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A Climatology of Late-spring Freezes in the Northeastern United States

Brian E. Potter and Thomas W. Cate

NOTE: The maps contained in this report are accessible on the world wide web at **http://climate.usfs.msu.edu**. We encourage readers to use them in whatever format best serves their needs. We also welcome feedback on the report and maps. Send letters to Brian Potter, North Central Research Station, 1407 S. Harrison Road, Suite 220, East Lansing, MI 48823 or call (517) 355-7740, extension 28. There is also a link on the web page allowing readers to send comments regarding the maps via email.

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When plants start to unfurl their leaves in the spring, each individual species does so at its own particular time. Each species, and in some cases each subspecies, also has its own tolerance for freezing, and this determines how readily subfreezing temperatures damage new foliage. Two species of tree may flush at the same time, but one may be susceptible to freeze damage earlier or longer than the other during flushing. Or one species may be able to survive air temperatures just below freezing better than the other species.

Forest managers and plant or animal physiologists concerned with freeze-sensitive species need to know the character of the species' sensitivity, and what the freeze climate is for geographic areas where they are working. Traditionally, the primary form of freeze information available is the average date of the last spring freeze. In some areas, more information about the probability of a freeze after certain dates may be available. This information does not always help, however, because plant phenology does not always follow a human calendar closely. All trees of a given species do not flush on the same calendar day every year; they generally flush later if the spring is cool, and earlier if it is warm. Biological research often relates information about development and growth to heat sums. Heat sums are a way of quantifying how warm the weather is, and for how long. They are typically expressed in units of growing degree days (Dunster and Dunster 1996), with reference to a particular base temperature. A heat sum of one growing degree day (GDD) can result from a temperature 2 °C above the base for half a day (12 hours), or from a temperature 1 °C above the base for one day, a temperature 3 °C above the base for one-third of a day (8 hours), or any similar combination.

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Thomas W. Cate, Computer Clerk, received a B.S. in geography from Michigan State University and assisted with this study while working as a student employee of the North Central Research Station.

The analysis we discuss here describes the late-spring freeze climate of the North-central and Northeastern United States based on heat sums with a base temperature of 5 °C. We examined the geographic region extending from the United States-Canada Border south to Missouri, Kentucky, and Virginia, inclusive, and from the Atlantic Ocean westward to Minnesota, Iowa, and Missouri, inclusive.

The data used in our analysis included daily maximum and minimum temperatures for 421 stations in the National Weather Service's Cooperative Observers Network. The precision of these measurements is 0.6 °C. We examined temperatures for each station for the 30-year period from 1961 through 1990. By spatially interpolating this data, we created maps of the average calendar day for freezes, average freeze temperature, and average frequency of late-spring freezes for freeze events that occurred after each of several heat-sum thresholds. We also produced maps showing the calendar day on which the chosen heat-sum thresholds occur each spring. All of these maps appear in this report.

Following a discussion of the meteorological conditions that lead to late-spring freezes and some general comments regarding the maps and patterns on them, we offer several examples of how the maps can be used in practice. Technical information regarding the data and analysis techniques used to produce the maps appears in the appendix.

Meteorologically, several physical processes can contribute to the development of subfreezing air temperatures. The most common processes are radiative loss of energy at night under calm, clear conditions, and the movement of a cold air mass into an area—often the result of a passing cold front or local cold-air drainage. Radiative energy loss results when the amount of infrared radiation (also known as longwave or thermal radiation) passing upward from the ground to the sky is greater than the amount of radiation flowing downward from the sky. These conditions lead to the ground and near-ground air being colder than overlying air (fig. 1). When a cold air mass moves into an area, the air is relatively well mixed and has a temperature that varies little over height (fig. 1). In nature, both processes contribute to any cooling event, but often one is much stronger than the other.

Clearly, which process dominates can be important to a specific forestry-related question due to its influence on freeze duration and vertical temperature structure. Because of the nature of the temperature records we used, it was not possible to distinguish these two types of events in this analysis. Thus, the final data include all events where the temperature fell below freezing at any time on a given day.

DISCUSSION

The maps display two general patterns. All maps show some influence of latitude, and the

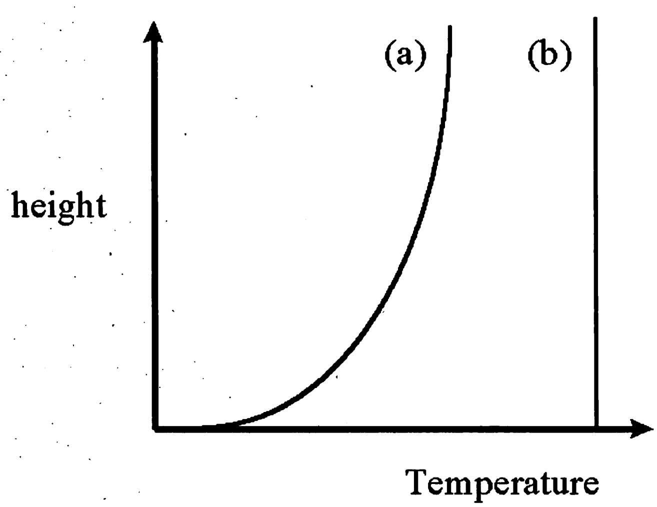

Figure 1.—*Typical temperature profiles for (a) radiation-driven freeze and (b) air-mass freeze.*

threshold and freeze-day maps also show dependence on elevation. Superimposed on these, the microsite characteristics of the stations produce much of the spottiness on the maps. Water treatment plants, airports, and dams are common sites for surface air weather stations. Each of these types of sites has its own particular influence on airflow, radiation, and humidity, and these can, in turn, influence heat-sum accumulation and freeze occurrence. The biases created by microsite are not systematic, and even their magnitude is rarely known. Because of microsite influences and the spatial interpolation of the data, the accompanying maps should be used to ascertain regional (20 to 50 km) or larger scale patterns, not the properties of smaller, specific locations. One must always bear in mind that for a specific site, there is no substitute for on-site measurements of weather variables.

The impact of elevation on threshold and freeze days is most evident around Mount Washington, New Hampshire and in the Appalachian Mountains of West Virginia and Virginia. Atmospheric temperatures decrease with increasing altitude, and sometimes increased clouds or fog reduce temperatures at higher elevations. Because of this, the rate of heat accumulation is slower and these locations reach specific thresholds later in the year than similar locations at lower elevations.

On the maps of freeze temperature, the Ozarks of Missouri are the most distinctive feature. Freezes here are typically 1 °C colder than those at the same latitude anywhere between the Ozarks and the Atlantic Ocean. The Ozarks, along with the Appalachians, experience more freezes than any other regions in the study area; roughly twice as many. There is also a localized region of frequent, cold freezes in the northern lower penninsula of Michigan.

Finally, the influence of the Great Lakes merits mention. The Lakes have a moderating influence on the climate along their shores, appearing on the maps as less intense freezes and fewer freezes. These effects are visible in the Door Peninsula of Wisconsin, in the Upper Peninsula of Michigan, and in western New York.

No lake effect appears on the maps of threshold days. This is a result of the nature of threshold days. All types of weather integrated over many days determine threshold days. Many of these days experience weather conditions that the Great Lakes do not significantly influence, and as a result the Lakes do not influence heat-sum accumulation. Freezes, however, result from very specific types of weather events, and the Great Lakes are known to influence these particular types of events.

For higher thresholds, there are some locations where the average freeze day precedes the average day for attaining the threshold. Figure 2 shows these areas shaded gray for the 200 GDD threshold. This inversion of the expected order of events results from individual years in which the threshold is attained much earlier than usual, so that freezes may occur prior to the average date for attaining the threshold. The earlier threshold date appears on the maps averaged with another 29 dates, while the freeze dates enter the calculation of average freeze date as a larger proportion.

As one example, consider Quincy, Illinois. Quincy is just south of the point where Iowa, Illinois, and Missouri meet, in the shaded area on figure 2. On average, Quincy reaches 250 GDD on day 111. In 1990, however, it reached this threshold on day 100, and temperatures dropped below freezing on 3 days between day 100 and day 111; overall, 7 of the 17 freezes at Quincy following 250 GDD came before day 111. Similar events produced the reversal of freeze and threshold days at other stations.

EXAMPLES

We now present three examples of possible application of the maps in this report. They are somewhat specific, but the general concepts in each case are more broadly applicable. Our intent in providing these scenarios is threefold. First, we hope to demonstrate the broad range of potential uses for the maps. Second, we wish to show that the biological or physiological information needed to use the maps does exist in research literature for some applications. Last, we hope the examples will spark ideas in the reader's mind for ways to use the maps.

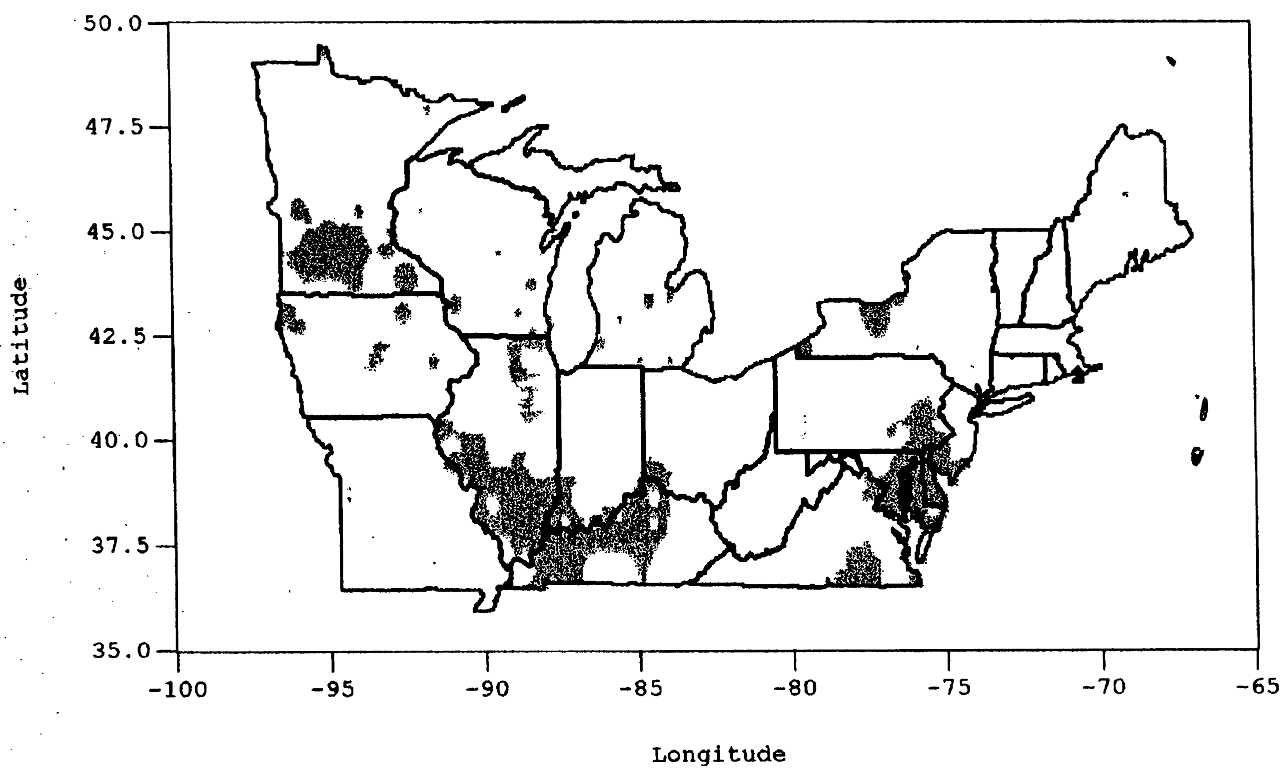

Figure 2.—*Regions where average day of freeze occurrence following 200 growing degree days precedes average day for attaining 200 growing degree days, shaded.*

Example 1

The saskatoon-berry (*Amelanchier alnifolia* (Nutt.) Nutt.) is a native of the Great Plains with some potential as a commercial fruit crop. Junttila *et al.* (1983) describe the development of saskatoon-berry buds in the spring and St. Pierre (1989) notes the importance of frost in causing fruit abscission. Of the immature fruits dropped by the plant, over 70 percent were damaged by frosts as mild as 0 to -1 °C. The data in Junttila *et al.* and St. Pierre suggest the flower buds are sensitive to freezing damage between 150 GDD and 200 GDD. Furthermore, the 'Smoky' cultivar tolerates freezes about 1.3 °C colder than the 'Pembina' cultivar. What are the prospects for cultivating this species in the North-central and Northeastern United States? The saskatoon-berry tolerates many soil textures and pH conditions (Junttila *et al.* 1983), but where in the USA would the climate be most suitable?

One approach to determining the viability of saskatoon-berry cultivation is to consider the average temperature of freezes that follow 150 GDD. Based on the values stated above, the 'Smoky' cultivar needs a location where temperatures remain above approximately -2 °C; the 'Pembina' cultivar is more sensitive and must have a location where temperatures remain above -0.5 °C. From the map showing freeze temperatures for events following 150 GDD, it appears 'Smoky' is viable in most places north of 41 °N, with the exception of the Ohio-Pennsylvania border region. 'Pembina,' on the other hand, would do well in central Maine, far northeastern Minnesota, or just south of Green Bay, Wisconsin.

A second approach is to find areas where the freezes that follow 150 GDD tend to occur after 200 GDD as well, thus placing them after the period when flowers are sensitive to freezing. Looking at the map for date of freezes following 150 GDD and the map showing the average date for reaching the 200 GDD threshold, one can see that the northern lower penninsula of Michigan, around Gaylord or Grayling, and the area around Munising, Michigan on the upper penninsula, each have about 1 week between the end of their sensitive period and the average freeze after the start of that period. These would be reasonable places to grow saskatoon-berry, in terms of climate. Furthermore, since the freezes follow the sensitive period, the 'Pembina' cultivar may be viable here, even though the freezes are colder than it could tolerate during its sensitive period.

Example 2

Johnson *et al.* (1983) data suggest initial eclosion for gypsy moth at approximately 228 GDD. According to the maps, Mora, Minnesota (45° 53' N, 93° 18' W) and Cumberland, Wisconsin (45° 32' N, 92° 1' W) reach 200 GDD at about the same time, calendar day 130. However, the two locations differ with respect to spring freezes. After reaching the 200 GDD threshold, Mora has an average of three freezes each year, with an average minimum temperature of -2.0 °C, and the average freeze day is calendar day 137. Cumberland, on the other hand, typically freezes once each year after reaching 200 GDD, with an average temperature of -0.7 °C and average day of occurrence of calendar day 129. The average day of freezes following 200 GDD in Cumberland is, in fact, the same as the average date for reaching that threshold, i.e., most freezes after 200 GDD occurred in years when the threshold was reached unusually early, due to early warm temperatures. As a result of these climate differences, the long-term dynamics of gypsy moth population dynamics and mortality will likely differ between the two sites.

Example 3

Field data obtained in northern Wisconsin suggest that northern red oak (*Quercus rubra* L.) and white ash (*Fraxinus americana* L.) are susceptible to freezing damage (Zasada, pers. comm.). Ash suffered damage from a freeze between 240 and 330 GDD; oak survived that freeze, but succumbed to a freeze between 330 and 390 GDD. Temperatures as moderate as -1 °C can kill fresh foliage at this stage.

Consider a forest manager in western New York who needs to decide where to regenerate these two species on several stands in the region owned by a particular client with the least risk of freezing damage to the saplings. Every location west of Syracuse has experienced some freezing after 200 GDD, though some locations have no freezes after 300 GDD. Therefore, ash will be more vulnerable in the general region than oak. Both will fare better closer to Lake Erie or Lake Ontario where freezes are less common and less intense. The manager might choose to plant ash only on southwest-facing sites with wetter soils, away from depressions where drainage of cold air could increase mortality, and with some overstory vegetation to protect against freezing temperatures. Furthermore, cutting prescriptions for regenerating ash might require creating smaller gaps than those for regenerating oak.

CONCLUSIONS

The maps produced in this study reveal large-scale dependencies on latitude. Latitude has a definite influence on threshold and freeze days. Freeze frequency and intensity are greatest in the Ozarks and the Appalachians, though the reason or reasons for this regional difference are not clear. Proximity to the Great Lakes reduces the intensity and frequency of freezes, but does not affect the days for attaining thresholds or the average day for freezes.

More important than any other determining factor are the characteristics of a station's microsite. The results shown on the maps reflect the microsite influence of the weather stations we used, and there is no way to remove this influence. Conversely, an individual concerned about freezes at a specific location will be dealing with a unique set of microclimate influences: slope, aspect, soil type, soil moisture, vegetation density, and air drainage patterns. In such a situation, the individual's level of concern may dictate making microclimate measurements at the location of interest. This is the only way to know the true conditions influencing a specific site.

ACKNOWLEDGMENTS

We wish to thank Dr. Jeff Andresen of the Department of Geography at Michigan State University for providing data for many of the Michigan stations, and for helpful discussions during the analysis of the data.

