SPATIAL ANALYSIS OF FREEZE EVENTS IN FLORIDA

CLYDE W. FRAISSE*, GUILLERMO A. BAIGORRIA
AND TAPAN B. PATHAK
University of Florida, IFAS
Agricultural and Biological Engineering Department
239 Rogers Hall
Gainesville, FL 32611-0570

Additional index words. citrus, cold weather, surface trend analysis, GIS

Abstract. **In spite of the mild winters, severe cold weather occurs in Florida when the polar jet stream moves further in the southern region of the US. Oranges are usually damaged when the fruit are exposed to temperatures below -2°C (28°F) for 4 hours or more. The main objective of this study was to understand the spatial distribution of two major freezes that severely affected the citrus industry during the last century and to determine their impact on the citrus production areas of the state. Minimum temperature data collected at individual weather stations during the freezes of December 25, 1983 and January 21, 1985 were analyzed and interpolated using surface trend analysis. The resulting maps were analyzed in conjunction with land use maps to estimate the area of citrus production impacted by different temperature ranges. In 1985, 100% of the citrus production areas located in the northern production zone was subjected to temperatures below -2°C (28°F). In the central, western, Indian River and southern zones, the fractions of the production areas affected were 70%, 52%, 52%, and 6%, respectively. During the freeze of 1983, the fractions of the production areas affected were 50%, 57%, 42%, 3%, and 1% for the northern, central, western, Indian River, and southern production zones, respectively.**

Most of Florida consists of a low elevation, 400 mile long peninsula which is part of the southeastern coastal plain that stretches from Texas to Virginia. Mean average temperature for the coldest month (January) ranges from 10-12°C (50-53°F) in the north to the 19-21°C (67-70°F) in the south (Winsberg, 2003). In spite of the relatively mild winters when compared to northern parts of the country, severe cold weather can occur in Florida when the polar jet stream moves towards the southern region of the US. Cold weather may cause severe damage to the citrus and winter vegetable industry, especially if the temperature falls below 0°C (32°F). Oranges are usually damaged when the fruit are exposed to temperatures below -2°C (28°F) for 4 hours or more (Parsons and Boman, 2003). The frequency of freezes in a given location is a function of several factors including latitude, local relief, proximity to water bodies, and type of soil (Bradley, 1975).

There are two types of freezes: radiation and advection. Radiation freezes occur on cold nights when relative humidity is low and winds are calm. During radiation freezes heat is lost, or radiated, from the earth's surface into the atmosphere. Radiation freezes are much more restricted geographically than advection freezes and radiation freezes are most common in low areas since colder, dense air may sink from higher elevations. The composition of the soil also plays a role in the frequency of freezes since moist sandy soils are less prone to radiation freezes than the dark muck soils (Winsberg, 2003). Advection freezes occur when a mass of cold air displaces a mass of warmer air at the earth's surface. This displacement can be caused by a temperature inversion or when masses of cold, polar air move into warmer areas. Advection freezes in Florida usually take place when frigid air comes from Canada or Siberia. One of the most devastating sequence of events to citrus growers is an early freeze in November or December followed by a month of warm weather and then another freeze in February. The warm weather between freezes may cause the trees to loose freeze hardiness making them extremely vulnerable to a second hard freeze. This sequence occurred during the 1894-1895 citrus season when a severe freeze on December 29, 1894, was followed by a mild winter and a second hard freeze occurred on February 7, 1895 (Attaway, 1997). The December 1894 freeze killed young trees and weakened mature trees whereas the February 15 freeze killed 90 percent of all the trees north of a line between Tampa and Melbourne. Fruit shipments dropped from 5.1 million boxes in the 1893-94 season to 147,000 in 1895-96 and it took 15 years for shipments to reach the level of the 1893-94 season.

