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A Ground Frost Climatology for Illinois

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ABSTRACT

Routine observations of ground frost depth were made by members of the Illinois Cemetery Association for 16 consecutive winters (1980-96). Maps of average and extreme depths are presented. Ground frost is generally found in northern Illinois by late November, continuing until mid-March or early April. In southern Illinois, a continuous frost season exists in all but the southernmost counties. In mild winters, ground frost is temporally and spatially discontinuous in the southern quarter of the state. Depths vary from as much as 30 inches (75 cm) or more during the height of the season in the northwest, to a few inches in the south.

Ground frost in Illinois varies substantially from winter-to-winter. The greatest thicknesses and longest tenure were observed during the winter of 1981-82 (the ninth coldest for the state since 1895), with the least occurring during the 1991-92 winter (where the mean December, January and February temperatures were among the 21 warmest since 1895). In addition to winter temperatures, ground frost is also impacted by the persistence and depth of snow on the ground, soil type and moisture content.

INTRODUCTION

Ground frost depth plays a major role in the magnitude of spring surface water runoff versus percolation into soil and therefore flooding potential, the mortality of insects or larvae buried in the soil over-winter, the length of the dormant season in soil and specification of minimum building foundations, among others. However, frost depth information is not generally available, at least not on a routine, spatially continuous basis. Although soil temperature data can assist in frost depth determination (a parameter measured at some National Weather Service sites), routine observations of soil temperatures, too, are few in number.

Relative to the Upper Midwest, ground frost information has been published by the National Weather Service, showing mean and extreme (1899-1938) ground frost depths for the eastern two-thirds of the U.S. gathered "from unofficial sources" (Anon., 1981). Bi-weekly annual and mean frost depths (1961-1977) are available for Wisconsin by climate district (Anon., 1978), and maximum depth of frozen soil for Minnesota from 1959 to 1965 is presented by Baker & Swan (1966).

In order to improve the coverage of ground frost information, the Illinois Cemetery Association was contacted in 1980 to determine whether members located at cemeteries about Illinois would be willing to measure and report frost depth at routine times during

the winter season. An article was prepared for the Association's Newsletter, to which about 40 cemeteries responded favorably. The respondents were supplied with instructions as to how to properly observe and postcards on which to record the observations. Each observer was asked to record frost depth determined visually at a fresh excavation at one or more locations every two weeks during the frost season. In addition, information on a number of surface conditions in the area of measurement was requested, including whether the site was (1) moist or dry, (2) on a rise, hollow, or a slope, (3) bare ground, (4) short or long grass-covered, (5) trees overhead, and (6) whether the soil was of fine or coarse texture, mainly sand, loam or clay. Essentially all comments which follow are based on measurements made under sod.

Observations began in December 1980 and continued through March 1996, from which this summary is compiled. Some 41 cemeteries participated in the study, their locations shown in Fig. 1. The number of reports (and reporting sites) varied from month-to-month, and from year-to-year, averaging about 70 per season, varying from 35 to 102. The number of seasonal observations varied inversely with the mean winter temperatures, with most originating from the northern two-thirds of the state since ground frost is not always present in southern Illinois. In addition to varying interest with time, observations were at times prohibited by the lack of burials, particularly in smaller towns. In some cases, temperatures at some northern sites were sufficiently cold and frost sufficiently thick that burials were delayed until such time that grave excavations were possible, also precluding observations.

RESULTS

Mean ground frost conditions

Mean frost depths as of the end of December, January and February are shown in Fig. 2. In the mean, at the end of December frost varies from about six inches (15 cm) in northwestern Illinois to only one inch (2-3 cm) from about St. Louis northeastward to about Effingham and Vermilion Counties. The influence of Lake Michigan can be seen in the moderated frost depths of northeastern Illinois, a condition noted throughout the season. Mean thicknesses in the southeastern third of the state at this time of the year vary from less than one inch to zero in the far south, and are often temporally and spatially discontinuous. By January's end, mean frost thickness varies from some 14 inches (~35 cm) in northwestern counties to about six inches (~15 cm) in central Illinois to less than two inches, and probably discontinuous frost in the south. By the end of February, mean frost thicknesses have declined to about eight inches (20 cm) in northwestern Illinois, less than four inches (10 cm) in the southernmost seven climate districts, and essentially none in the south.

