.222	-0.063	-1.205
Hiram	1893-94	97	0.083	0.011	0.808	0.134	0.059	0.716
Mineral Ridge Wtr Wks	1939-40	51	-0.138	-0.034	-0.698	0.180	0.067	0.967
Painesville 4 NW	1949-50	41	-0.188	-0.055	-1.191	0.100	0.041	0.533
Warren 3 S	1892-93	99	-0.084	-0.012	-0.850	-0.092	-0.035	-0.487
Youngstown WSO AP	1948-49	42	-0.324*	-0.092	-2.167*	0.019	0.007	0.100
WEST CENTRAL DIVISION								
Bellefontaine Sewage	1894-95	91	0.006	0.001	0.061	0.088	0.037	0.464
Celina 3 NE	1956-57	34	-0.042	-0.015	-0.236	0.037	0.016	0.196
Greenville Water Plt	1893-94	97	-0.195	-0.026	-1.940	-0.054	-0.026	-0.288
Kenton	1890-91	100	0.041	0.005	0.402	0.166	0.070	0.888
Sidney 1 S	m1883-84	44	0.123	0.019	0.804	—	—	—
Urbana Sewage Plant	1895-96	95	-0.001	-0.000	-0.005	0.157	0.071	0.840
CENTRAL DIVISION								
Circleville	m1894-95	74	0.021	0.003	0.471	0.071	0.034	0.376
Columbus Valley X-ing	1948-49	42	-0.127	-0.057	-1.016	0.158	0.033	0.358
Columbus WSO AP	1948-49	42	-0.159	-0.041	-0.812	0.068	0.070	0.844
Delaware	1921-22	69	-0.219	-0.043	-1.802	0.079	0.037	0.417
Irwin	1941-42	49	-0.181	-0.045	-1.259	-0.029	-0.012	-0.155
Lancaster	1895-96	89	-0.008	-0.001	-0.073	0.060	0.028	0.318
London Water Works	1935-36	54	-0.131	-0.031	-1.252	0.099	0.042	0.527
Marion	m1894-95	82	-0.104	-0.013	-1.013	0.187	0.070	1.009
Marysville	1935-36	55	-0.123	-0.031	-0.900	0.108	0.049	0.577
Newark Water Works	1935-36	55	0.018	0.005	0.133	0.133	0.058	0.708
Westerville	1952-53	37	-0.101	-0.044	-0.598	0.226	0.123	1.227
CENTRAL HILLS DIVISION								
Ashland 2 W	m1894-95	84	-0.098	-0.013	-0.886	-0.115	-0.042	-0.615

TABLE 3 (*Continued*)

Linear relationship of extreme minimum winter temperature over time.