During the twentieth century severe freezes affected the citrus industry in 1981, 1983, 1985, and 1989. The freezes of 1983 and 1985 were the most costly and recovery was almost impossible for many citrus growers (Aerts and Nesheim, 2000). The freeze in 1983 occurred on Christmas Day and temperatures in central Florida reached about -5°C (the low 20s°F). The 1985 cold wave occurred on 21 January and caused temperatures in Tallahassee to drop to -14°C (6°F), -7.2°C (19°F) in Orlando, -6.6°C (20°F) in Lakeland, -6°C (21°F) in Tampa and 1°C (34°F) in Miami (Wisenberg, 2003). The night of January 22 was also severely cold, with temperatures falling below freezing as far south as Miami. Following the 1985 freeze, the area planted with citrus declined to 26 percent of that in 1982. The harvest of the 1984-85 season was only half of that of the 1979-80 season.

Since the freezes of the 1980s, the state's citrus industry has largely recovered and recent threats to the industry are mostly associated with hurricanes and diseases such as citrus canker and greening. Nevertheless, freezes are always a main source of concern and understanding the spatial distribution of major freeze events can help increase the industry preparedness and also better estimate potential impacts across the state once a freeze event has occurred.

Spatial Interpolation of Temperature Data. The rationale behind spatial interpolation is the very common observation that, on average, points that are close together in space are more likely to have similar values of a property of interest than points that are farther apart (Burrough, 1986). Based on observed data, estimation of meteorological variables at unsampled locations can be accomplished by a variety of stochastic and deterministic interpolation methods. Depending on the spatial attributes of the data, accuracies vary widely

Funding for this project was provided by the USDA-Risk Management Agency (USDA-RMA), the Office of Global Programs at the National Oceanic and Atmospheric Administration (NOAA), and the USDA-Cooperative State Research, Education and Extension Service (USDA-CSREES).