Average frost depths reported for southern Wisconsin at the end of December and January are similar to those reported herein, however depths reported as of the end of February are somewhat greater than reported in adjacent Illinois counties. These differences are likely due to the fact that the Wisconsin data (Anon., 1978) were collected from 15 winters beginning 20 years earlier than the sampling period in Illinois, and because the Wisconsin data represent district averages (an average of some 6,000 square miles) whereas those of Illinois data are site-specific.

Worst ground frost depth conditions

The longest ground frost season, and that with the deepest penetration in Illinois during the 16 winters of record occurred in 1981-82. Frost was continuous over the northern half of the state by early November 1981 (not shown), and persisted over the same area until late March. The frost was at least 10 inches (25 cm) thick by the end of December over northern and western counties. By the end of January, similar thicknesses were common over the northern two-thirds of the state, with 30 inches (75 cm) reported in north-central counties (roughly, Ottawa and north). Ground frost greater than two inches (5 cm) was reported in all of southern Illinois at the end of January 1982, the only month with such extensive coverage during the period of record. At February's end, frost of at least 10 inch (25 cm) thicknesses persisted over the northeastern third of the state, with extreme northern counties still supporting 30 inches (75 cm). As with the average depth data, extreme depths for southern Wisconsin districts were somewhat greater than adjacent Illinois counties, likely for similar reasons given above.

Not surprisingly, Illinois statewide temperatures for December through February 1981-82 were the 9th coldest of all Illinois winters since 1895, whereas those for December 1981 were the 27th, January 1982 were the 9th, and February 1982 were 21st coldest for the same period, respectively.

Winter with shortest ground frost conditions

The winter with the shortest ground frost season and that with the shallowest depths during the period of record was that of 1991-92, when continuous frost first developed in northern Illinois during the last week of November 1991, and only reached thicknesses of eight inches or so (20 cm) in extreme northwestern counties by the end of January 1992. Ground frost had totally disappeared by the end of February (a condition only observed during one other winter during the period of record, February 1987. Statewide mean temperatures at the end of December 1991, January and February 1992 were the 21st, 15th and 7th warmest, respectively since 1895.

Thickest ground frosts reported during years of record

Fig. 3 shows the deepest ground frost reported during any of the 16 winters, by month. The values suggest that all but extreme southern Illinois is susceptible to ground frost by the end of December, with maximum thicknesses of 15 inches (38 cm) or more in northern counties. By the end of January, maximum thicknesses vary from 32 inches (80 cm) in north-central counties to less than five inches (13 cm) in the far south. At February's end, essentially all the state is still susceptible to ground frost, with extreme depths of 30 inches (75 cm) in the north to some five inches (13 cm) in the far south.

To put the shortest and thickest ground frost seasons in some perspective, Table 1 presents a summary of the mean and extreme times of occurrence of first autumnal and last spring frost events. Dates are presented for both 32F (0C) and 28F (-2.2C) because although 32F represents frost, 28F is often used to represent a frost of sufficient duration to kill vegetation and perhaps initiate ground freezing.

Maximum frost depths during any month of the 16 winters of observation vary from about 32 inches (80 cm) in the north to some 5 inches (13 cm) in southern Illinois. For

comparison purposes, extreme frost depths reported by the National Weather Service from data collected from 1899-1938 varied from about 37 inches (94 cm) in northwestern Illinois to about 15 inches (38 cm) in southern Illinois (Anon., 1981).

The earliest onset of ground frost during the period of record is shown on Fig 4, and varies from the last week or so of November in northwestern counties to as late as mid-December in the far south, though often did not persist through the winter. The latest vestiges of ground frost during the period of record lingered as late as mid-March in the far south, and the first week of April in the north.

Mean temperature-frost depth relationship

The depth of ground frost at any given time is a function of air temperature during some period of time preceding the measurement, the temperature's temporal stability, soil moisture, soil type, vegetation cover, and the depth and persistence of snow cover. To investigate this relationship, frost depths reported at a west-suburban Chicago cemetery (one of the most complete frost records) at the end of each of the 16 Februaries were related to the mean December through February temperatures for the same winter. Numbers plotted above data points indicate the number of December-February days with at least four inches (10 cm) snow cover. When plotted (Fig. 5), a relationship between frost depth and mean temperature is not readily apparent, likely due to variations in soil type and moisture, and snow and vegetation cover. Dry, bare soil with little snow cover promotes deeper frost than wet, sod- and deep snow-covered soil.