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A. Station Selection

For our initial selection of stations, we required the daily maximum temperature (T_{max}) and daily minimum temperature (T_{min}) records to be at least 99 percent complete for the station's period of record and to encompass the interval from 1961 to 1990. We found 382 of these stations in the study area. Because the geographic distribution of these stations left several large areas unrepresented, we added stations with as little as 98 percent coverage to fill these gaps. These latter stations could have no more than 700 missing values for T_{max} and T_{min} combined. The final set for analysis included 421 stations (figure A1).

B. Treatment of Missing Data

We classified each gap in the data series as short (fewer than four consecutive values missing) or long (four or more consecutive values missing). When a short gap involved only one of the two variables, we filled it by interpolating the diurnal temperature range from the nearest nonmissing values. For example, if days 2 and 3 had missing values of T_{min}, the differences between T_{max} and T_{min} for days 1 and 4 were calculated and interpolated. We then subtracted the interpolated difference values from T_{max} for days 2 and 3, producing values for the T_{min} on these days. When short gaps in T_{max} and T_{min} coincided, we interpolated each variable individually from adjacent days.

We filled long gaps by regression against a nearby station without any missing values. We determined a statistical linear relationship between the missing variable and the same variable at the nearby station, and then used that relationship to fill in the missing values. All of the linear regressions produced in this way had correlation coefficients, r, greater than 0.90.

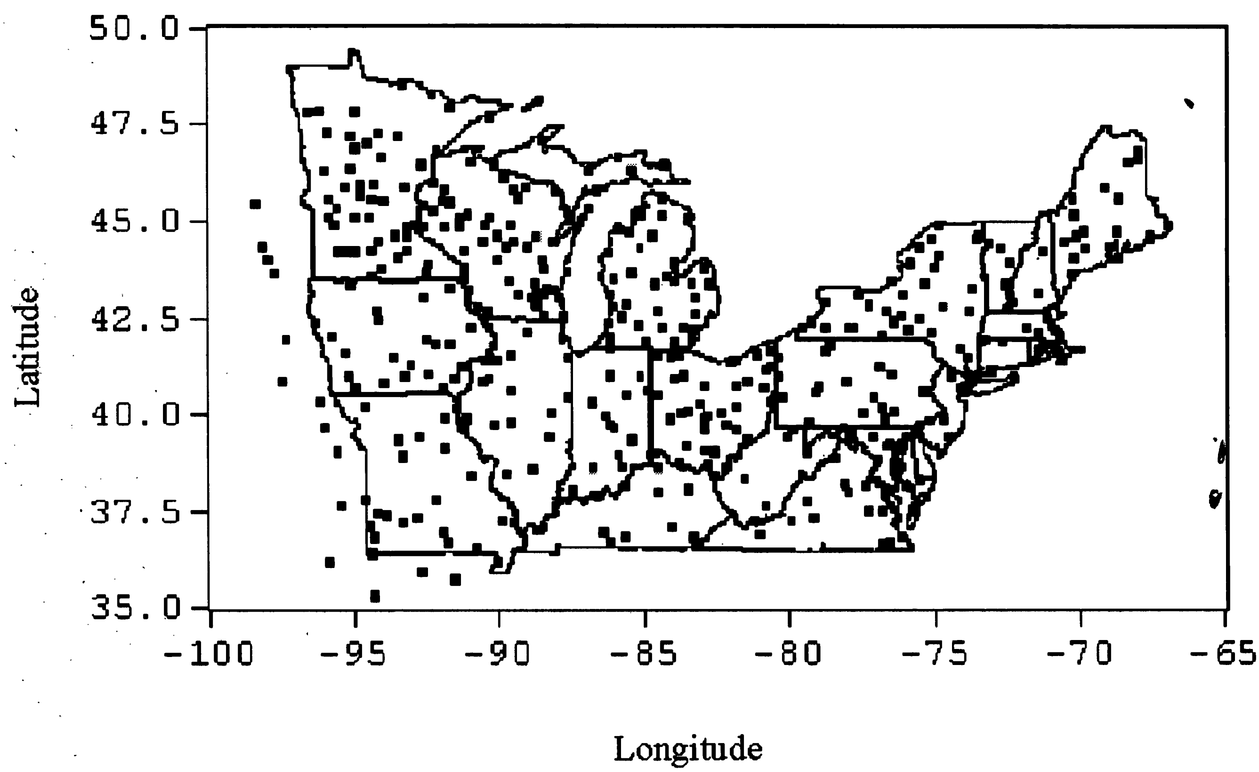


Figure A1.—*Locations of stations used to produce the maps in this study.*

C. Analysis

1. *Heat sums*: In calculating heat sums, we used the method described by Baskerville and Emin (1969). This method yields nonzero heat sums for days when the maximum temperature exceeds the temperature base, even if the day's average temperature falls below the base. We used a temperature base of 5 °C.

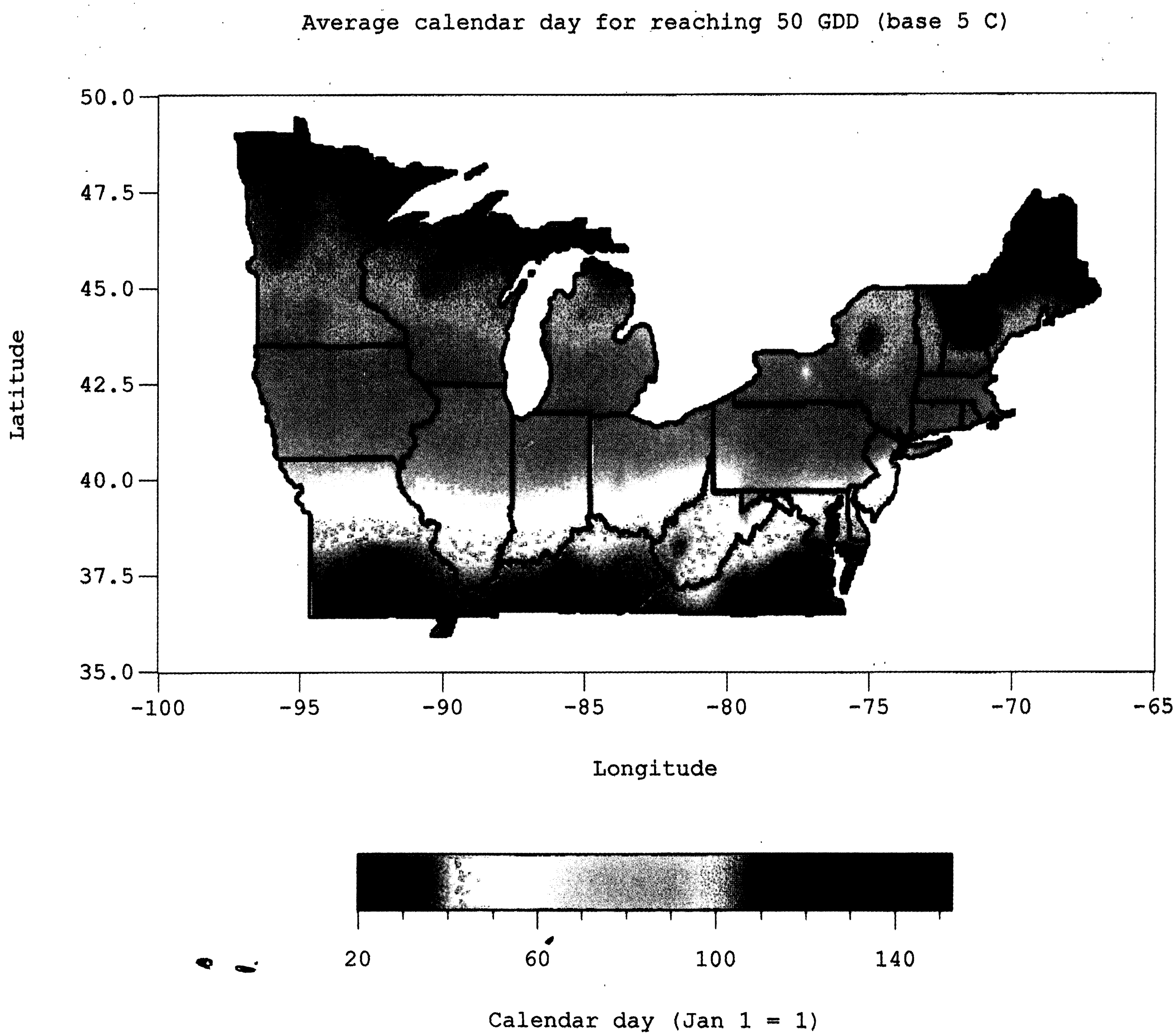
2. *Freezes*: We computed freeze statistics for seven heat-sum thresholds. These began at 50 degree days and continued through 350 degree days in increments of 50 degree days. For each station and year, we recorded the date on which each threshold occurred; the dates of all freezes following a given threshold but before July 31; and the temperature minimum for each such freeze. These data, along with the number of freezes, were used to produce the maps in this report.

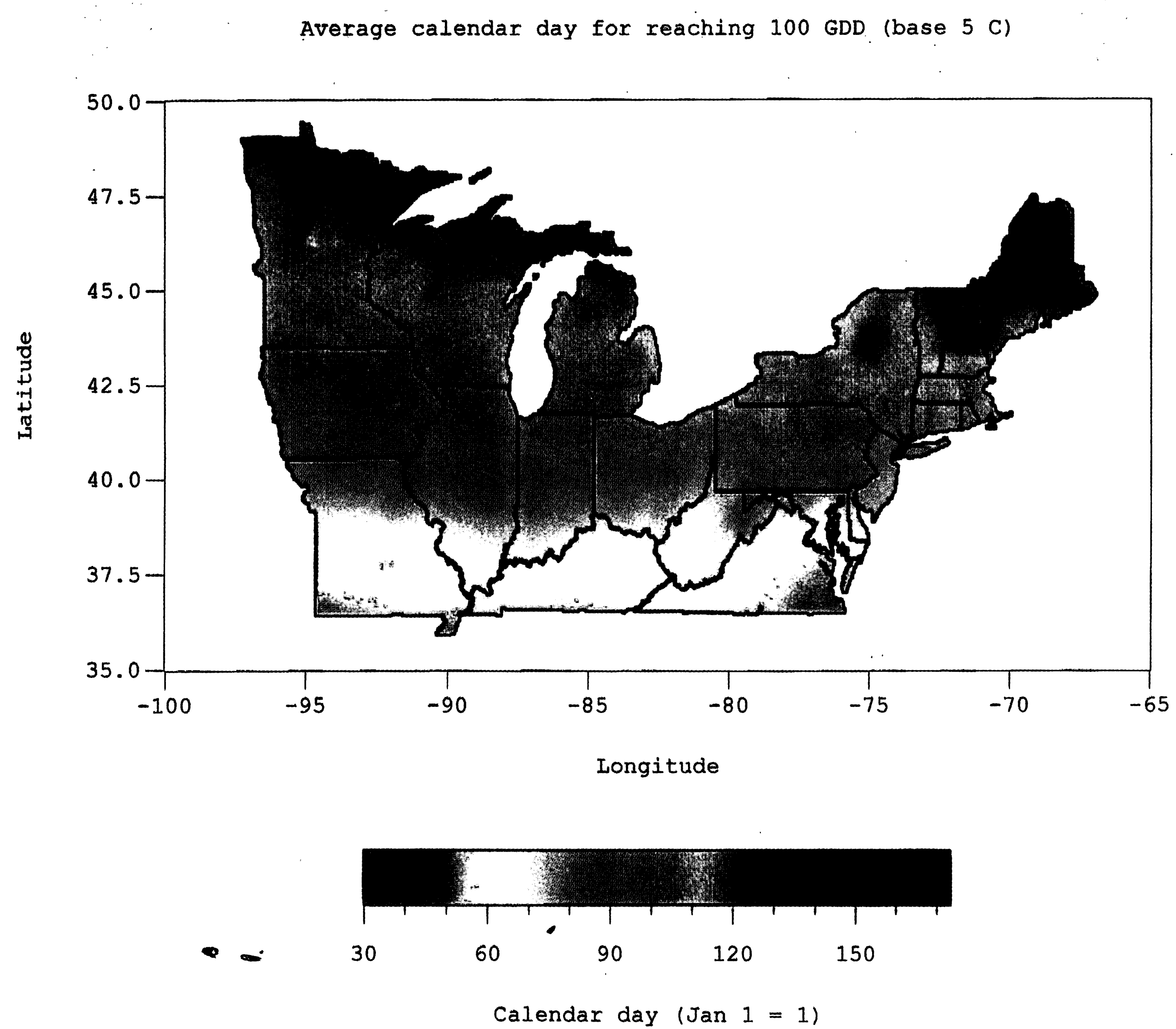
A note is in order here regarding the temperature records. At each station, observations are made once a day using maximum-minimum thermometers. The time of observation may be morning or evening, but it remains the same at a given station. Due to this once-a-day protocol, it is possible for a temperature extreme on a given day to occur after the observation for that day and appear as the next day's extreme. The result of this is that morning observers may experience carryover in the minimum temperature record, and evening observers may experience carryover in the maximum temperature record (Mitchell 1958). Such carryover is uncommon, but can lead to slightly cool average temperatures at morning observation sites and slightly warm average temperatures at evening observation sites. Carryover could influence heat-sum accumulations, but would not affect the freeze record.

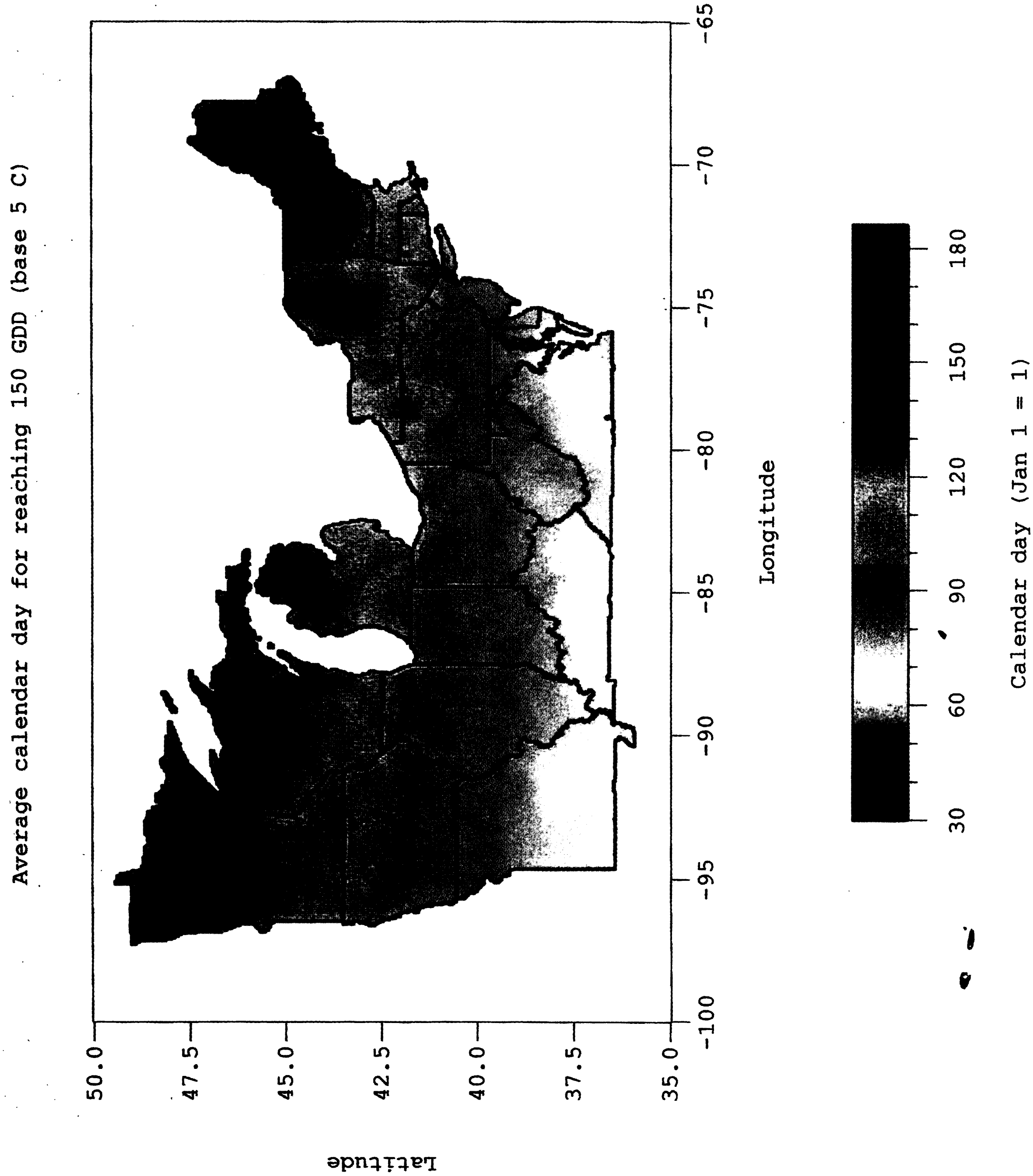
3. *Leap years*: We dropped February 29 from leap-year records. This is largely irrelevant in northerly locations, where few degree days occur this early in the year. However, it could impact the southernmost States in the analysis for low heat-sum thresholds. Heat-sum accumulations on this one day are likely quite small, and with only seven leap years in the sample, the error due to this approach should be extremely small.