	Test for Entire Time Series					Test for Normal Period 1960-61 to 1989-90		
	Time Series	*N*	r^2	Beta	Test H_o B = 0	r^2	Beta	Test H_o B = 0
Centerville	1950-51	39	-0.063	-0.021	-0.383	0.070	0.032	0.370
Charles Mill Lake	1938-39	49	-0.335*	-0.094	-2.439*	0.129	0.058	0.650
Coshocton Sewage Plt	1935-36	55	-0.197	-0.054	-1.459	0.134	0.063	0.714
Coshocton Agri Rsch	1956-57	34	0.000	0.000	0.001	0.048	0.021	0.252
Fredericktown 4 S	1949-50	41	-0.243	-0.083	-1.340	-0.113	-0.050	-0.603
Mansfield WSO AP	1948-49	39	-0.307*	-0.093	-1.959*	-0.029	-0.011	-0.154
Mansfield 5 W	1948-49	42	0.093	0.029	0.631	0.460	0.183	2.742*
Wooster Exp Station	1883-84	107	0.070	0.008	0.718	0.176	0.066	0.944
NORTHEAST HILLS DIVISION								
Cadiz	1903-04	87	-0.092	-0.014	-0.824	-0.063	-0.028	-0.332
Canfield 1 S	1916-17	73	-0.378*	-0.069	-3.315*	0.106	0.037	0.564
Millport 2 NW	1921-22	69	-0.249*	-0.048	-2.101*	0.148	0.064	0.793
New Philadelphia	1960-61	30	0.099	0.041	0.527	0.099	0.041	0.527
Steubenville	1941-42	49	-0.169	-0.044	-1.174	0.035	0.086	0.186
SOUTHWEST DIVISION								
Chilo Meldahl Lock & Dam	1937-38	53	-0.073	-0.020	-0.970	0.158	0.084	0.849
Cin Muni-Lunken Fld	1955-56	36	-0.006	-0.002	-0.035	0.106	0.059	0.563
Dayton	1883-84	106	0.219*	0.029	2.235*	-0.004	-0.002	-0.021
Dayton WSO AP	1950-51	40	-0.113	-0.038	-0.700	0.011	0.005	0.058
Eaton	1955-56	35	-0.197	-0.091	-1.160	-0.079	-0.044	-0.420
Franklin	1953-54	36	0.007	0.003	0.040	0.115	0.059	0.615
Hillsboro	1893-94	97	0.074	0.011	0.818	0.177	0.087	0.949
Ripley Exp Farm	1959-60	31	0.011	0.006	0.061	0.049	0.026	0.259
Wilmington 3 N	1921-22	69	-0.135	-0.028	-1.115	-0.084	-0.043	-0.447
Xenia 6 SSE	1935-36	55	-0.173	-0.050	-1.276	-0.059	-0.031	-0.313
SOUTH CENTRAL DIVISION								
Gallipolis	1935-36	55	-0.114	-0.031	-0.837	0.075	0.036	0.400
Ironton 1 NE	m1882-83	100	0.142	0.021	1.418	—	—	—
Jackson 2 NW	1935-36	55	-0.179	-0.057	-1.327	0.312	0.181	1.738
Portsmouth	1890-91	100	-0.142	-0.020	-1.422	-0.163	-0.087	-0.874
Waverly	1935-36	55	-0.134	-0.040	-0.981	0.201	0.101	1.083
SOUTHEAST DIVISION								
Barnesville-Frds	1939-40	50	0.212	0.006	0.147	0.422	0.187*	2.461*
Caldwell 6 NW	m1935-36	48	-0.341*	-0.089	-2.459*	-0.148	-0.067	-0.793
Cambridge Water Plant	m1894-95	68	0.211	0.030	1.752	—	—	—
McConnelsville Lock 7	1893-94	97	-0.000	-0.000	-0.009	0.020	0.009	0.106
New Lexington 2 NW	1941-42	49	-0.079	-0.026	-0.546	0.145	0.074	0.774
Philo 3 SW	1948-49	42	-0.251	-0.080	0.710	-0.019	-0.008	-0.101
Senecaville Lake	1939-40	48	-0.202	-0.067	-1.395	0.023	0.014	0.114
Tom Jenkins Lake	m1953-54	34	-0.167	-0.066	-0.428	—	—	—
Zanesville FAA AP	1945-46	45	-0.099	-0.029	-0.264	0.053	0.023	0.280

Time series = Winter the climate record began.
N = The number of winters in the climate record.
m = At least one missing year in the time series.
* = Significant linear relationship ($P < 0.05$).
Test H_o = Test of the null hypothesis that the slope Beta (B) is equal to zero.
r^2 = Pearson Correlation Coefficient.

from a cooler period of the Ohio climate record (1974-1986). The average EMWTs during the last 30 years are warmer than that depicted by the U.S.D.A. map. At least one 30-year period of data should be collected before plant hardiness zones are mapped.

Time Series Analysis

The most recent "normal period" (Table 2) is the coldest on record for most stations. Most stations in Ohio have shown either no change over time, or a significant cooling trend in the most recent decades. The increasing frequency

TABLE 4

Polynomial regression tests of extreme minimum winter temperature over time.