The extreme depths for winter mean temperatures, however, appear to be linearly related, i.e., colder mean winter temperatures support greater frost extremes, although lesser depths can also prevail due to reasons stated above. The following relationships describe the relationship between mean winter temperature and extreme frost depth as of the end of February:

Extreme frost depth (in) = -1.5 mean Dec-Feb temperature (F) + 50.0,
Extreme frost depth (cm) = -7.9 mean Dec-Feb temperature (C) + 1.6.

From Fig. 5, it appears that ground frost can exist when mean winter temperatures fall below about 33F (0.7C). Shallower than these extreme frost depths for any given mean winter temperature are undoubtedly due to variations of within-winter temperatures and soil moisture.

An empirical study (Lowenherz & Wendland, 1988) based on these frost observations from 1980-1985 found that frost depth at any given time responded primarily to frost depth two to four weeks preceding the time of observation, and freezing degree days accumulated during that interval.

CONCLUSIONS

This 16-season review of Illinois ground frost reveals that ground frost is essentially spatially and temporally continuous in the northern two-thirds of the state from mid- to late-December through early March. Ground frost in the southern half of the state can be temporally and spatially discontinuous.

Thicknesses are generally greatest in northwestern counties, averaging as much as about 14 inches (35 cm) in mid-winter, decreasing by a few inches in northeastern counties, and decreasing further to four to six inches (10-15 cm) in central Illinois. On average, sites in southern Illinois experience only a few inches, and the frost episodes may be sporadic through the winter. During the period of observation, extreme frost depths were as much as 30 inches (75 cm) in north-central Illinois and about five inches (13 cm) in southern counties.

Data from this study suggest that ground frost can exist at the end of February whenever the mean winter temperature falls below about 33F (0.7C).

ACKNOWLEDGMENTS

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Table 1. Earliest, 10%, 90% and latest dates for 32F and 28F temperatures in fall and spring in Illinois, by climate district, based on 1961-1990 data, the period for which current climate "normals" are calculated.

Climate	Dates for first fall 32F frost in Illinois				Dates for last spring 32F frost in Illinois			
District	ERLST	90%	10%	LTST	ERLST	90%	10%	LTST
NW	9/12	9/26	10/26	11/14	3/28	4/11	5/10	5/28
NE	9/21	10/02	10/27	11/30	3/25	4/14	5/14	6/12
W	9/03	9/30	11/01	11/14	3/23	4/06	5/05	5/11
C	9/14	9/30	11/01	11/09	3/30	40/9	5/07	5/29
E	9/21	9/30	10/27	11/12	3/31	4/10	5/10	5/27
SSW	9/22	10/03	11/01	11/20	3/18	4/03	5/01	5/20
SSE	9/01	10/03	11/02	11/15	3/21	4/05	5/08	5/28
SW	9/22	10/02	11/0	11/19	3/21	3/29	4/30	5/10
SE	9/22	10/06	11/05	11/20	3/21	3/21	4/40	5/28

Climate	Dates for first fall 28F frost in Illinois				Dates for last spring 28F frost in Illinois			
District	ERLST	90%	10%	LTST	ERLST	90%	10%	LTST
NW	9/23	10/06	11/07	11/20	3/21	4/03	4/30	5/10
NE	9/22	10/13	11/13	12/02	3/15	4/10	5/01	5/22
W	9/30	10/11	11/12	11/28	3/14	3/28	4/23	5/10
C	9/22	10/06	11/13	11/25	3/05	3/28	4/24	5/29
E	9/23	10/09	11/12	12/02	3/18	3/29	4/29	5/10
WSW	9/23	10/12	11/14	12/15	2/25	3/21	4/18	5/10
ESE	10/02	10/12	11/14	11/28	3/07	3/22	4/17	5/10
SW	10/01	10/14	11/20	12/05	3/06	3/16	4/14	5/05
SE	10/03	10/14	11/18	12/05	2/28	3/16	4/15	5/27

ERLST and LTST refer to earliest and latest reported frost dates-ever, 90% and 10% refer to percent of frost dates occurring after-given date.