Once we determined threshold dates, number of freezes, freeze intensity, and freeze dates at all of the stations, we used Transform®[1] from Fortner Research, LLC., for spatial interpolation and map generation. We compared four different types of interpolation to determine which method gave the smallest error in the interpolated quantities. The techniques included linear regression of a given variable against latitude, longitude, and elevation; kriging (Isaaks and Srivastava 1989); interpolation with inverse distance squared (IDS) weighting of the stations; and the gradient plus inverse distance squared (GIDS) technique described by Nalder and Wein (1998). Of the four techniques, we found IDS and kriging yielded the smallest errors. Kriging produced noticeably larger errors around stations that had no frosts for a given threshold. For these reasons, and because IDS was more objective and faster, all maps in this study were produced using IDS.

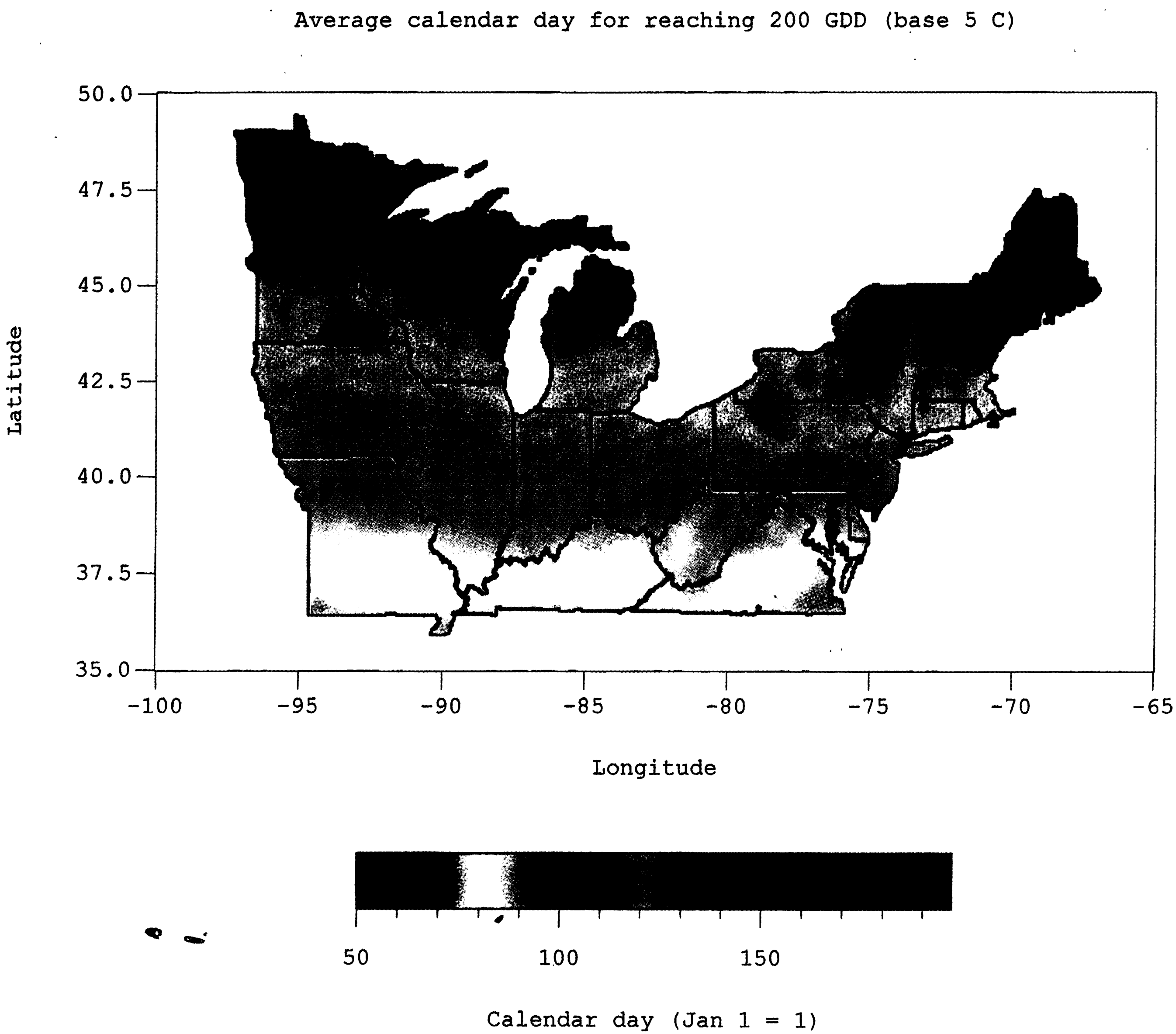
[1] *Mention of trade names does not constitute endorsement by the USDA Forest Service.*


Average calendar day for reaching 50 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
20
60
100
140
Calendar day (Jan 1 = 1)

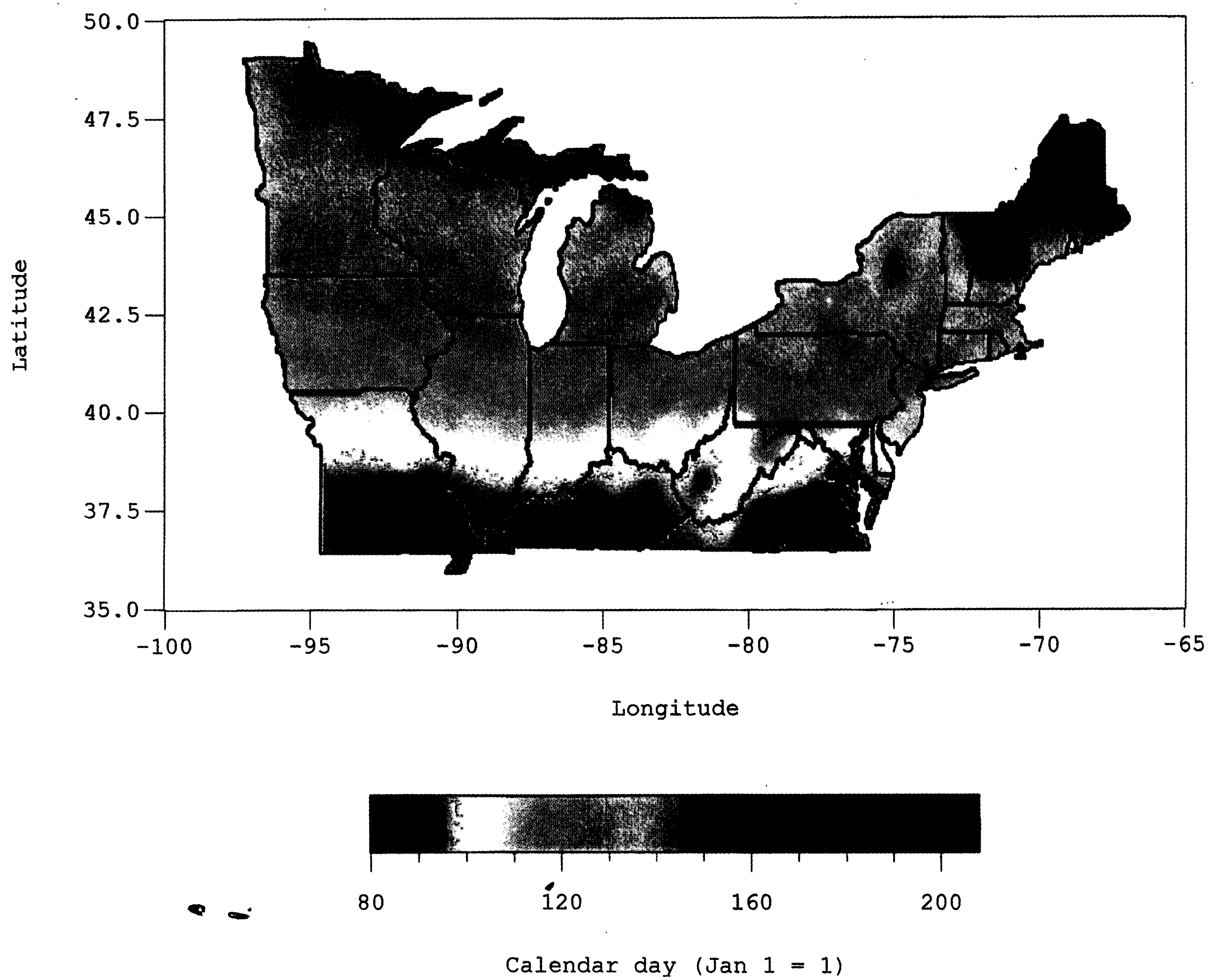

Average calendar day for reaching 100 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
30
60
90
120
150
Calendar day (Jan 1 = 1)

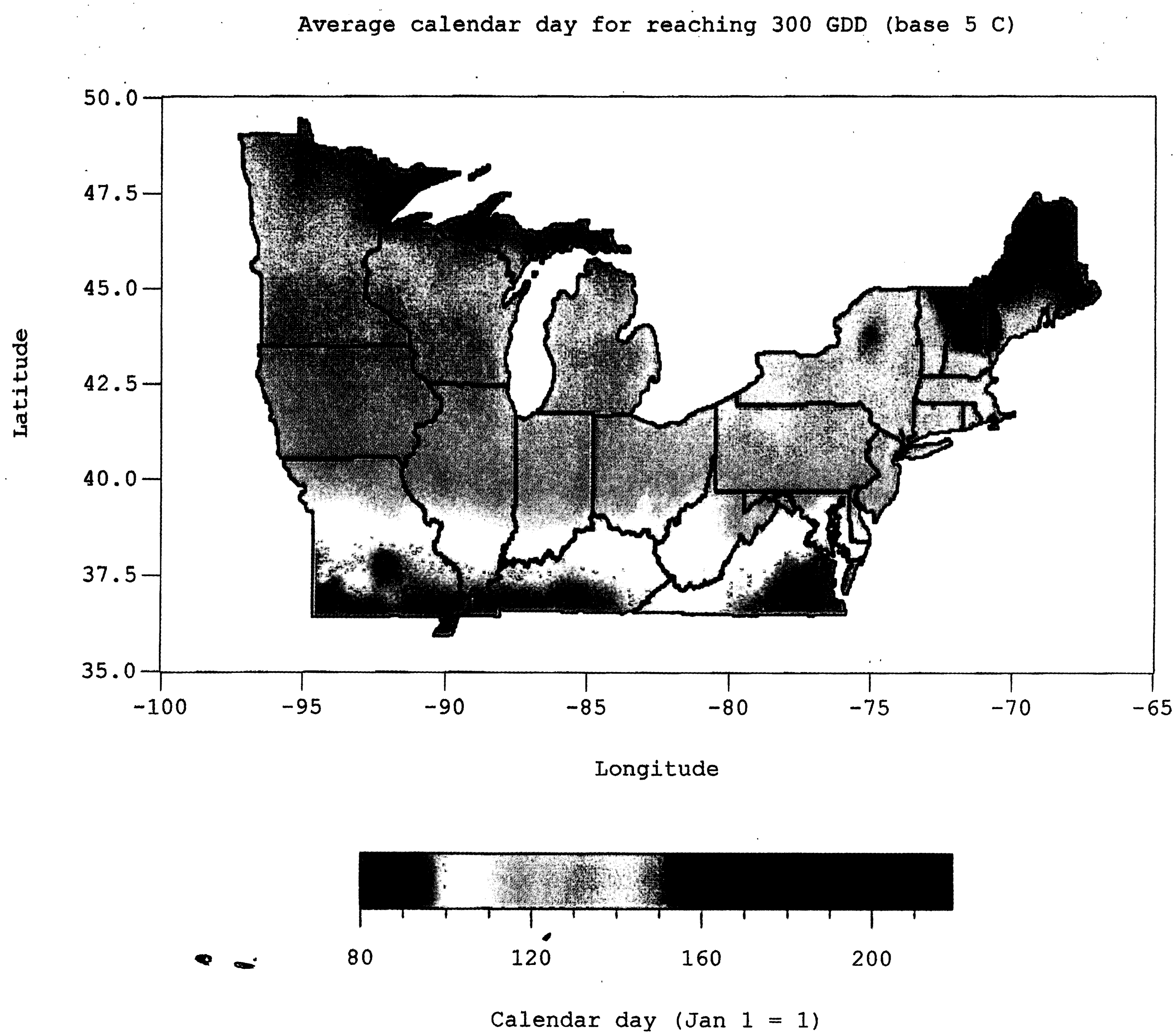


Average calendar day for reaching 150 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Longitude
-100
-95
-90
-85
-80
-75
-70
-65
30
60
90
120
150
180
Calendar day (Jan 1 = 1)


Average calendar day for reaching 200 GDD (base 5 C)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Latitude
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
50
100
150
Calendar day (Jan 1 = 1)

Average calendar day for reaching 250 GDD (base 5 C)





Average calendar day for reaching 300 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
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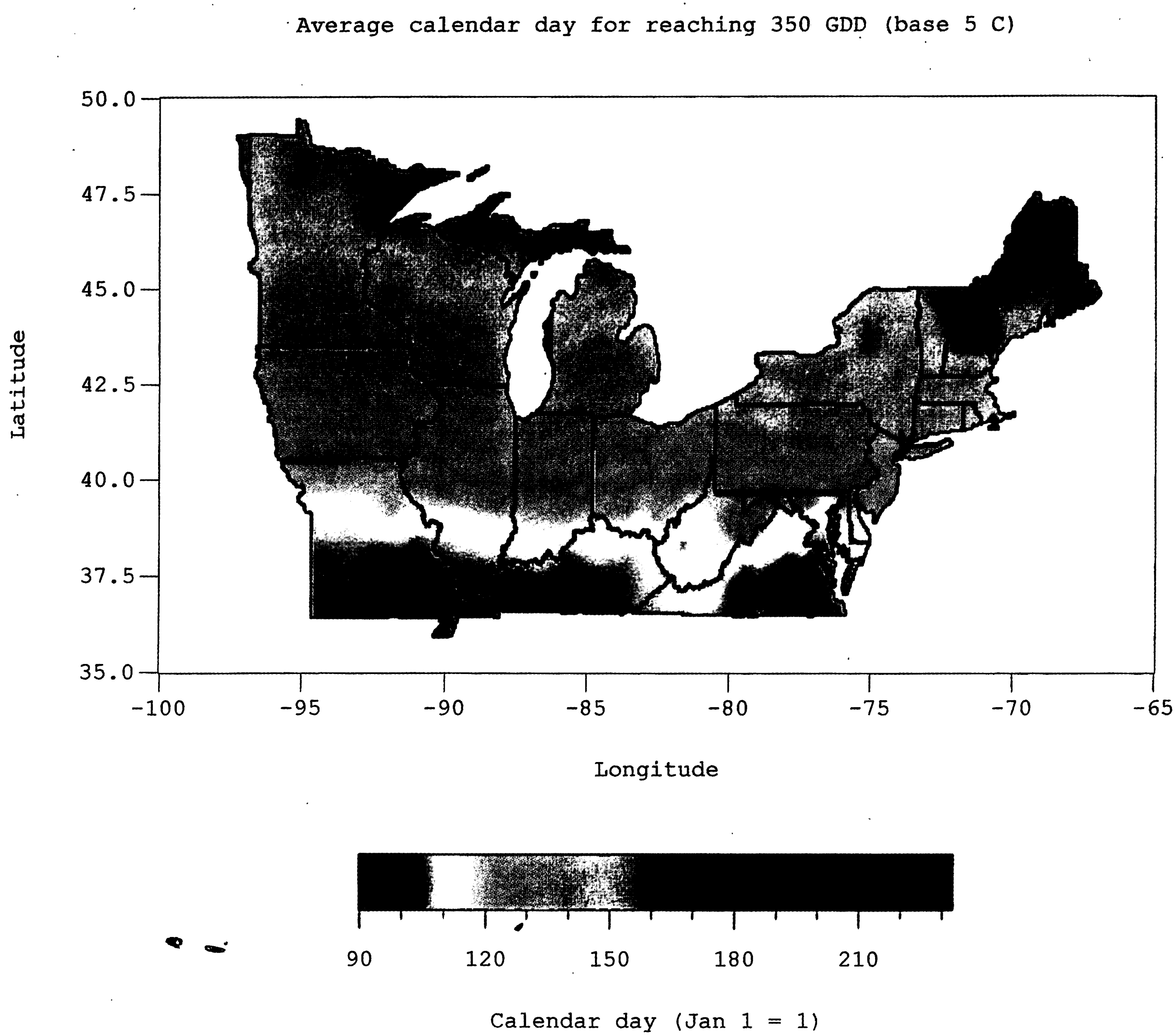
-95
-90
-85
-80
-75
-70
-65
Longitude
80
120
160
200
Calendar day (Jan 1 = 1)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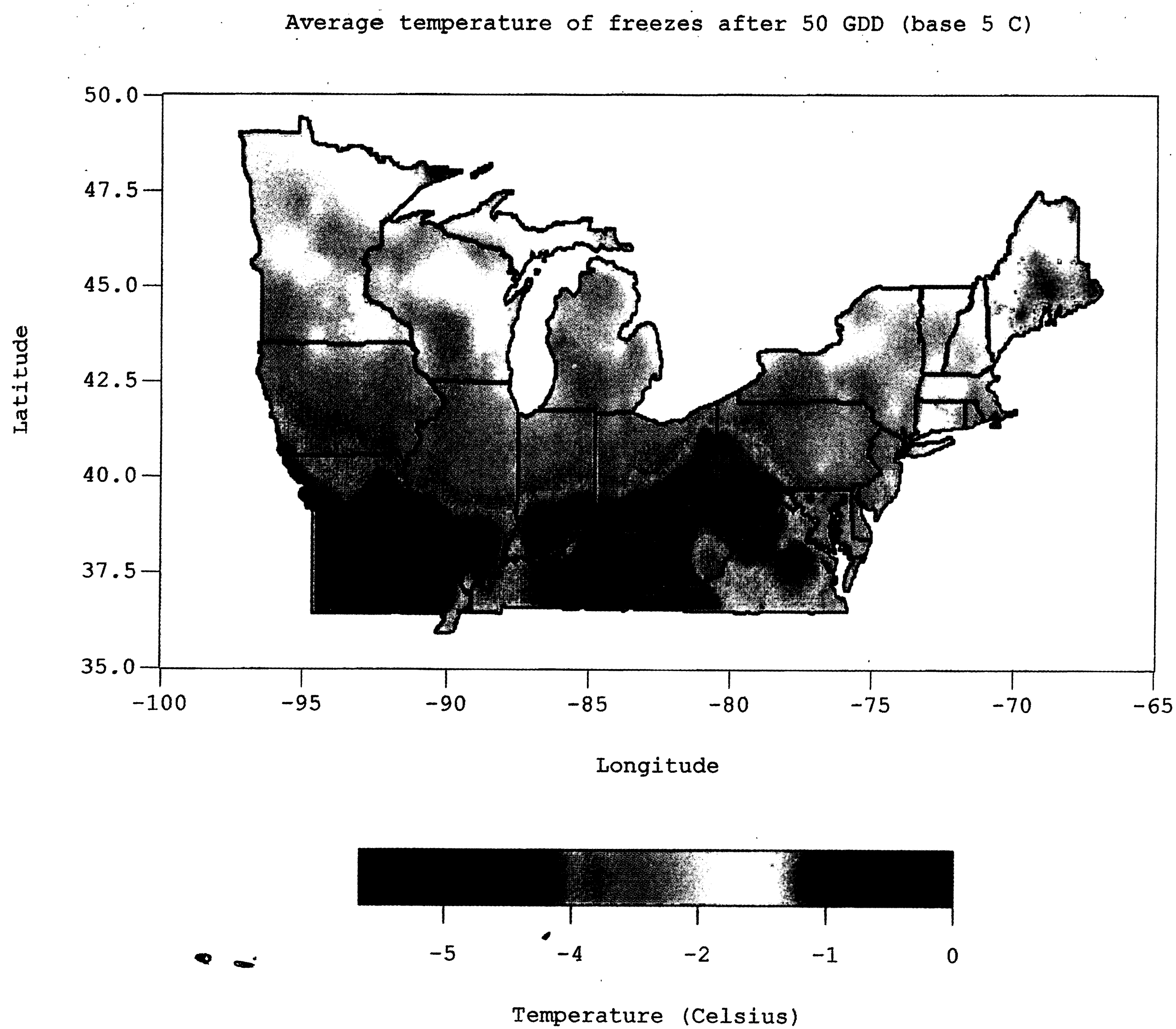
-70
-65
Longitude
90
120
150
180
210
Calendar day (Jan 1 = 1)