	Record Started	Test for H_0: B = 0 N	X^2	X^3	X^4	X^5	X^6	X^7
NORTHWEST DIVISION								
Bowling Green Swg Pl	1894-95	96	-2.001*	-1.024	1.117	0.644	-0.695	—
Defiance	m1894-95	77	-2.220*	1.406	1.630	0.631	-0.676	—
Findlay FAA AP	1948-49	42	1.590	-0.466	-0.255	—	—	—
Findlay Sewage Plant	1894-95	93	-1.871	0.709	1.336	0.536	-1.579	—
Hoytville	1952-53	38	1.615	-0.369	0.365	—	—	—
Lima Sewage Plant	1901-02	89	-1.629	1.204	1.392	0.789	-1.891	—
Montpelier	m1891-92	88	-3.492*	1.057	1.754	2.098*	-0.183	—
Napoleon	m1893-94	52	-0.076	-1.026	0.147	-1.073	0.574	—
Pandora	1949-50	41	1.763	-0.166	-0.048	—	—	—
Paulding	1935-36	55	0.499	1.956*	0.142	—	—	—
Toledo Express AP	1954-55	36	1.993*	-0.907	-0.675	—	—	—
Toledo Blade	m1870-71	91	-1.598	-1.119	1.004	1.232	-0.889	-0.871
Van Wert	m1894-95	71	-1.717	0.387	1.009	0.219	-1.067	—
Wauseon Water Plant	1870-71	120	-3.042*	0.107	0.679	0.953	0.237	-0.184
NORTH CENTRAL DIVISION								
Bucyrus	1894-95	96	-1.573	1.230	1.200	-0.962	-0.597	—
Elyria	1949-50	41	1.175	0.124	0.921	—	—	—
Fremont	1952-54	38	1.527	-1.301	0.506	—	—	—
Norwalk	m1894-95	64	-1.247	-0.560	0.198	0.287	-1.132	—
Oberlin	1884-85	106	-2.870*	-1.031	2.702*	0.853	-2.030*	—
Put-In-Bay Perry Mon	m1921-22	63	-1.963*	1.453	0.392	-0.306	—	—
Sandusky	1883-84	107	-2.941*	0.191	0.207	1.172	-1.382	-0.182
Tiffin	1886-87	104	-0.780	-1.484	1.641	0.328	-0.628	-0.877
Upper Sandusky	1882-83	108	-2.443*	-0.769	0.728	1.835	-1.698	0.274
NORTHEAST DIVISION								
Akron-Canton WSO AP	1948-49	42	1.039	0.298	0.734	—	—	—
Ashtabula	1951-52	39	0.770	-0.228	0.563	—	—	—
Chardon	1945-47	45	0.231	3.142*	0.524	—	—	—
Chippewa Lake	1935-36	55	1.104	0.639	-0.164	—	—	—
Cleveland WSO AP	1948-49	42	1.358	-0.220	0.186	—	—	—
Dorset	1956-57	34	1.978*	0.704	0.736	—	—	—
Hiram	1893-94	97	-2.102*	0.818	0.004	0.927	0.231	—
Mineral Ridge Wtr Wks	1939-40	51	0.749	0.962	-0.125	—	—	—
Painesville 4 NW	1949-50	41	1.569	0.540	0.697	—	—	—
Warren 3 S	1892-93	98	-4.214*	0.358	2.578*	1.631	-0.345	1.175
Youngstown WSO AP	1948-49	42	1.366	0.170	0.613	—	—	—
WEST CENTRAL DIVISION								
Bellefontaine Sewage	1894-95	91	-1.588	-0.432	1.315	0.090	-1.135	—
Celina 3 NE	1956-57	34	0.464	0.005	0.305	—	—	—
Greenville Water Plt	1893-94	97	-2.760*	0.786	1.216	0.890	0.019	—
Kenton	1890-91	100	-0.933	0.014	1.637	0.611	-0.722	—
Sidney 1 S	m1883-84	44	-2.562*	0.912	-0.710	1.353	-1.196	—
Urbana Sewage Plant	1895-96	95	-1.877	0.789	1.402	-0.901	-0.317	—
CENTRAL DIVISION								
Circleville	m1894-95	74	-0.898	0.385	0.151	0.315	-0.111	—
Columbus Valley X-ing	1948-49	42	0.734	-0.560	0.431	—	—	—
Columbus WSO AP	1948-49	42	1.024	-0.975	0.773	—	—	—
Delaware	1921-22	69	-0.826	0.930	-0.454	-1.065	—	—
Irwin	1941-42	49	-0.043	0.405	-0.271	—	—	—
Lancaster	1895-96	89	-0.966	-0.011	0.205	0.712	0.987	—
London Water Works	1935-36	54	-0.275	0.146	-0.084	—	—	—
Marion	m1894-95	82	-1.847	2.172*	1.020	-0.626	-0.539	—
Marysville	1935-36	55	0.503	0.393	0.274	—	—	—
Newark Water Works	1935-36	55	0.490	-0.701	0.373	—	—	—
Westerville	1952-53	37	1.735	-1.431	1.555	—	—	—
CENTRAL HILLS DIVISION								
Ashland 2 W	m1894-95	84	-3.354*	-0.282	1.902	-0.033	-0.163	—
Centerville	1950-51	39	0.358	-0.652	0.433	—	—	—