Figure 1. Illinois climate districts. Locations of participating cemeteries indicated by dots.

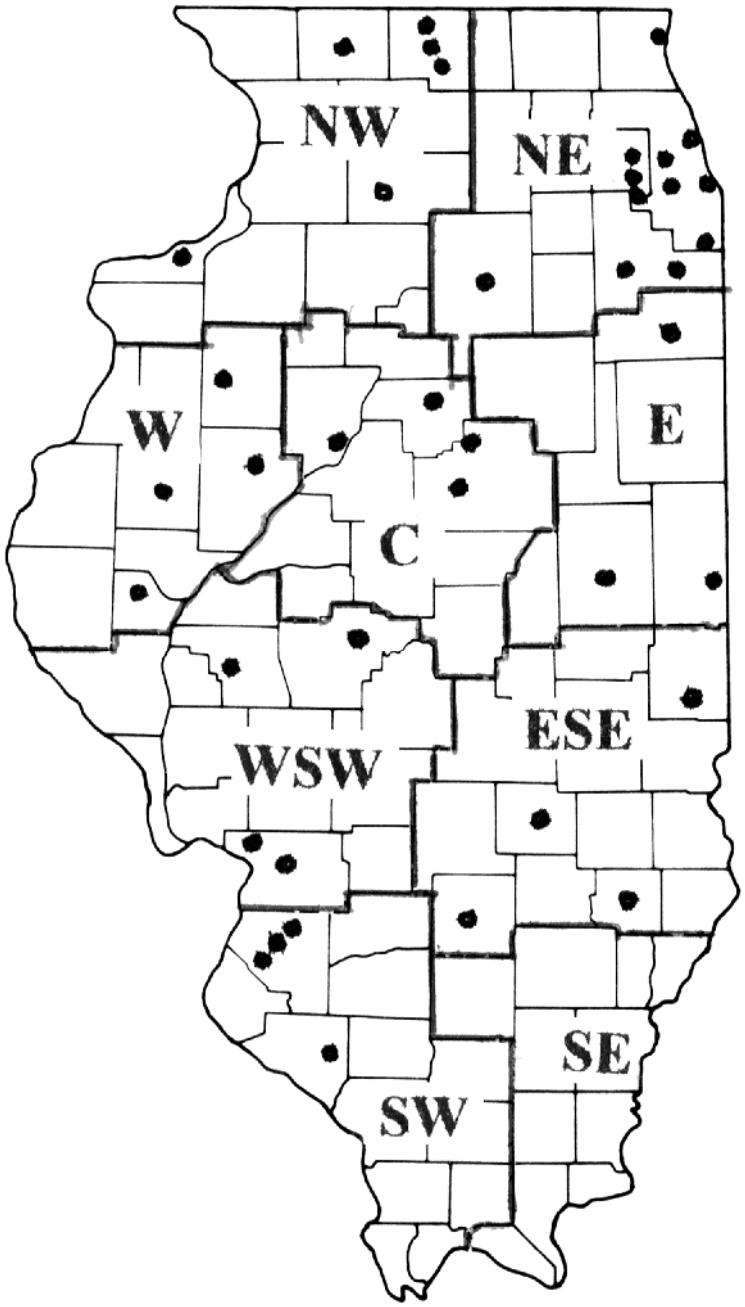


Figure 2. Mean frost depth (1980-96) at end of December, January and February (inches).