*Corresponding author; e-mail: cfraisse@ufl.edu

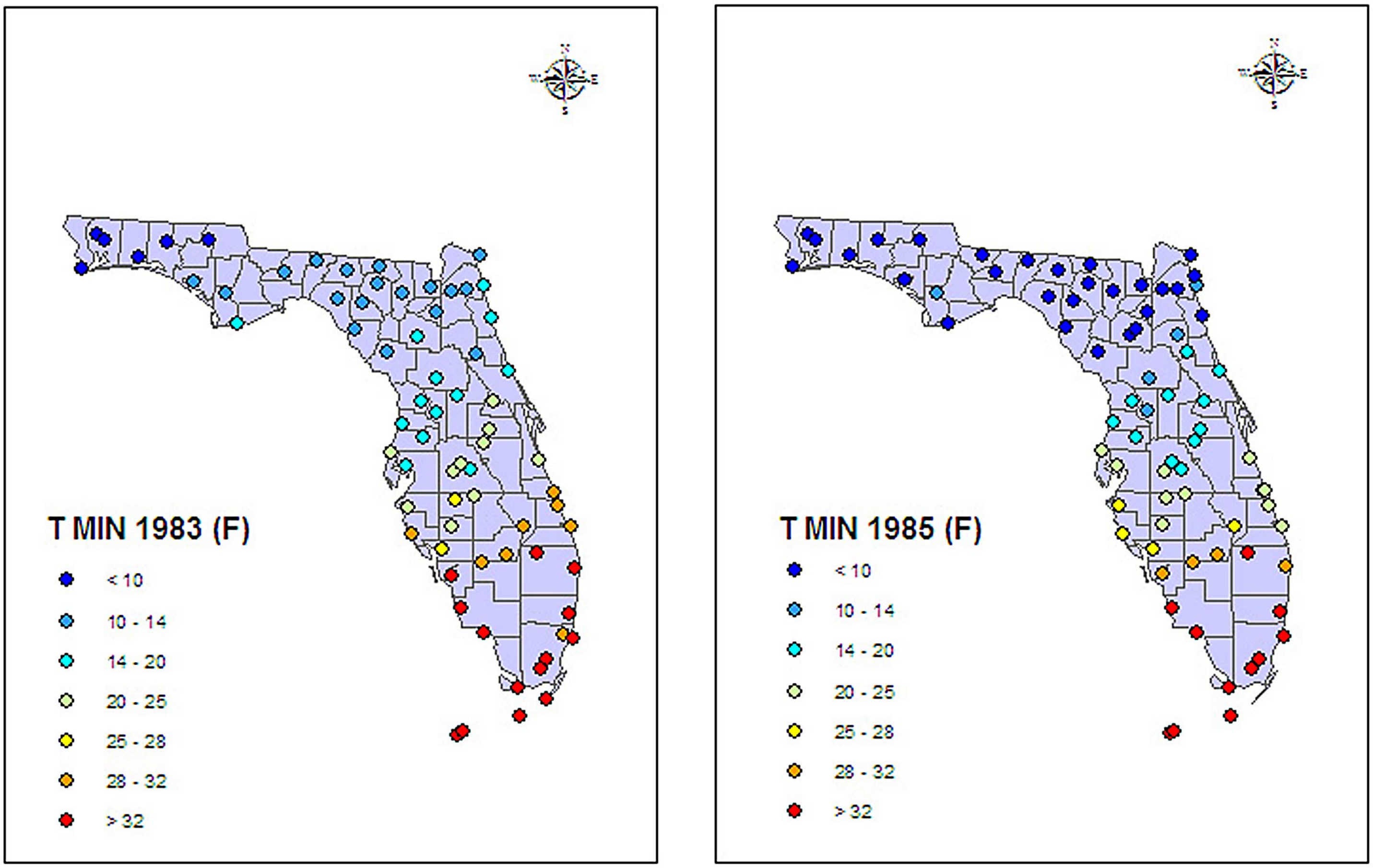

Fig. 1. Minimum temperature data set compiled from the National Weather Service's Cooperative Network for December 25, 1983 (left) and January 21, 1985 (right).

among different spatial interpolation methods (MacEachren and Davidson, 1987).

Collins and Bolstad (1996) compared various spatial interpolation techniques across two regions (eastern and western North America), two temperature variables: maximum temperature and minimum temperature, and three temporal scales (10 year mean, seasonal mean and daily). The methods used in the comparison included inverse distance weighted averaging (IDW), splining, polynomial regression, trend surface analysis, kriging, and cokriging. They concluded that data characteristics influence the choice of spatial interpolation technique. Temperature range, temperature variance, and temperature correlation with elevation influence the choice of interpolation technique. Spatial scale and relative spatial density and distribution of sampling stations also impacts interpolation. Overall, polynomial regression was most representative of the original data and had the lowest mean absolute error value of the methods ranked.

IDW is a deterministic estimation method based on the assumption that values closer to the unsampled location are more representative of the value to be estimated than samples farther away. Splining is a deterministic technique to represent two dimensional curves on three dimensional surfaces (Eckstein, 1989; Hutchinson and Gessler, 1994). Spline functions are mathematical equivalents of a flexible ruler. Splines assume smoothness of variation and are typically used for creating contour lines from dense regularly-spaced data.

Polynomial regression is a stochastic, global technique which fits the variable of interest to some linear combination of regressor variables (Myers, 1990). Typically, the goal when using polynomial regression is to obtain the best fit with the simplest model. The addition of regression variables which do not contribute significantly to the model has the unwanted effect of increasing multicollinearity. Trend surface analysis (TSA) can be thought of as a subset of polynomial regression. TSA is a stochastic technique which separates the data into regional trends and local variations. The regional component of TSA can be thought of as a regression surface fit to the data, whereas the local variations can be thought of as a map of residuals. Values at unsampled locations may be estimated using the mathematical relationship between the locational variables X, Y and the regionalized meteorological variable of interest.

Kriging is a stochastic technique similar to inverse distance weighted averaging in that it uses a linear combination of weights at known points to estimate the value at an unknown point. Kriging uses a semivariogram, a measure of spatial correlation between two points, so the weights change according to the spatial arrangement of the samples. Cokriging is similar to kriging except it uses additional covariates, usually more intensely sampled, to assist in prediction. Cokriging is most effective when the covariates are highly correlated. Both kriging and cokriging assume homogeneity of first differences.