TABLE 4 (*Continued*)

Polynomial regression tests of extreme minimum winter temperature over time.

	Record Started	N	Test for H_O: B = 0 X^2	X^3	X^4	X^5	X^6	X^7
Charles Mill Lake	1938-39	49	0.827	0.674	0.169	—	—	—
Coshocton Sewage Plt	1935-36	55	0.860	0.084	-0.453	—	—	—
Coshocton Agri Rsch	1956-57	34	-0.310	0.198	0.620	—	—	—
Fredericktown 4 S	1949-50	41	0.649	1.695	1.764	—	—	—
Mansfield WSO AP	1948-49	39	0.637	0.207	0.078	—	—	—
Mansfield 5 W	1948-49	42	2.087*	-0.445	-0.400	—	—	—
Wooster Exp Station	1883-84	107	-1.285	-1.053	2.144*	1.009	-1.954	0.908
NORTHEAST HILLS DIVISION								
Cadiz	1903-04	87	-1.625	-0.339	1.031	0.395	-0.393	—
Canfield 1 S	1916-17	73	-1.921	3.339*	0.831	0.207	—	—
Millport 2 NW	1921-22	69	0.354	0.748	0.567	-0.640	—	—
New Philadelphia	1960-61	30	-0.830	1.244	—	—	—	—
Steubenville	1941-42	49	-0.254	1.079	-0.929	—	—	—
SOUTHWEST DIVISION								
Chilo Meldahl Lock & Dam	1937-38	53	0.501	0.327	0.461	—	—	—
Cin Muni-Lunken Fld	1955-56	35	0.269	-0.765	0.547	—	—	—
Dayton	1883-84	106	-3.447*	-0.450	0.720	0.864	-1.074	0.906
Dayton WSO AP	1950-51	40	-0.143	0.451	-0.448	—	—	—
Eaton	1955-56	35	0.901	0.478	1.224	—	—	—
Franklin	1953-54	36	0.077	-1.193	1.671	—	—	—
Hillsboro	1893-94	97	-1.021	0.759	-0.358	0.103	-0.439	—
Ripley Exp Farm	1959-60	31	-0.665	0.192	0.994	—	—	—
Wilmington 3 N	1921-22	69	-1.214	-0.215	0.872	-0.235	—	—
Xenia 6 SSE	1935-36	55	-1.010	0.381	0.097	—	—	—
SOUTH CENTRAL DIVISION								
Gallipolis	1935-36	55	-0.178	0.520	-0.288	—	—	—
Ironton 1 NE	m1882-83	100	-3.093*	-1.064	-0.997	-0.720	-1.325	-0.180
Jackson 2 NW	1935-36	55	1.492	0.658	-0.771	—	—	—
Portsmouth	1890-91	100	-2.309*	-1.575	1.417	-0.857	0.666	—
Waverly	1935-36	55	0.799	0.072	-0.750	—	—	—
SOUTHEAST DIVISION								
Barnesville-Frds	1939-40	50	1.592	0.717	-0.668	—	—	—
Caldwell 6 NW	m1935-36	48	-0.578	0.114	-0.159	—	—	—
Cambridge Water Plant	m1894-95	68	-2.685*	0.386	1.441	-0.887	0.910	—
McConnelsville Lock 7	1893-94	97	-2.309*	-0.001	1.424	0.219	0.561	—
New Lexington 2 NW	1941-42	49	0.203	0.301	-0.638	—	—	—
Philo 3 SW	1948-49	42	-0.591	0.551	—	—	—	—
Senecaville Lake	1939-40	48	-0.603	0.649	-0.094	—	—	—
Tom Jenkins Lake	m1953-54	34	-1.692	1.824	—	—	—	—
Zanesville FAA AP	1945-46	45	0.432	-0.272	-0.105	—	—	—