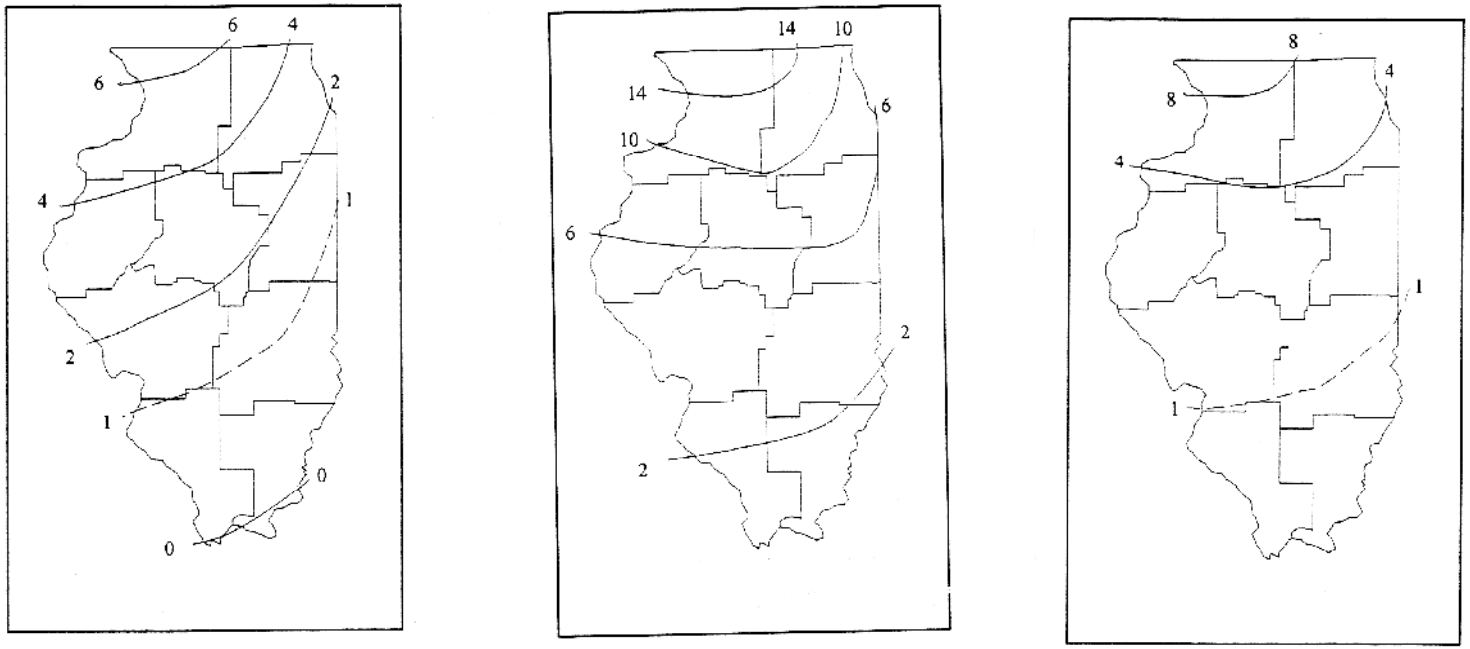


Figure 3. Deepest frost reported (1980-96) at end of December, January and February (inches on left, centimeters on right).