Average temperature of freezes after 50 GDD (base 5 C)
Latitude
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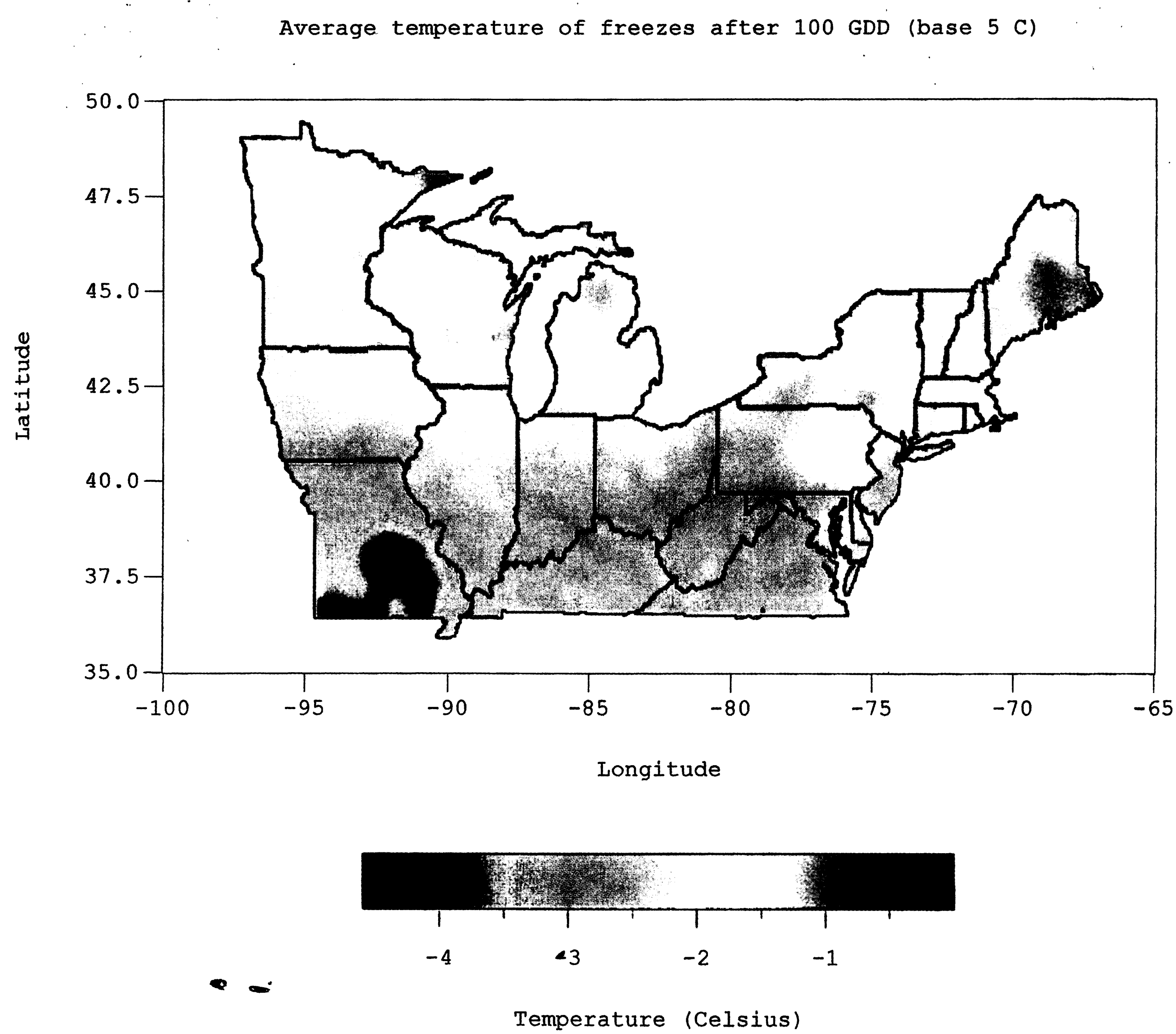
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
-5
-4
-2
-1
0
Temperature (Celsius)


Average temperature of freezes after 100 GDD (base 5 C)
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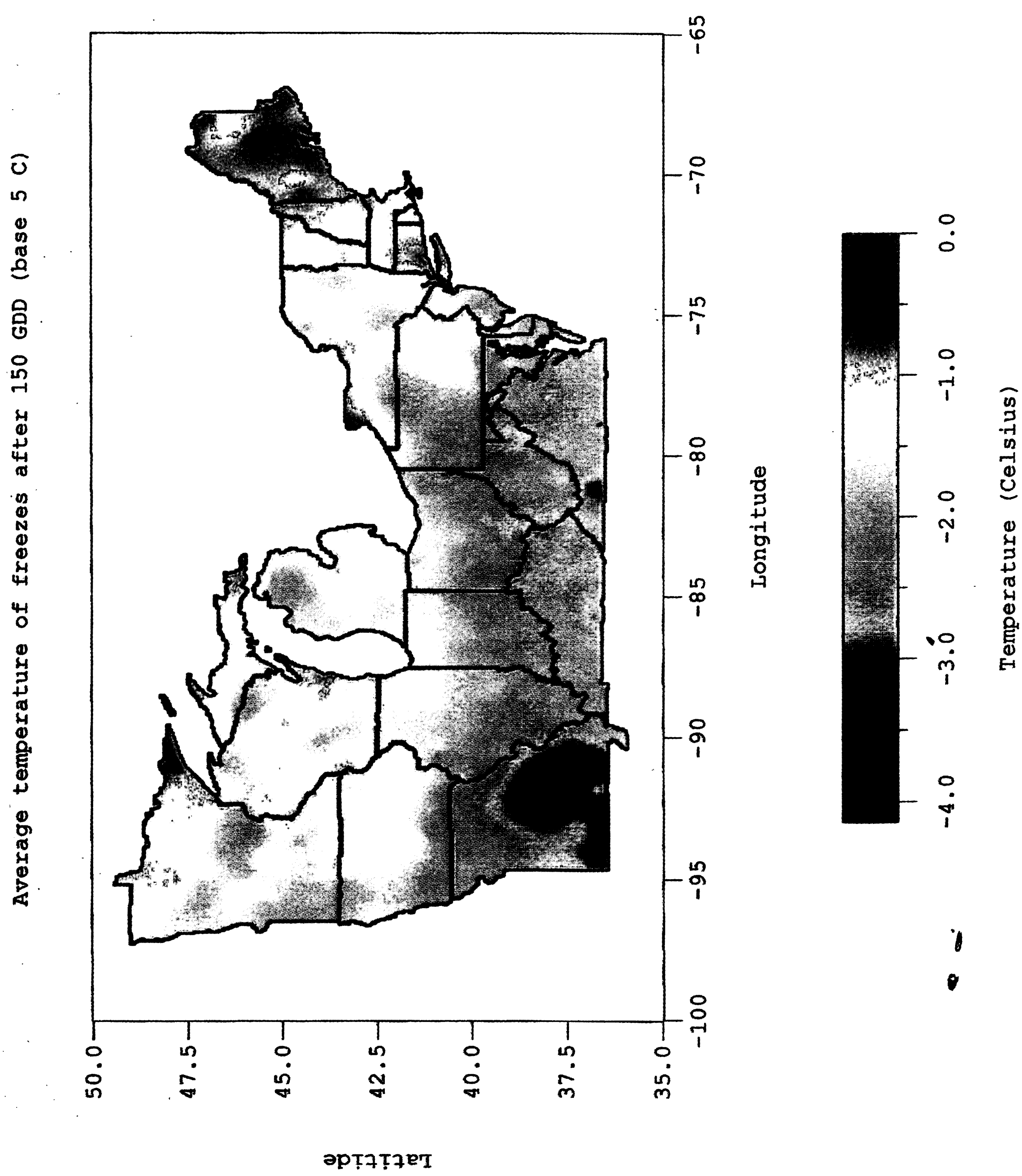
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
-4
-3
-2
-1
Temperature (Celsius)