N = Number of winters in the station record.
m = At least one missing year in time series data set.
* = Significant polynomial relationship (P <0.05).
X^2 = Quadratic relationship over time.
X^3 = Cubic relationship over time.
X^4 = Quartic relationship over time.
X^5 = Quintic relationship over time.
X^6 = Sextic relationship over time.
X^7 = Septic relationship over time.
H_O = Null hypothesis that the relationship is insignificant.

of extremes along the Lake Erie fruit belt (Fig. 3-A) is noteworthy. Fruit trees need a few years to grow to maturity. Even if greenhouse warming has contributed to increased average temperatures, the periodic occurrence of extreme cold in the life span of fruit trees would still limit their distribution. Recent warming during the late 1980s world-wide is considered by some climatologists to be evidence that global warming is well under way. Although the 1980s contain many of the warmest years on record at stations world-wide (Jones and Henderson-Sellers 1990), some of the coldest EMWTs at several Ohio stations were recorded during that decade (e.g., the Sandusky data plot). Perhaps Ohio EMWTs are not becoming warmer, but more variable.

Data provided by Jones (pers. comm., 1990) showed that the northern hemisphere warmed at a significant linear rate; however, the linear correlation and regression tests (Table 3) showed that Ohio EMWTs are not rising along with the significant linear hemispheric trend. In fact, in spite of mounting evidence of hemispheric warming (Jones and Henderson-Sellers 1990), Ohio EMWTs have remained steady or cooled in recent decades. The Dayton station is an exception, however, since the Dayton EMWT record began in 1883-84, the city has grown, and has been undoubtedly affected by a growing urban heat island. The rural (airport) station at Dayton had an insignificant negative slope since the EMWT record began in 1950-51. Urbanization has an influence on the time series analysis of temperature data (Jones et al. 1989) reported that urban bias accounted for a maximum of only 0.1° C change in northern hemisphere temperatures; however, the difference in EMWT between the two Dayton stations (Fig. 5) is much more striking.

The absence of linear significance is likely from the small number of short term climate fluctuations in the longer EMWT series. The stations whose time series began in the middle portion of the century (1935-36 to 1948-49) commonly had significant cooling trends, however. This is explained by the fact that the cool periods of the 1960s and 1970s contrast sharply with the warmer period of the 1930s, producing a significant negatively sloped regression line for these shorter-record stations.