The main objectives of this study were to analyze the spatial distribution of two major freeze events in Florida, 25 Dec. 1983 and 21 Jan. 1985, and to quantify citrus production areas that were impacted by different levels of freeze severity.

Materials and Methods

The study area consists of the state of Florida, between 31°10'N, 87°38'W and 24°57'S, 80°03'W. Elevation ranges between 0 to 105 m (345 feet) above sea level and covers a total area of 170,312 km^2 (65,758 sq mi.). Weather observations for 71 (1983) and 75 (1985) weather stations across the state were compiled from the National Weather Service's Cooperative Observer network (NCDC TD 3200) contained values of maximum temperature, minimum temperature, and precipitation during the two dates of interest (Fig. 1). In addition to the geo-referenced weather observations, spatial data sets used in this study included a basic coverage of the state of Florida with county boundaries and citrus production areas. All spatial data sets used in this study were transformed from a geographic coordinate (latitude, longitude) system (NAD 1927) to the Universal Transverse Mercator (UTM) system in order to facilitate the spatial analysis process.

Spatial Analysis. When a trend is present in the sample values, it is not possible to guarantee that interpolation methods will produce unbiased estimates. Most statistically based techniques assume that the sample data come from a fixed distribution. If the expected value is changing from place to place within the study area, the mean of the distribution is changing. This means that every sample is potentially from a different distribution and traditional geostatistical can not be used (Clark and Harper, 2001). Since spatial trends were detected in the temperature values, trend surface equations were modeled by a polynomial equation using X and Y coordinates as predictors. Linear, quadratic, and cubic polynomial equations were fitted to both data sets. Both in the cases of 1983 and 1985, cubic polynomial equations (Equation 1) were selected where $b_{0...,9}$ represent the polynomial coefficients.

$$T_{min} = b_0 + b_1X + b_2Y + b_3X^2 + b_4XY + b_5Y^2 + b_6X^3 + b_7Y^3 + b_8X^2Y + b_9XY^2 \quad \text{(Eq. 1)}$$

Trend surfaces are smoothing functions rarely passing exactly through the original data points unless these are few and the order of the surface is large. It is implicit in a multiple regression that the residuals from a regression line or surface are normally distributed, independent errors (Burrough, 1986). The main purpose of the trend analysis was to remove the geographical trends of the temperature values before using a spatial interpolation process. Calculated trend values were subtracted from observed values to compute residuals which were then interpolated using IDW. The interpolation process used was IDW due to the lack of any detectable spatial correlation that would suggest the use of ordinary Kriging. Interpolated maps were generated on a 3 km (1.9 miles) grid format. Minimum temperature maps of the 1983 and 1985 freezes were generated based on the interpolated residuals. Minimum temperature maps were reclassified in seven temperature classes according to Table 1.

To ensure the validity of the interpolation processes, Jackknife validations were performed by leaving 20% (13 stations) of the weather stations out of the interpolation process. These

Table 1. Minimum temperature classes used for reclassifying interpolated values.

Class	Temperature °C	Temperature °F
1	<-12	<10
2	-12 to -10	10 to 14
3	-10 to -7	14 to 20
4	-7 to -4	20 to 25
5	-4 to -2	25 to 28
6	-2 to 0	28 to 32
7	>0	>32

13 randomly chosen temperatures from each weather station were compared to those extracted from the interpolated maps at the same locations. Correlation analyses between the observed and interpolated minimum temperatures yielded Pearson's correlation of 0.9690 and 0.9925 for 1983 and 1985, respectively. In both cases, the analysis of variance resulted in non-significant statistical differences between the observed and interpolated minimum temperatures.