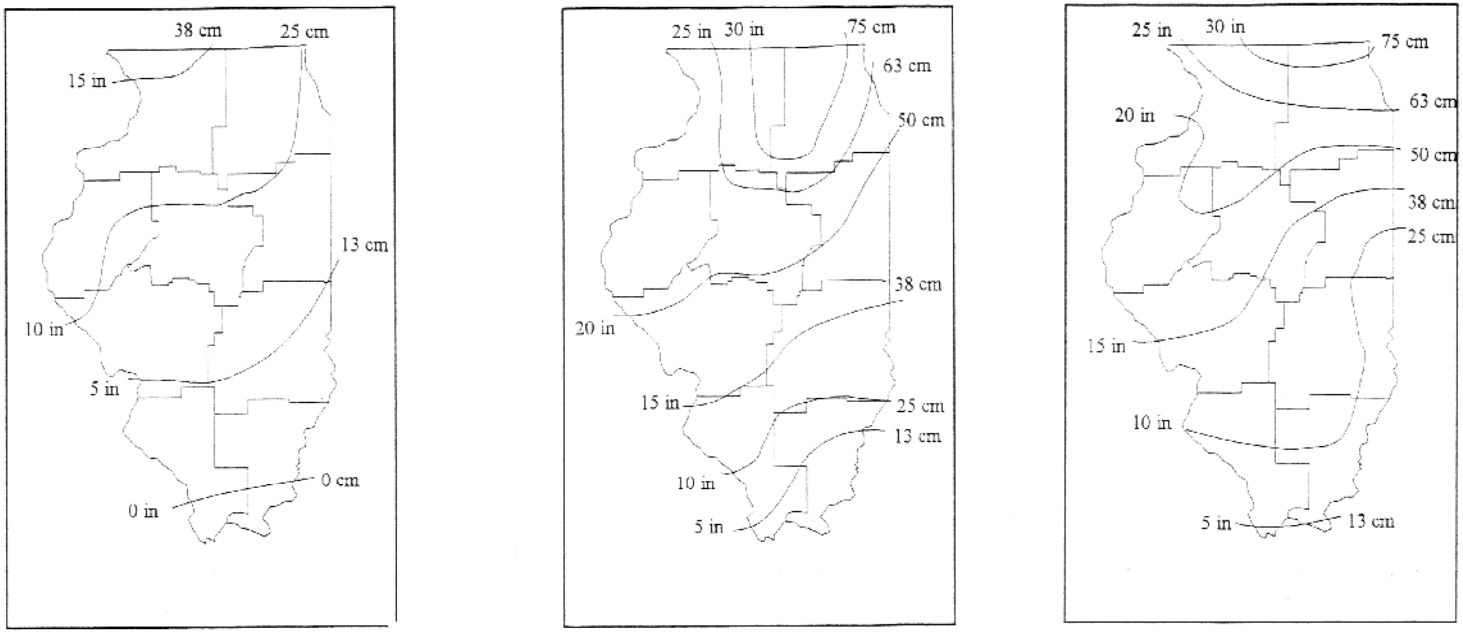
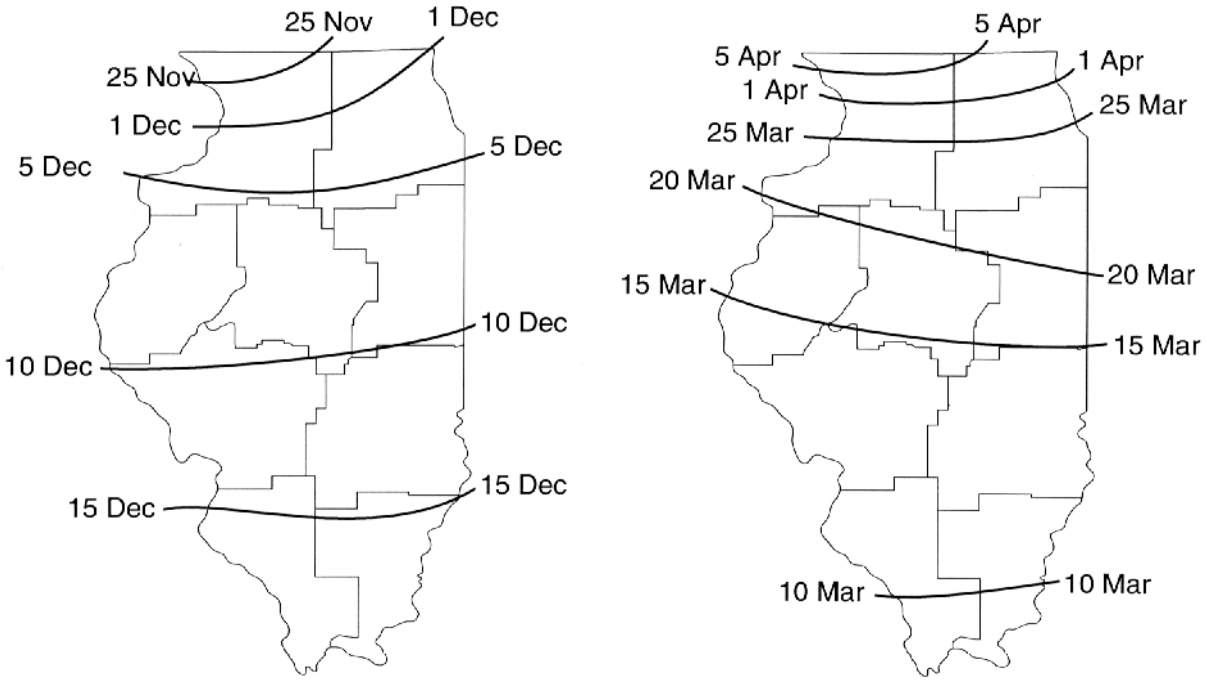


Figure 4. Earliest and latest reported dates of ground frost from 1980-1996.



Earliest onset of ground frost
(1980-1996)

Latest reported ground frost
(1980-1996)

Figure 5. Frost depth as of end of February as a function of mean winter temperature. Numbers above data points represent the number of December-February days with at least four inches (10 cm) snow cover.