Average temperature of freezes after 150 GDD (base 5 C)
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37.5
35.0
Longitude
-100
-95
-90
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-70
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Temperature (Celsius)
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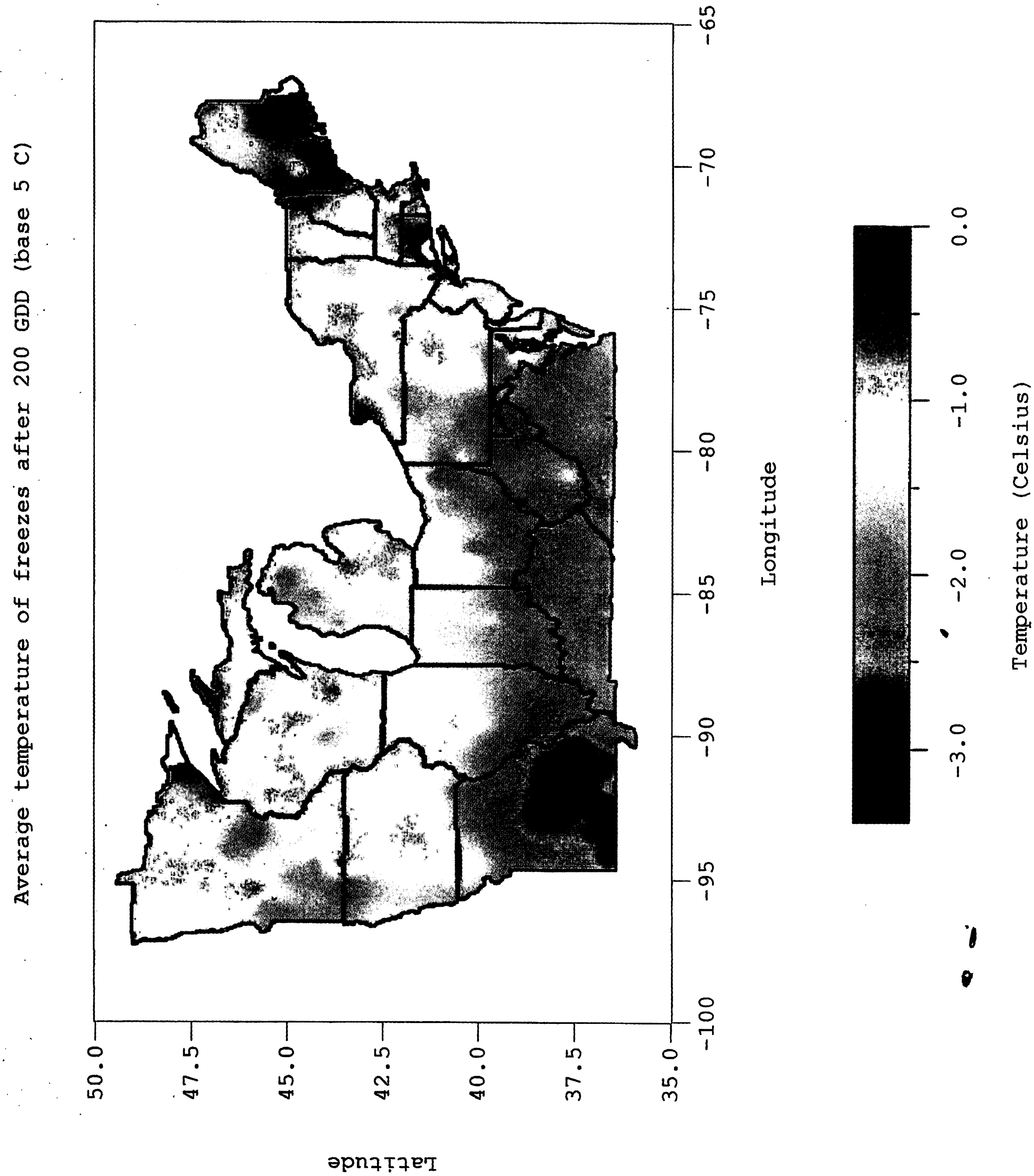
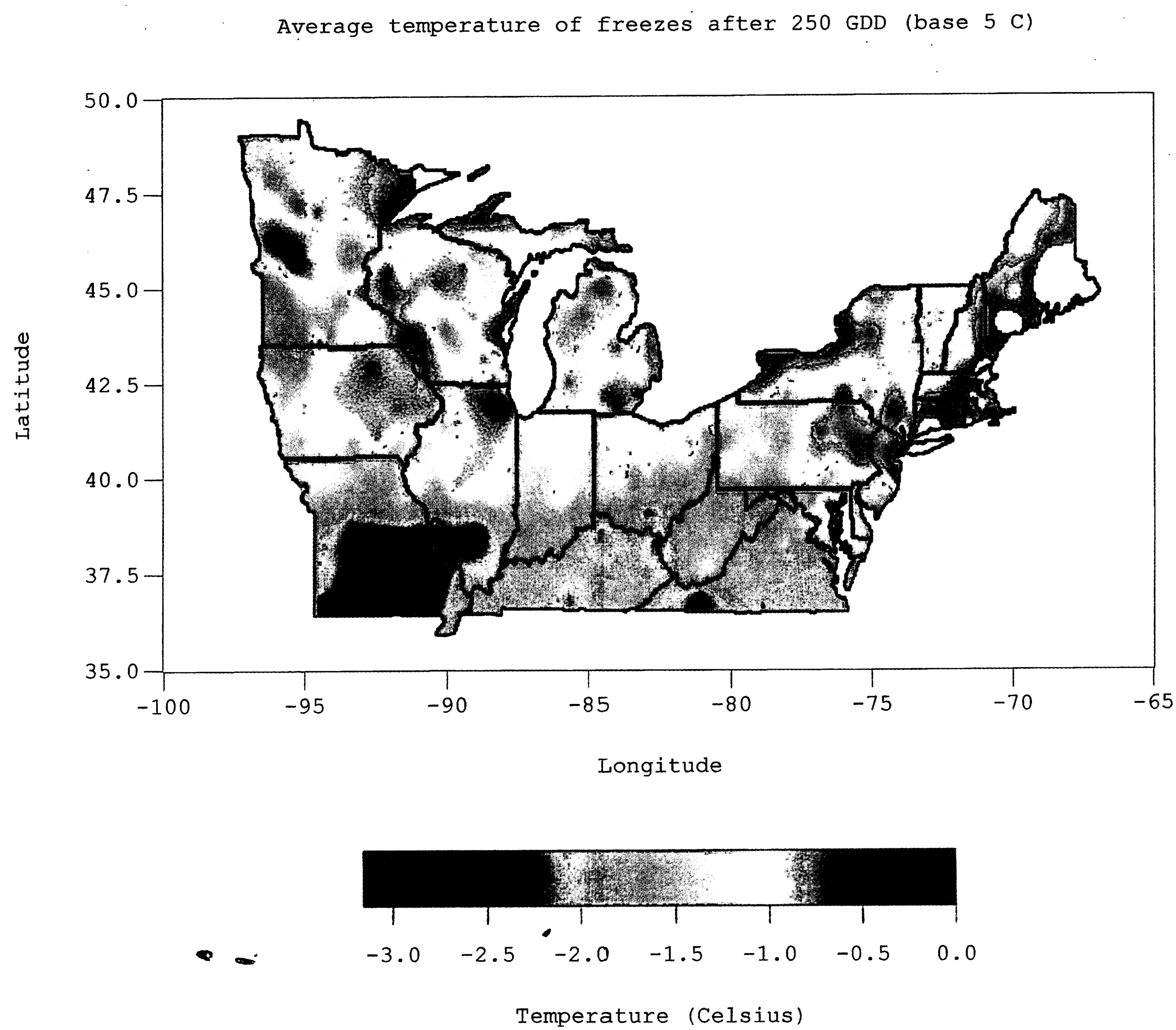
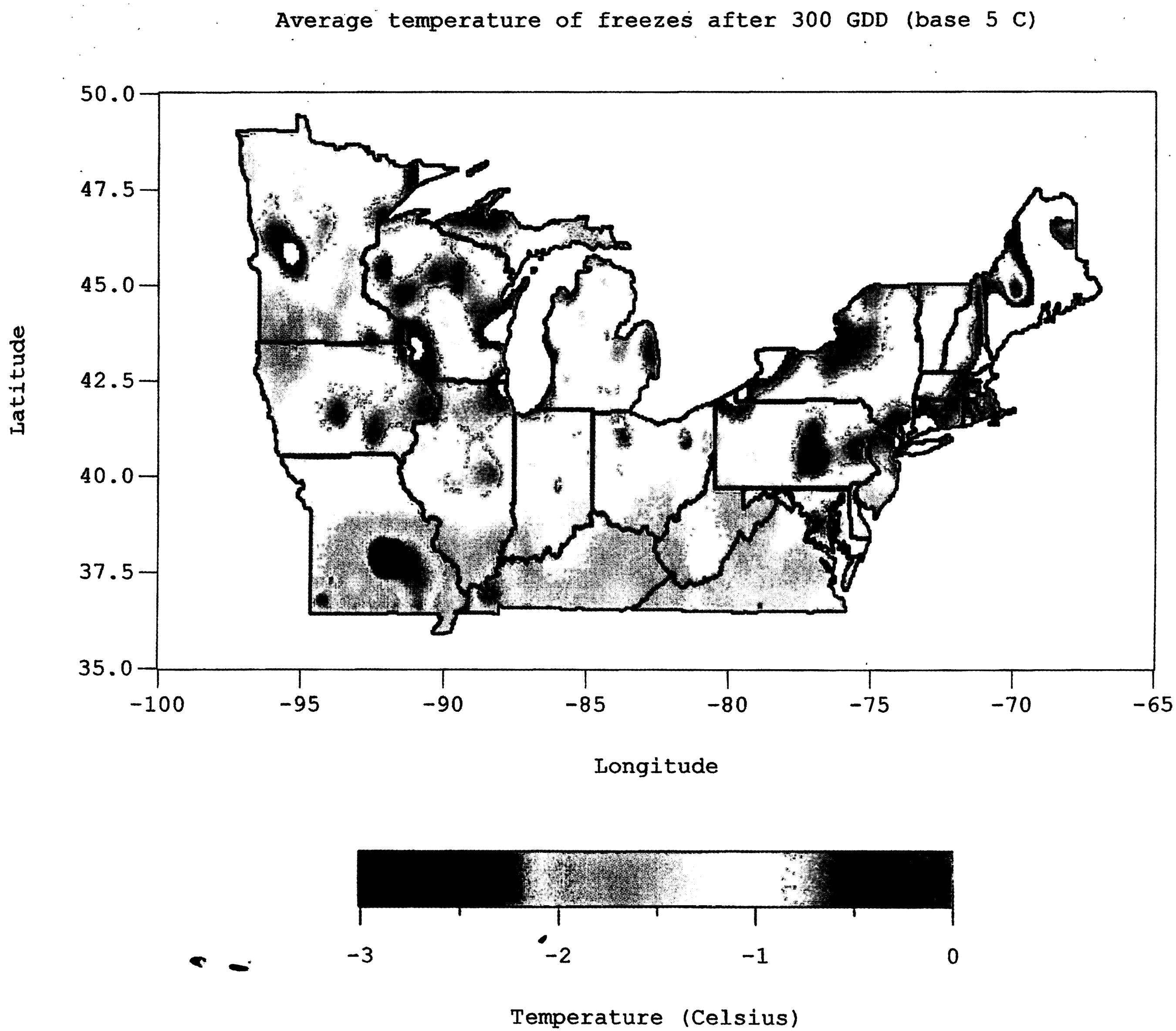
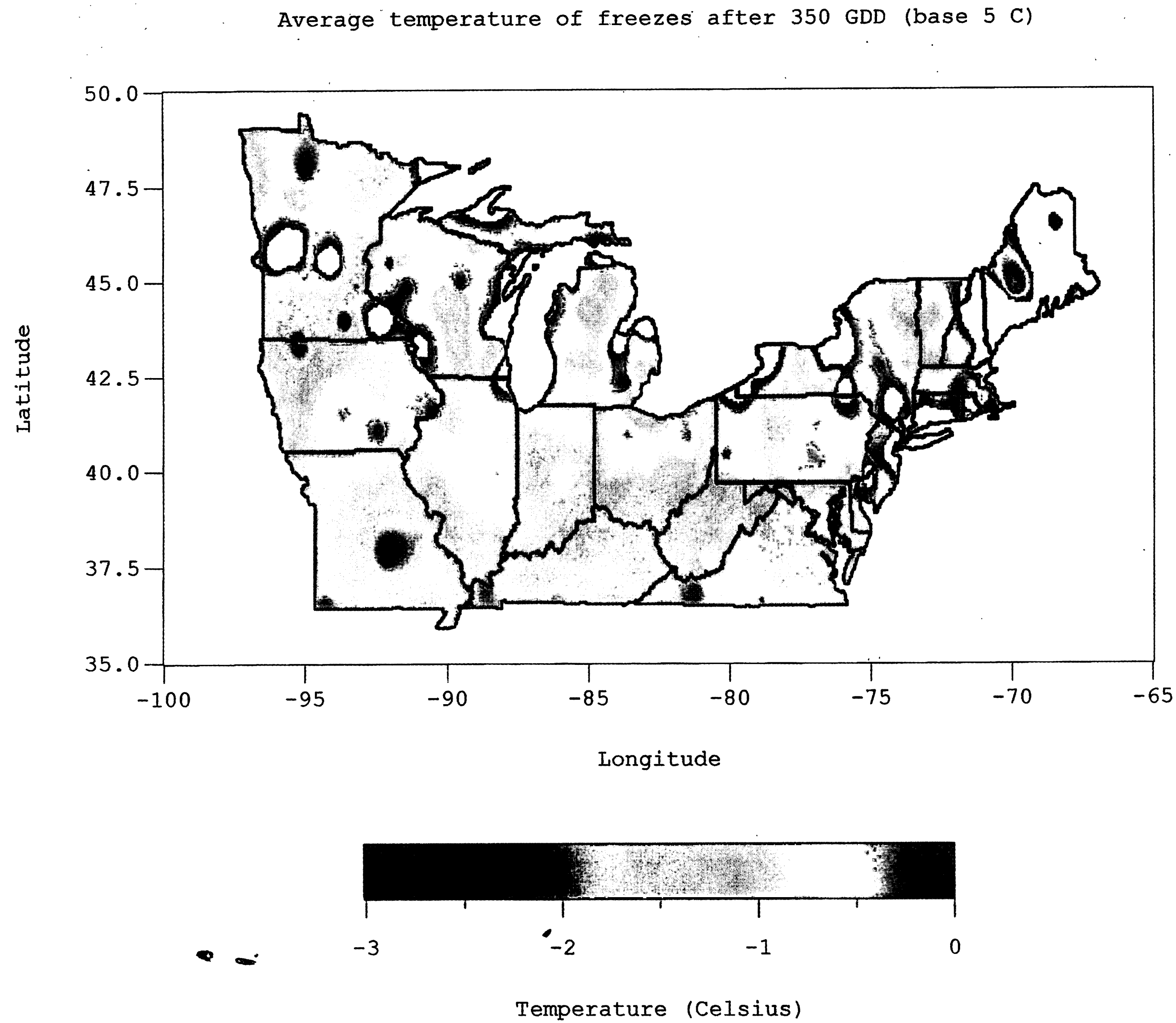
-3.0
-2.0
-1.0
0.0

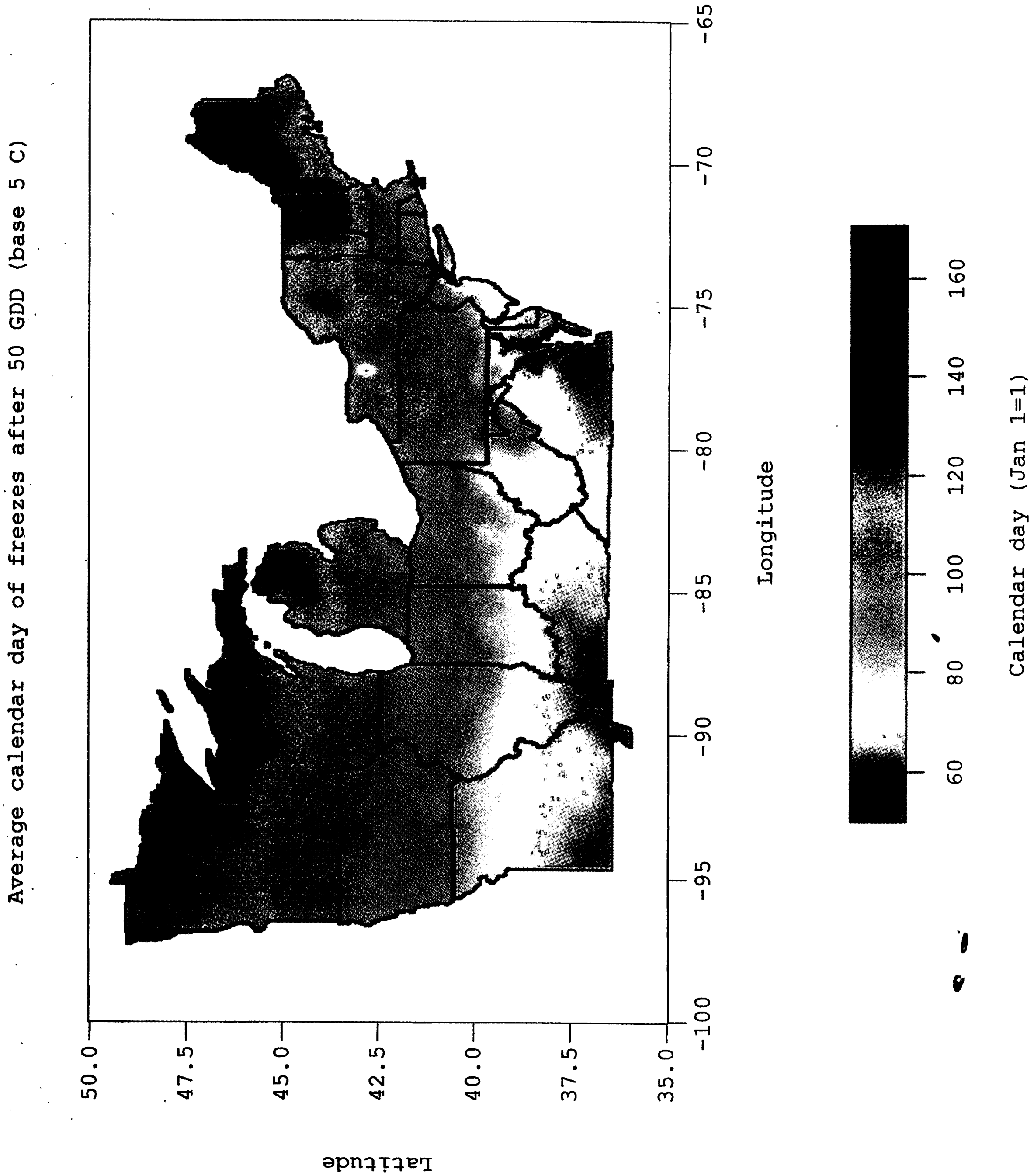

Average temperature of freezes after 200 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Longitude
-100
-95
-90
-85
-80
-75
-70
-65
Temperature (Celsius)
-3.0
-2.0
-1.0
0.0



Average temperature of freezes after 250 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
Temperature (Celsius)

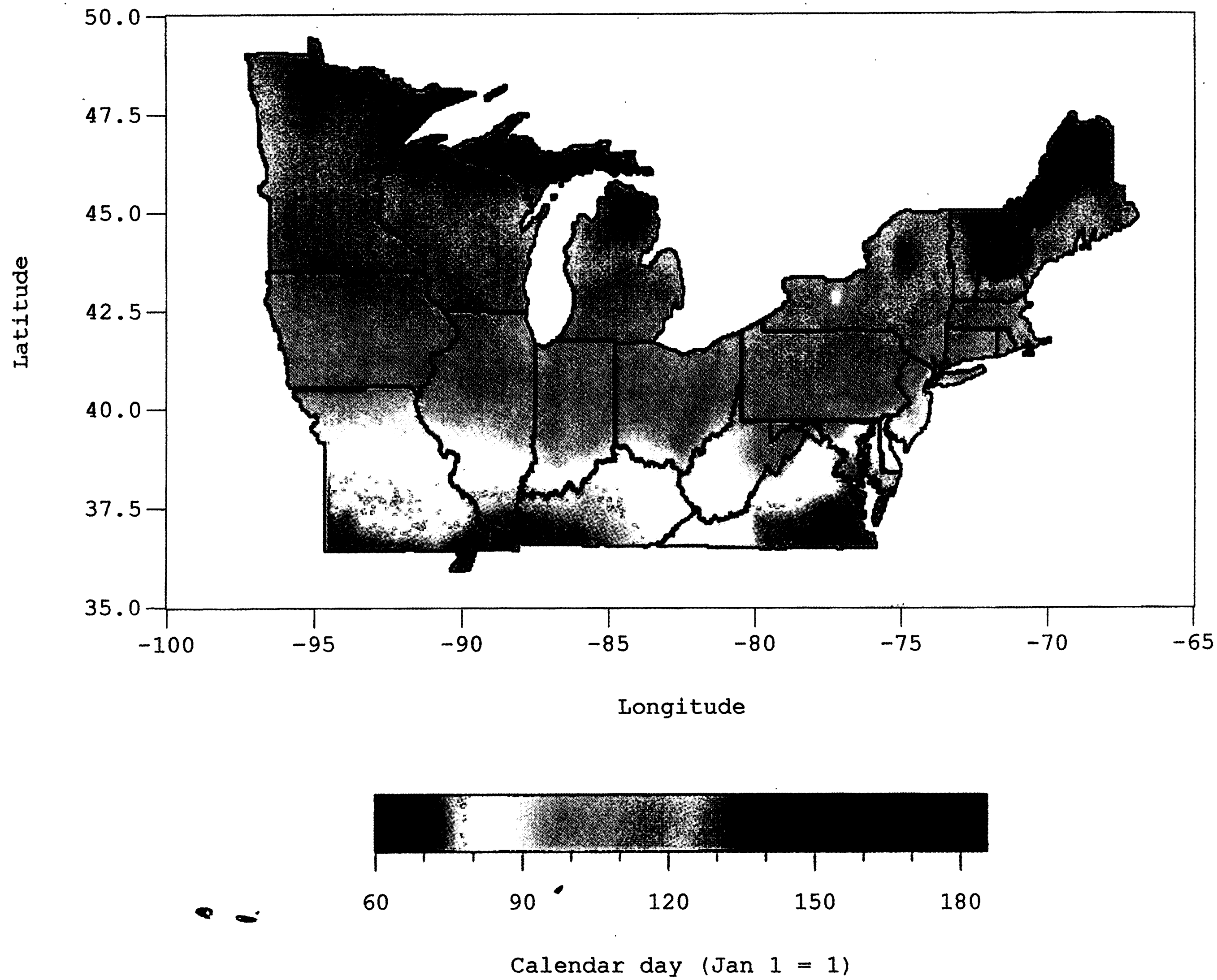

Average temperature of freezes after 300 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
-3
-2
-1
0
Temperature (Celsius)