Jones and Wigley (1990) had pointed out that the movement of the official weather observations from an urban site to (rural) airport locations may erroneously indicate a cooling trend. This might explain some cooling trends at some NWS official "first order" stations. Since rural areas are cooler, they argue, data from these airport locations may falsely refute the global warming hypothesis, or at least complicate the trend (Jones and Wigley 1990). This may be true in some areas of the United States and in some other parts of the world, but probably not EMWTs in Ohio. Since Ohio NWS first order station observations have been changed from cities to airports (1948-49), there has been a cooling trend for EMWT at most other stations as well. The (rural) first order stations had cooling trends simply because these started observations at the beginning of the cooling trend. More importantly, it is the cooperative network which supports the conclusion of no significant warming. Most cooperative stations were originally located in rural areas unaffected by heat islands, and remain unaffected by urbanization. The Northeast Division was unique because it has several stations with significant cooling trends since mid-century.

If the hemispheric temperatures measured and predicted by other geoscientists increases, a corresponding warming of Ohio EMWT may not necessarily follow the hemispheric average. Therefore, plants limited in range by cold winter temperatures would not be likely to expand their range.

Arguably, there could be a warming of EMWT, but not a linear trend. However, the polynomial regression

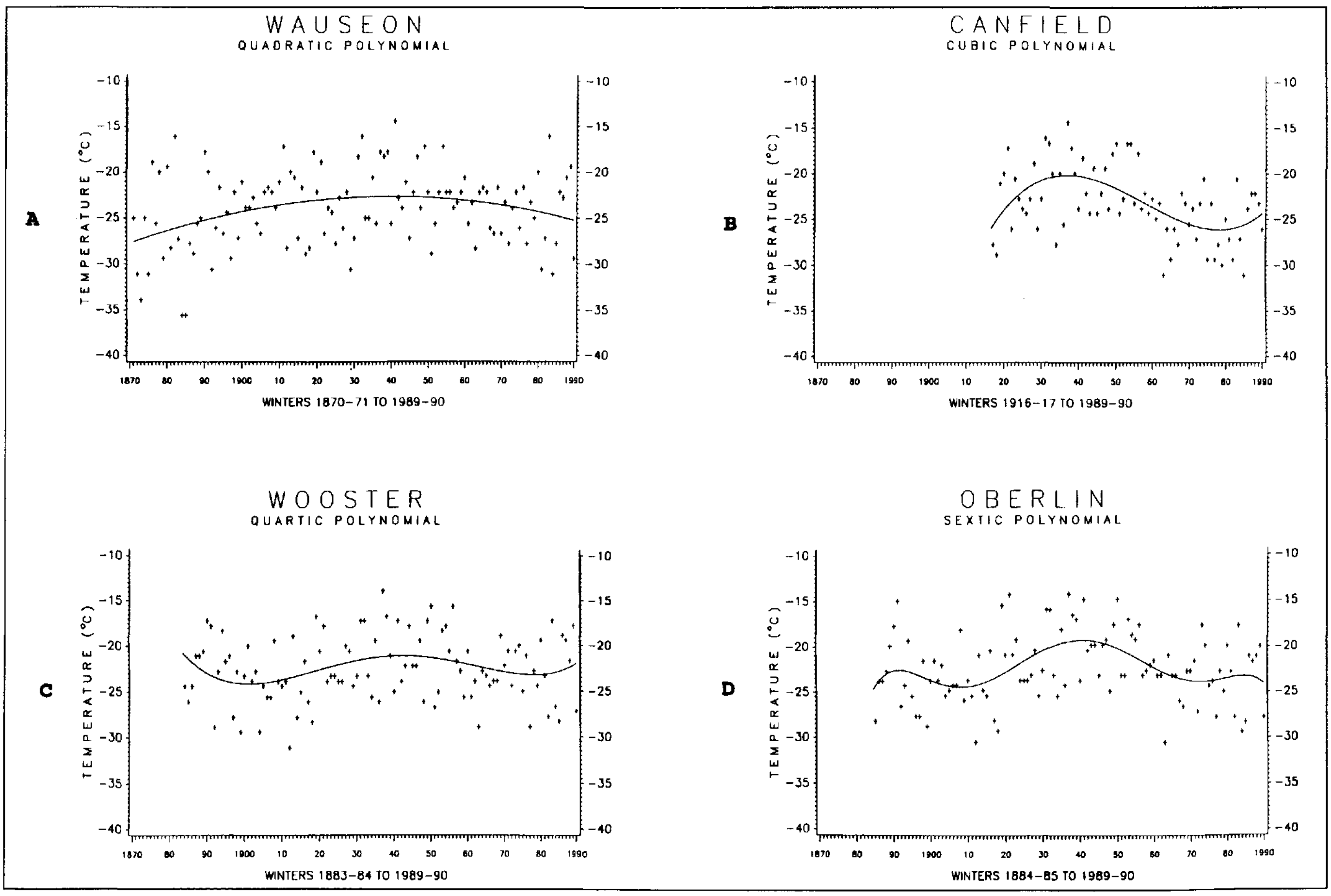

FIGURE 6. Example significant polynomial regression curves. A: Wauseon (Northwest Division) negative quadratic; B: Canfield (Northeast Hills Division), positive cubic; C: Wooster (Central Hills Division) positive quartic; and D: Oberlin (North Central Division) negative sextic.

analysis also indicated that there has been no overall warming, although some stations show an upward trend at the end of the eighties (Fig. 6). The negative quadratic polynomial curve seems to be the best descriptor of EMWT time series in Ohio. It is debatable whether the downward bow of the quadratic curve will continue or, if in the natural course of climatic fluctuations, there will be a trend back to warmer EMWTs.

In Ohio, the past three decades contain a procession of cooler than average winters during the 1960s, to the warm decade of the 1980s (Karl et al. 1983). Despite this potential for a warming of EMWT, there has not been a significant linear warming of Ohio EMWT. The data from the 1980s may indicate that a warming trend is beginning (Jones and Wigley 1990). However, short term fluctuations above and below average were common through the climate record. (Jones et al. 1982).