Citrus Production Zones in Florida. Florida is the nation's leader in citrus production accounting for more than 79% of the U.S. production in 2003/04 (Florida Agricultural Statistics Service). The total citrus production area in 2003-04 was

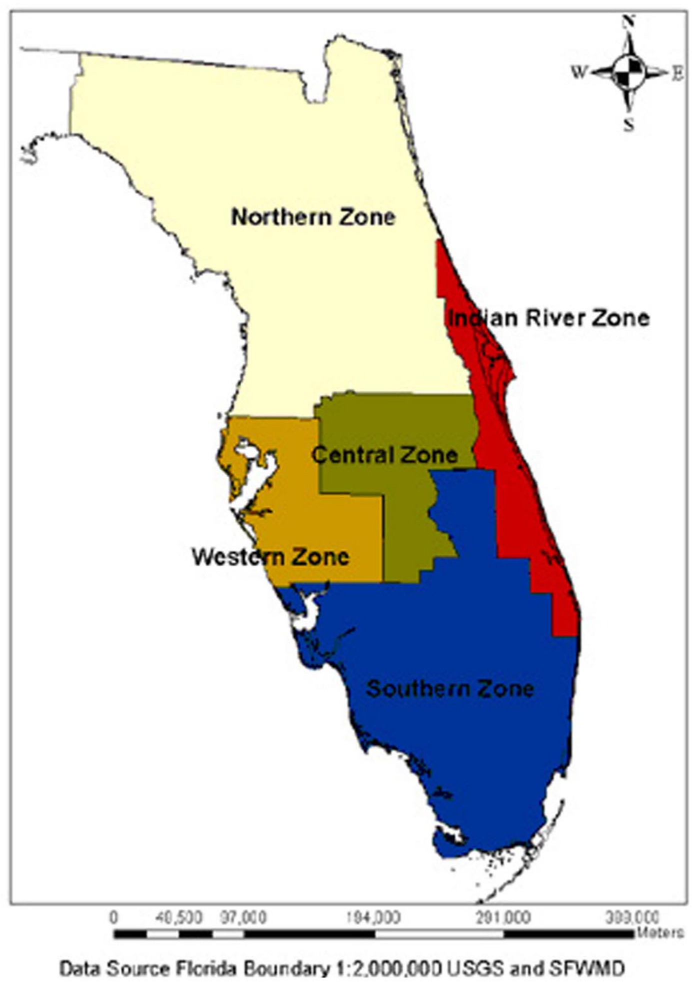

Fig. 2. Florida citrus production zones.