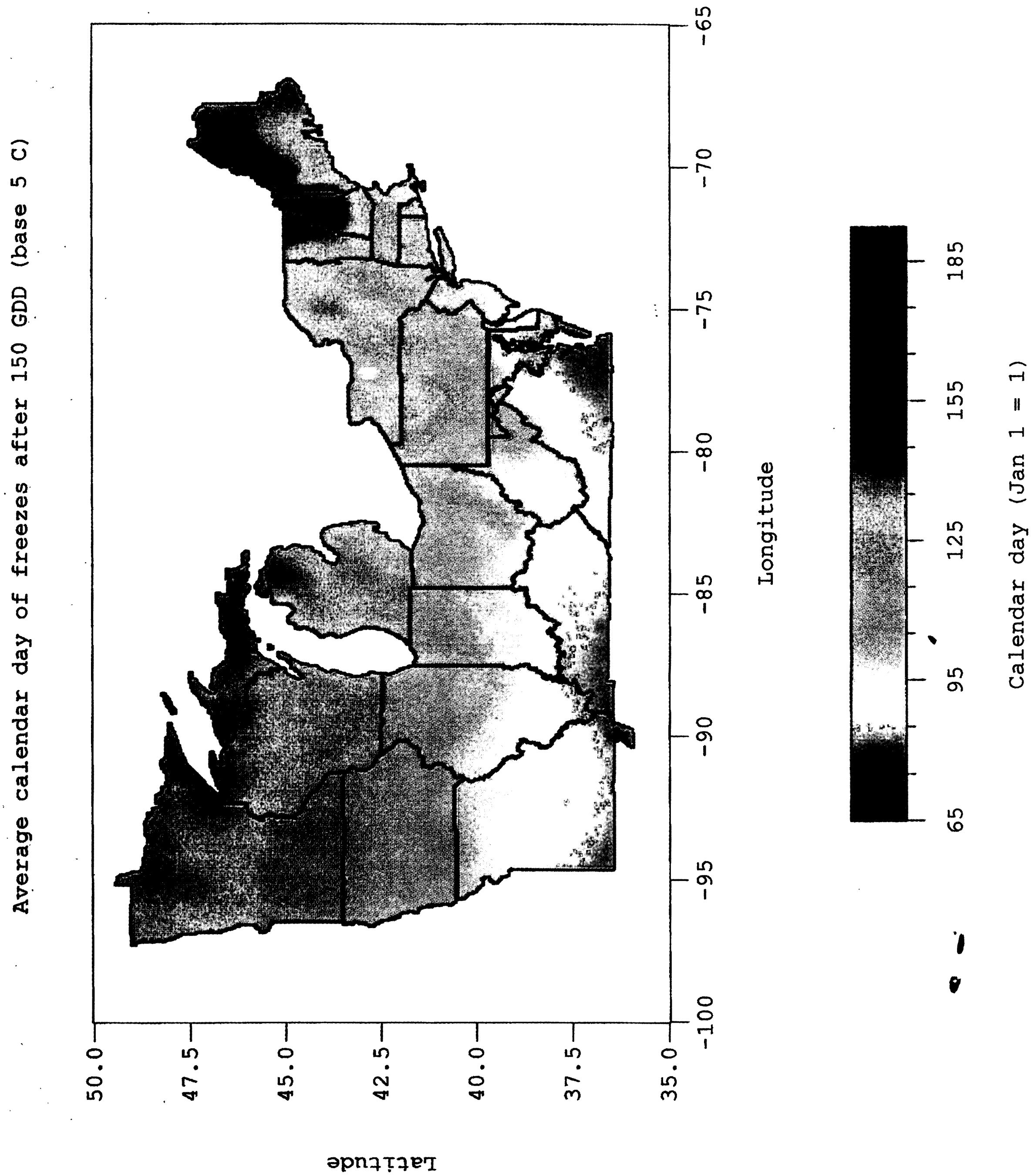

Average temperature of freezes after 350 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
-3
-2
-1
0
Temperature (Celsius)



Average calendar day of freezes after 50 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Longitude
-100
-95
-90
-85
-80
-75
-70
-65
Calendar day (Jan 1=1)
60
80
100
120
140
160

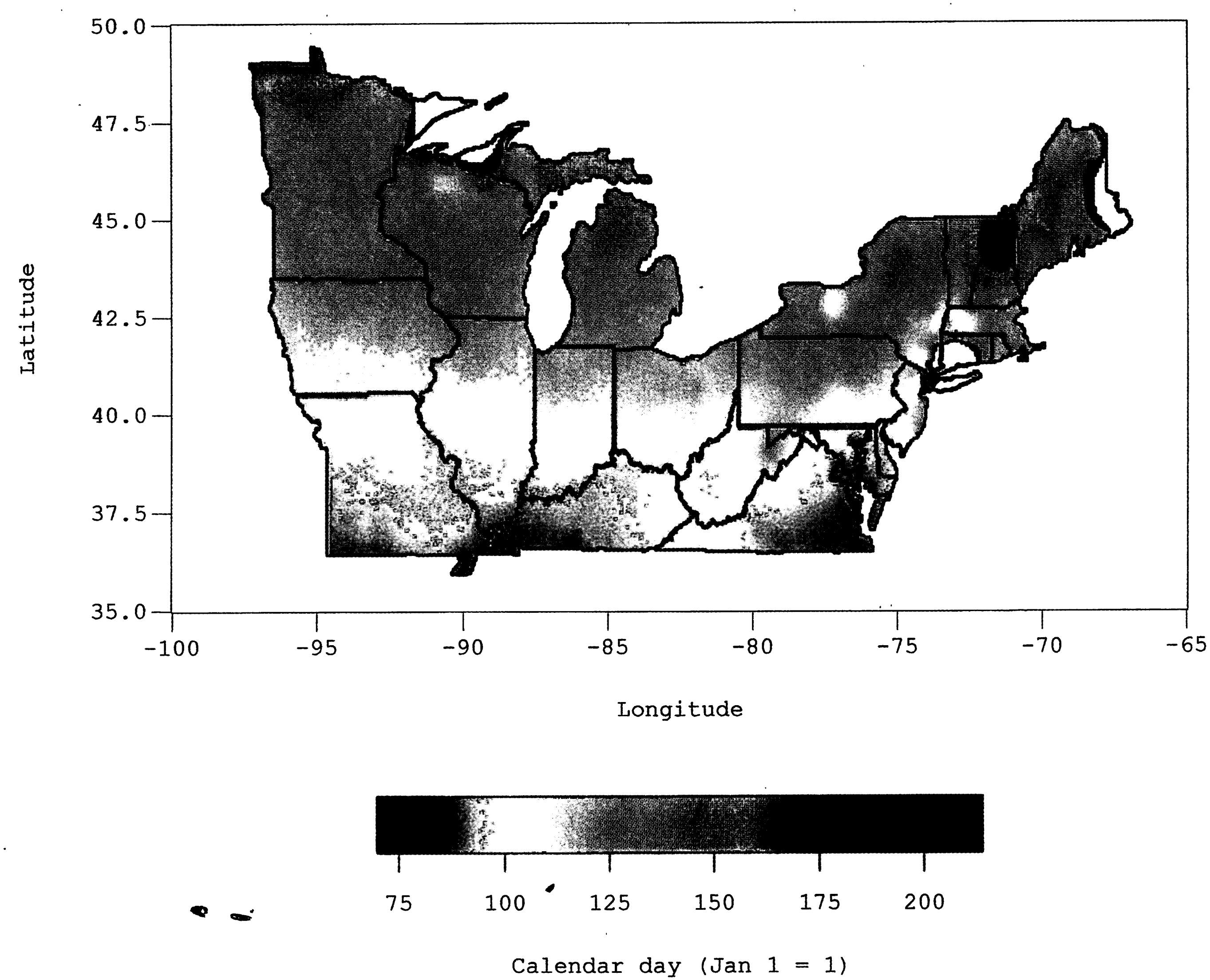
Average calendar day of freezes after 100 GDD (base 5 C)

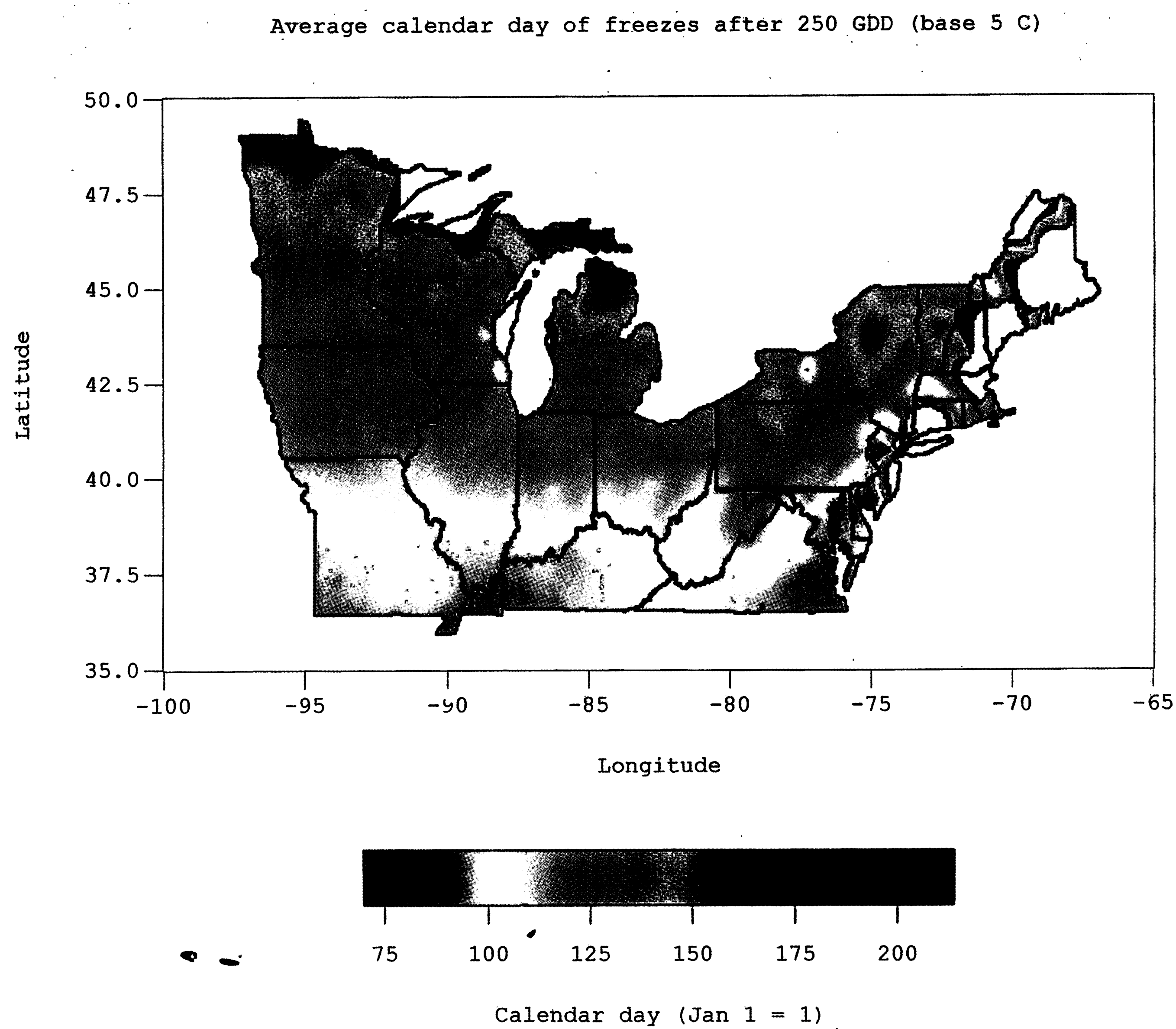


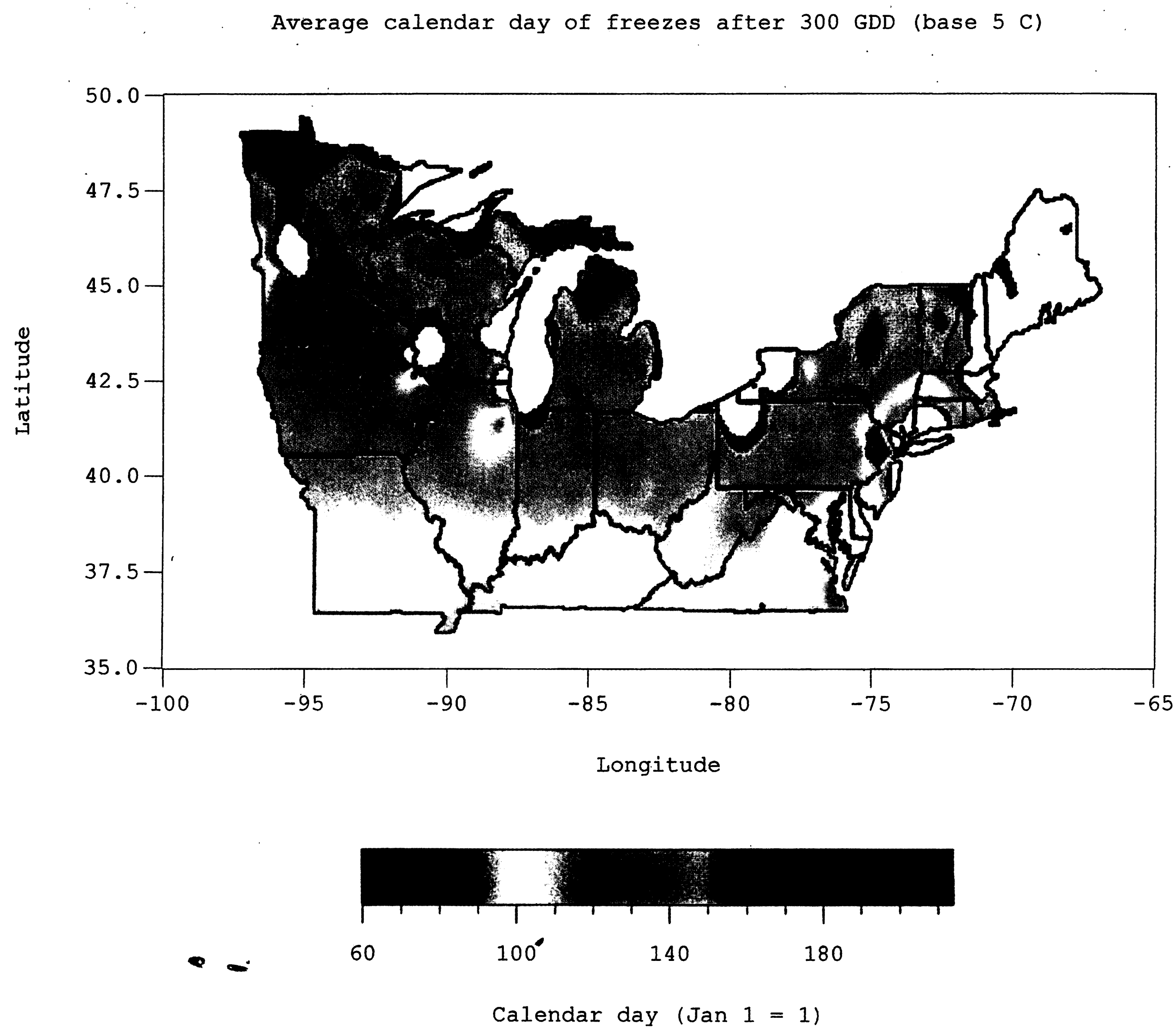


Average calendar day of freezes after 150 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
65
95
125
155
185
Calendar day (Jan 1 = 1)