A sustained steady rise in EMWT may not endure for a time span of several decades. Perhaps the 1990s will prove to be a warm decade, and perhaps Ohio is due to return to the warm temperatures of the 1930s. However, the EMWTs will have to warm several degrees just to attain the magnitudes reached during that dust bowl decade. If the EMWTs during the 1990s prove to be warmer than the 1980s, these temperatures could still be considered well within the range of expectations, considering what EMWT has occurred during the entire climate record in Ohio.

Although there have been relatively warm and cold periods of EMWT through time, exceptionally cold EMWTs may occur during any winter. The geographic distributions of plants that are limited by cold EMWT are not expected to change significantly in the near future, as long as EMWT remain as cold as they have been in the recent normal periods. Climate change is a complicated issue however, and these findings of no change in EMWT are not inconsistent with the predictions of some proponents of global warming (Olstead 1993).

In this time of possible global warming and increasing climatic variability, there is a need for more research on observed, not speculative or anticipated climate changes. Predictions and models have their place in climatology, yet geographical climatologists should not lose their unique regional perspectives, and should continue their analysis of real world data. There is a need for more applied studies (measurable information that has real world application) that do not subscribe to the global warming paradigm. This is an area for the geographical climatologists to participate in. Since a political agenda is often attached to the global warming issue (Riebsame 1990), climatologists should remain skeptical about the causes of global warming or other climate changes as more regional climate studies are completed. If global warming is expected to change temperature or precipitation patterns, or initiate more extreme events, then it is up to the geographer to map these real-world observed changes. The applied climatologist can check local validity of long term predictions. There is a need to examine the actual (measured) climatic response in specific ecosystems. Further studies of extreme values that will investigate possible increases in climatic variability are suggested. Geographical climatology is that part of climatology that will measure and assess future global changes, and should play a part in long term decision making.

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