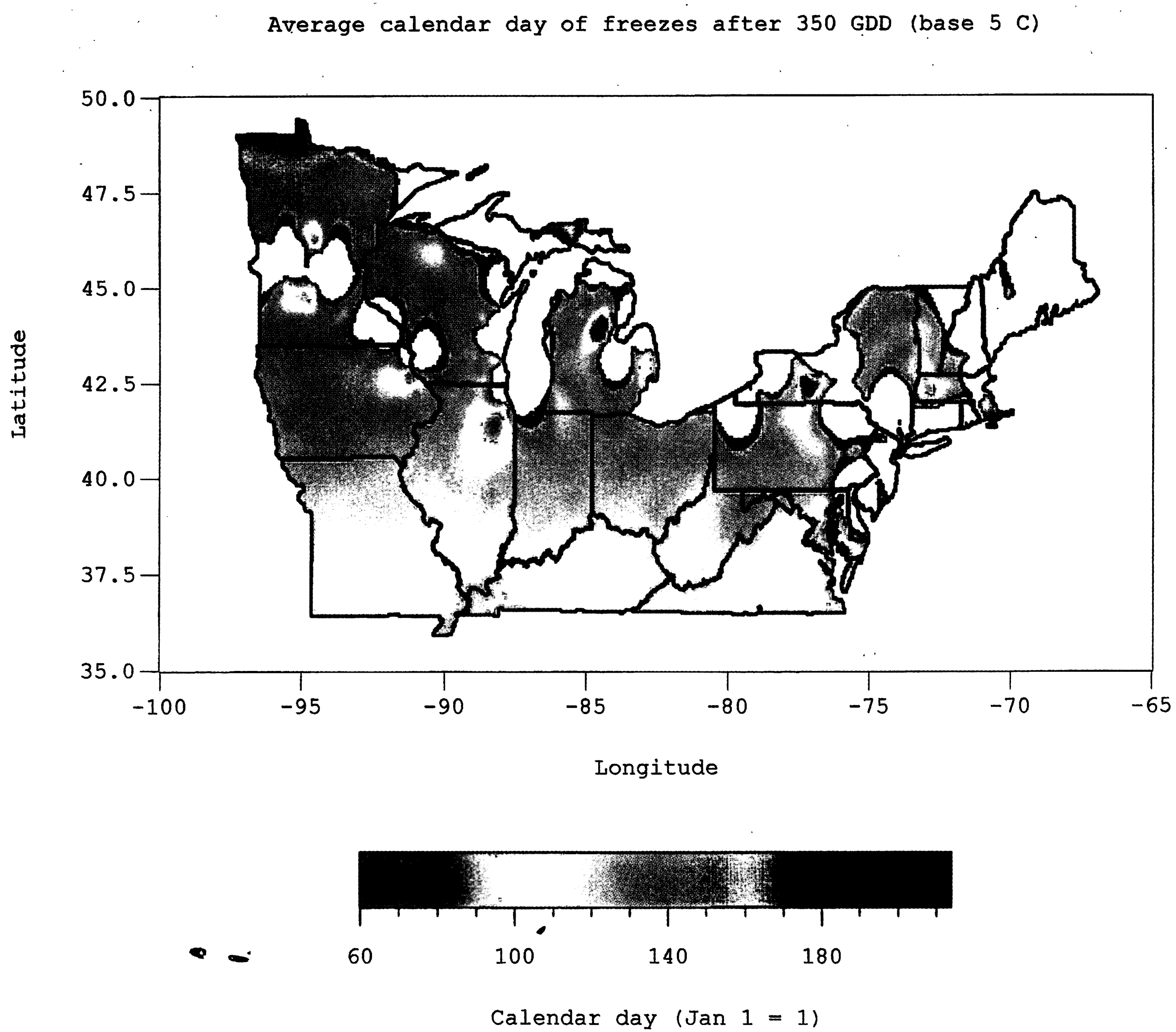
Average calendar day of freezes after 200 GDD (base 5 C)

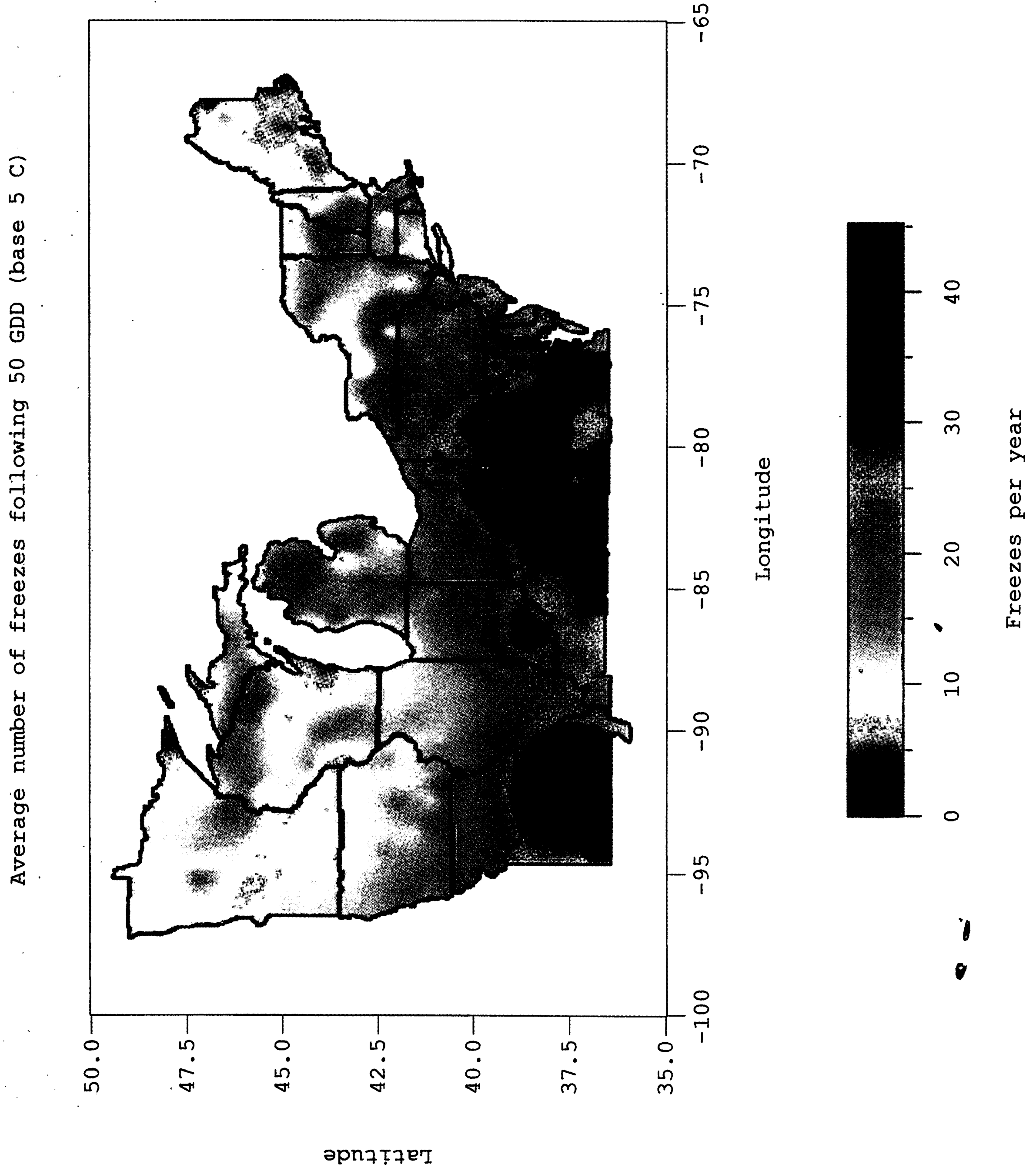


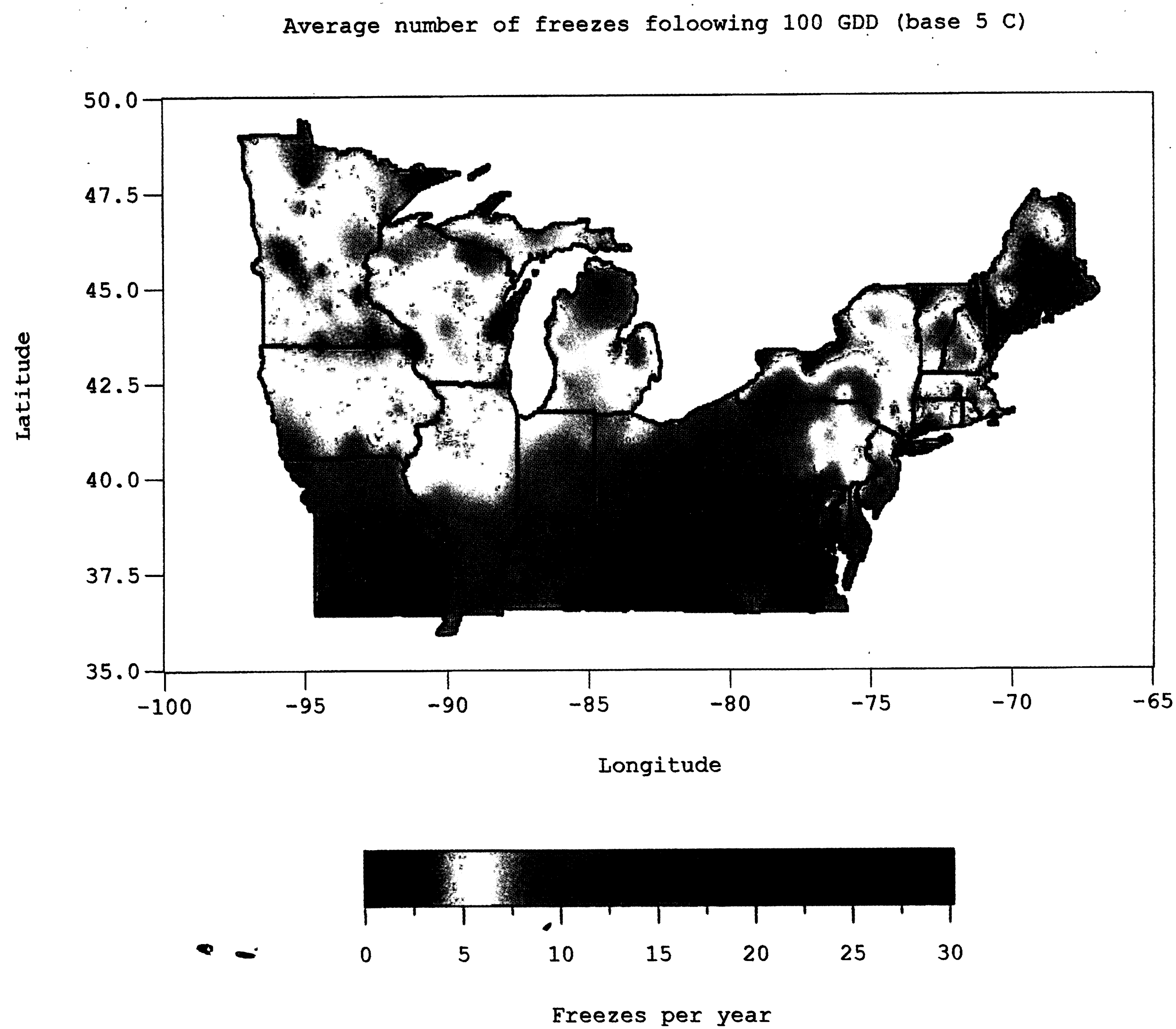

Average calendar day of freezes after 250 GDD (base 5 C)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Latitude
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
75
100
125
150
175
200
Calendar day (Jan 1 = 1)

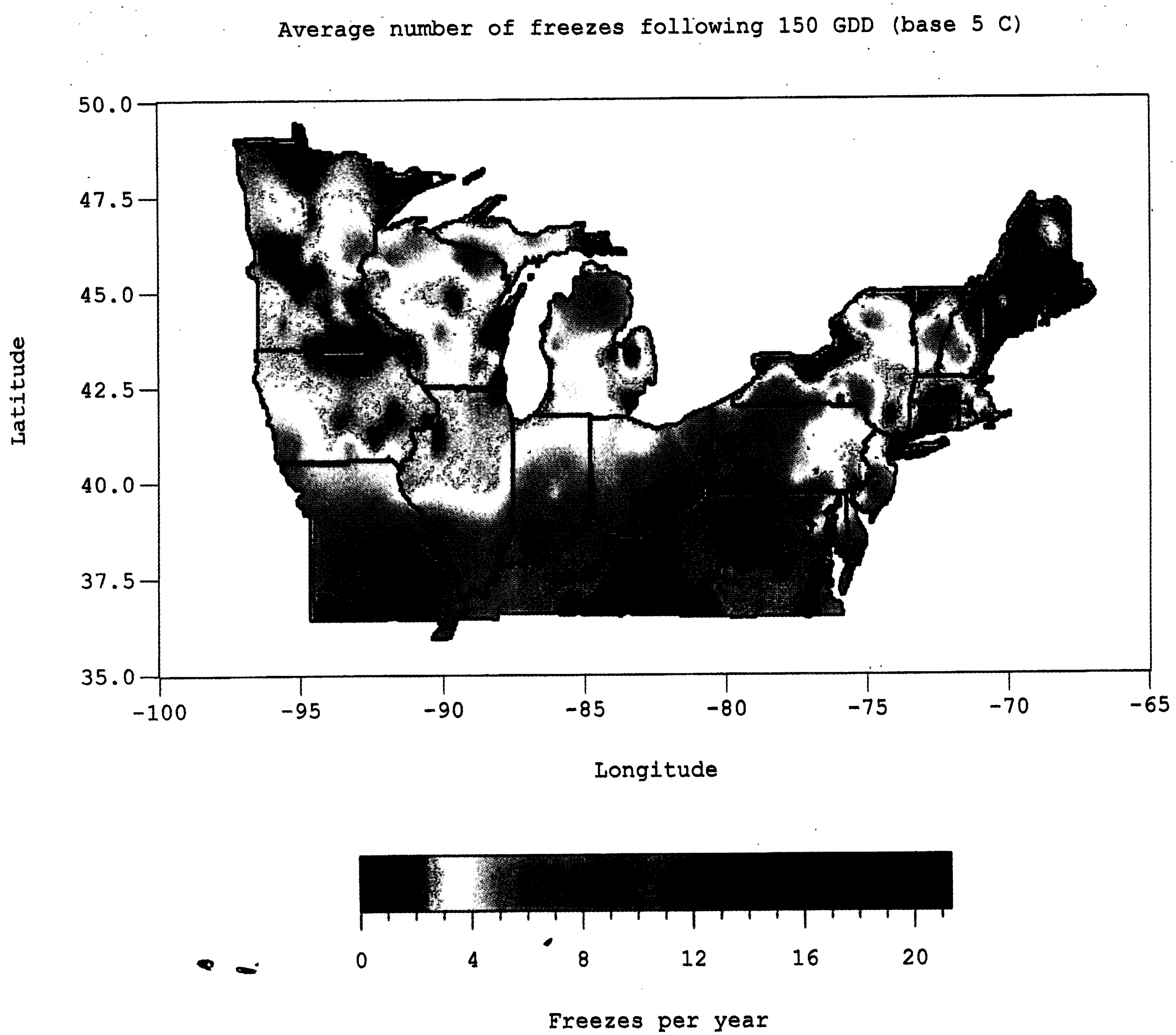


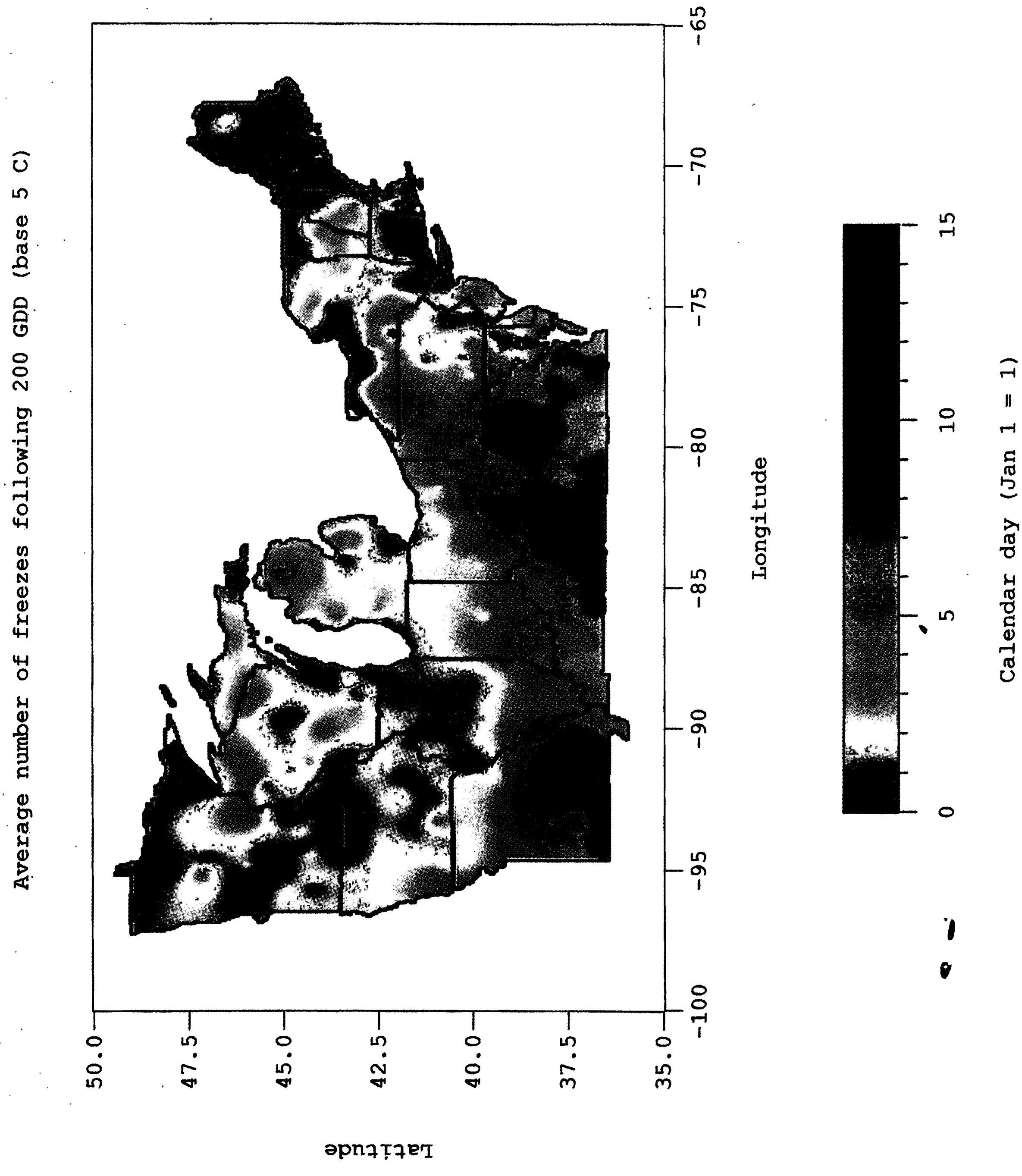
Average calendar day of freezes after 300 GDD (base 5 C)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Latitude
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
60
100
140
180
Calendar day (Jan 1 = 1)

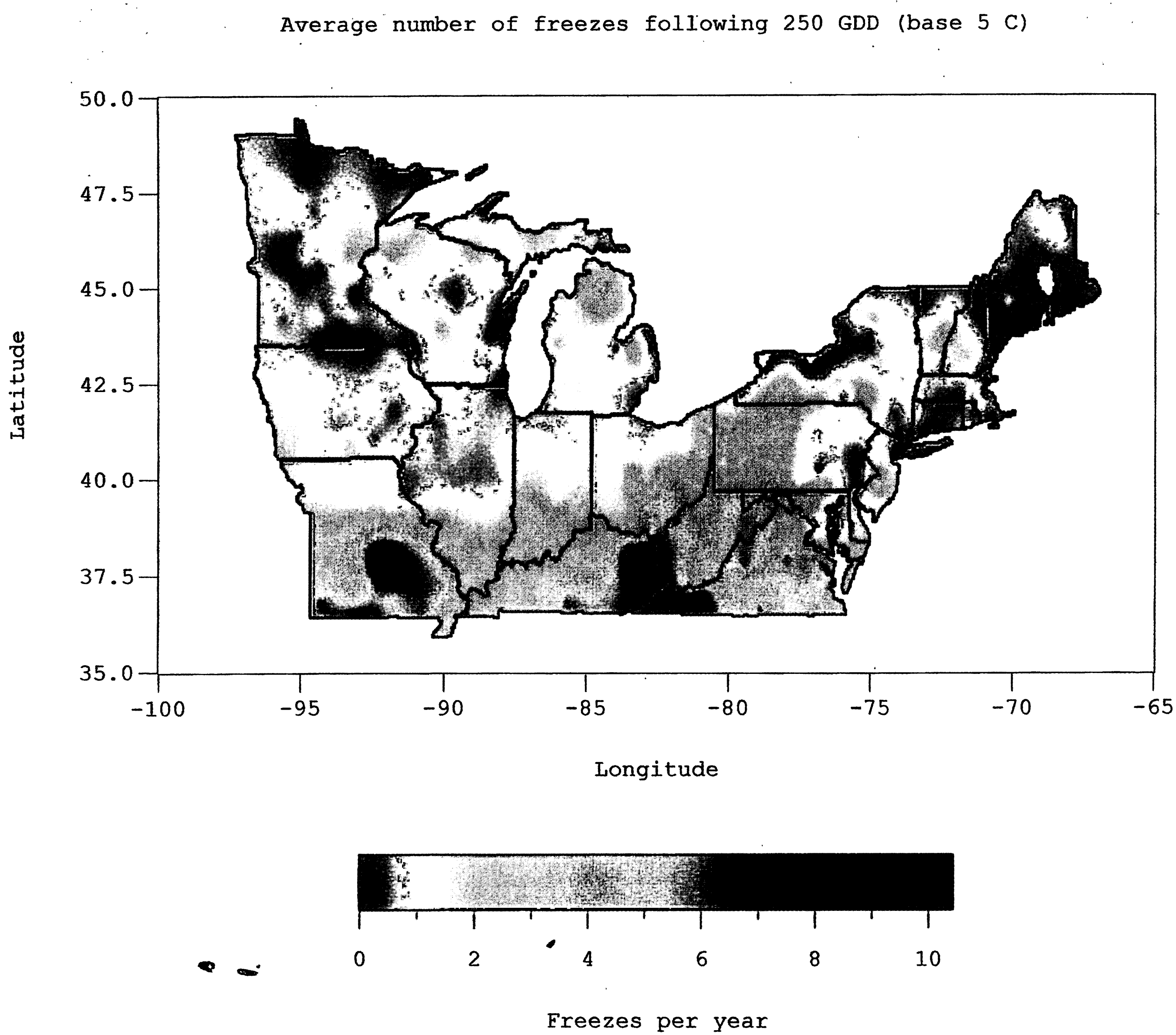

Average calendar day of freezes after 350 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
60
100
140
180
Calendar day (Jan 1 = 1)


Average number of freezes following 50 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Longitude
-100
-95
-90
-85
-80
-75
-70
-65
Freezes per year
0
10
20
30
40

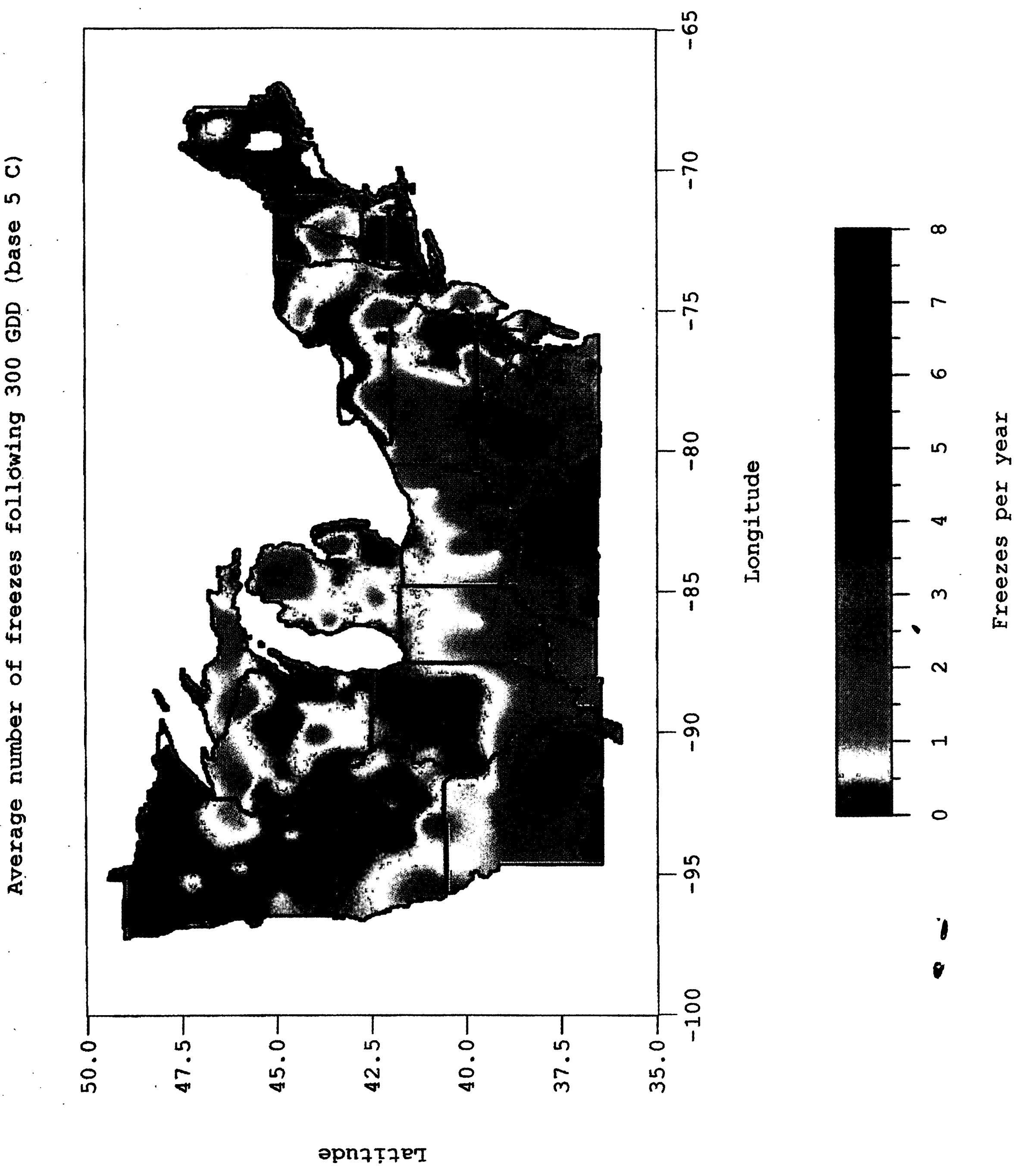

Average number of freezes foloowing 100 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
0
5
10
15
20
25
30
Freezes per year


Average number of freezes following 150 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
0
4
8
12
16
20
Freezes per year

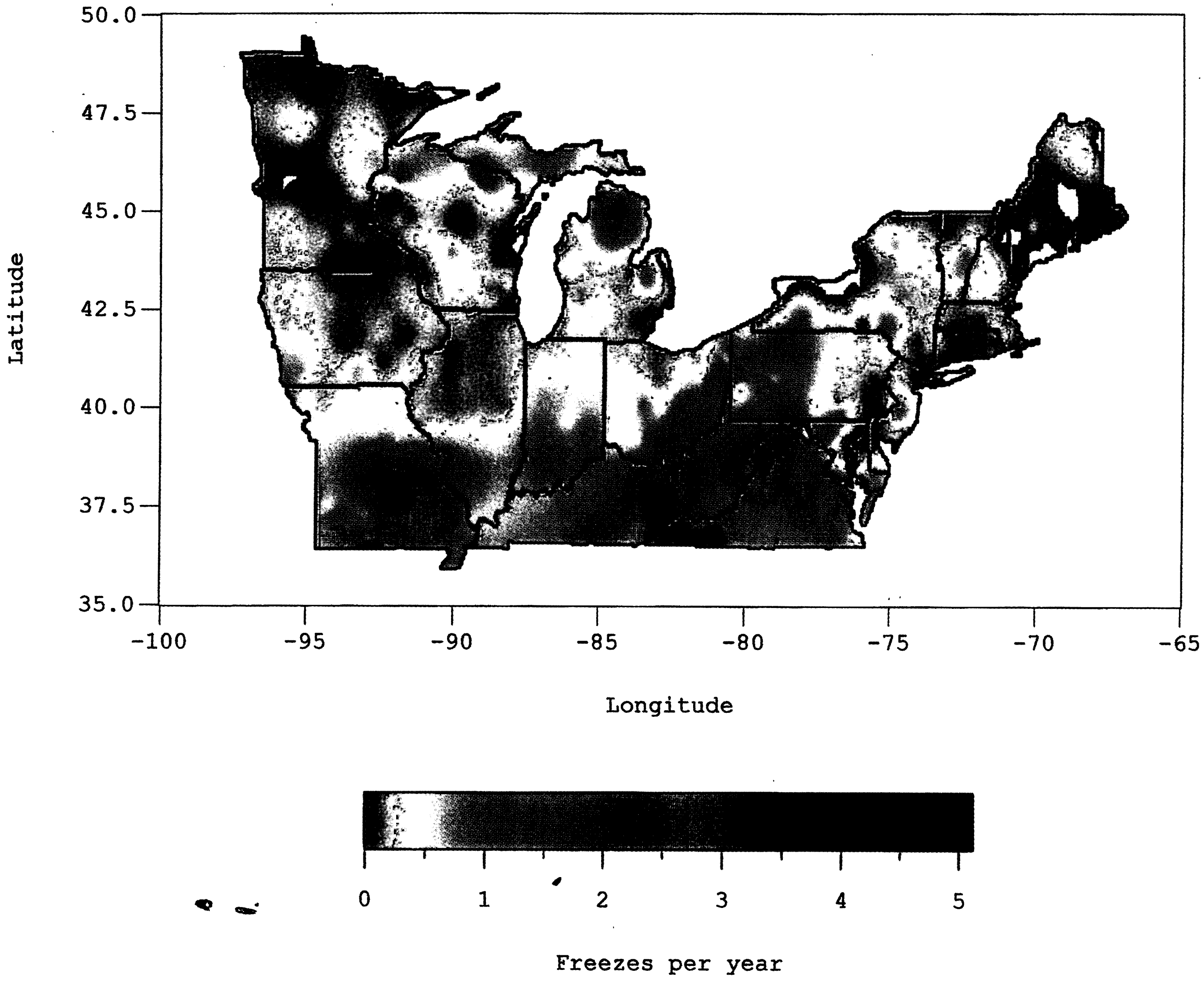

Average number of freezes following 200 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Longitude
-100
-95
-90
-85
-80
-75
-70
-65
0
5
10
15
Calendar day (Jan 1 = 1)



Average number of freezes following 250 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
-100
-95
-90
-85
-80
-75
-70
-65
Longitude
0
2
4
6
8
10
Freezes per year


Average number of freezes following 300 GDD (base 5 C)
Latitude
50.0
47.5
45.0
42.5
40.0
37.5
35.0
Longitude
-100
-95
-90
-85
-80
-75
-70
-65
Freezes per year
0
1
2
3
4
5
6
7
8

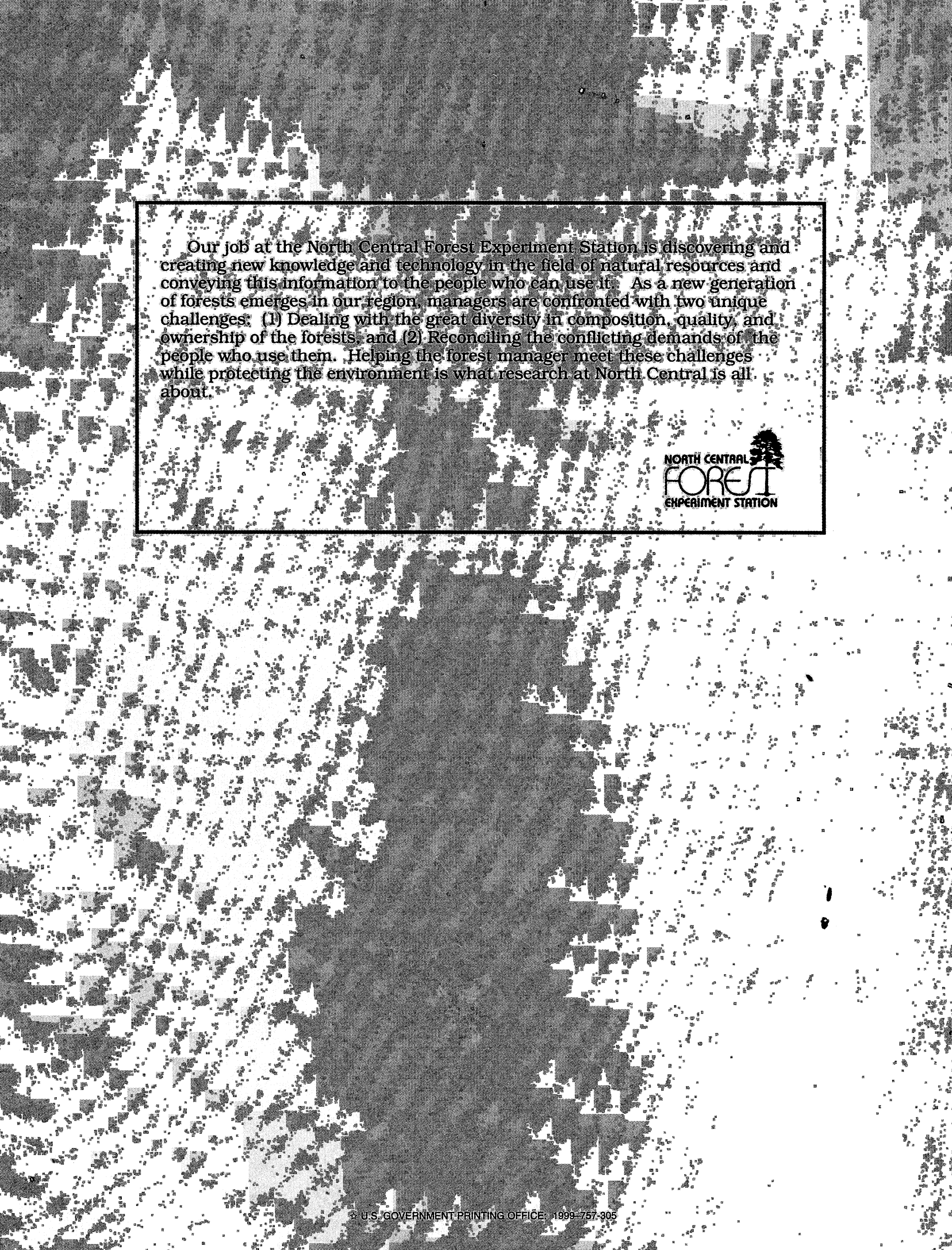
Average number of freezes following 350 GDD (base 5 C)



Potter, Brian E.; Cate, Thomas W.
1999. **A climatology of late-spring freezes in the northeastern United States**. Gen. Tech. Rep. NC-204. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 35 p.

Presents maps of late-spring freeze characteristics for the northeastern and north central United States based on heat-sum thresholds and historic climate data. Discusses patterns seen in the maps. Provides examples of ways these maps could be used by resource managers and research scientists.

KEY WORDS: freeze, climate.



Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION

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