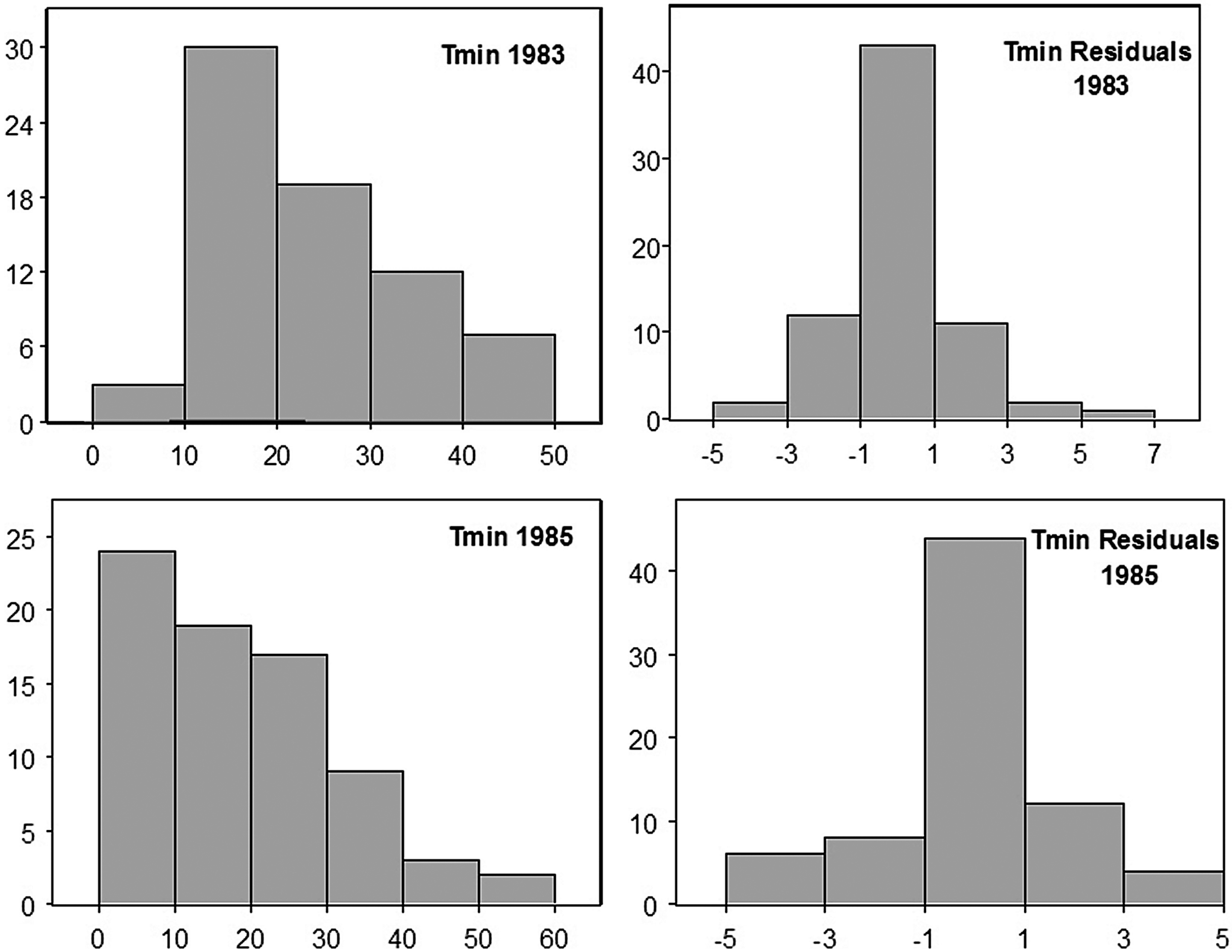

Fig. 3. Minimum temperature and residuals for 1983 (top) and 1985 (bottom).

estimated at 748,555 acres. Citrus production areas in Florida are divided in five zones: Central, Indian River, Northern, Southern, and Western zones (Fig. 2). In order to quantify zones that were affected by freeze, it was required to know the spatial distribution of total citrus production areas. A recent land use map was downloaded from the Florida Geographic Data Library (FGDL, available at http://www.fgdl.org/). The land use map used in this study was created by Florida Fish and Wildlife Commission (FFWC) that had one distinct class for citrus production areas. In this land use map the total area in the State of Florida under citrus production is estimated at 948,343 acres, or 26.7% above the total area estimated by the Florida Agricultural Statistics Service in 2003/04.

Results and Discussion

Observed minimum temperature in 1983 ranged from -13°C (8°F) in Walton County to 10°C (50°F) in Monroe County whereas in 1985, it ranged from -16.6°C (2°F) in Washington County to 12°C (54°F) in Monroe County. Table 2 shows summary statistics for both the years of 1983 and 1985.

Figure 3 shows the histograms of the observed minimum temperatures during the freezes of 25 Dec. 1983 and 21 Jan. 1985. The histograms and calculated skewness of the samples (Table 2) indicate that the original datasets were positively skewed. Histograms of the resulting residual data sets obtained after the trend surfaces were subtracted from the original datasets and show distributions not significantly different from a normal distribution.

Table 2. Summary statistics for observed minimum temperature (°C) during the 1983 and 1985 freezes.

Summary statistics	1983	1985
Arithmetic Mean	-5.25	-7.43
Standard Deviation	6.15	7.10
Skewness	0.76	0.79
Kurtosis	2.58	2.89
Coefficient of Variation	-1.17	-0.95
Number of samples	71.00	74.00
Minimum Value	-13.30	-16.70
Maximum Value	10.00	12.20

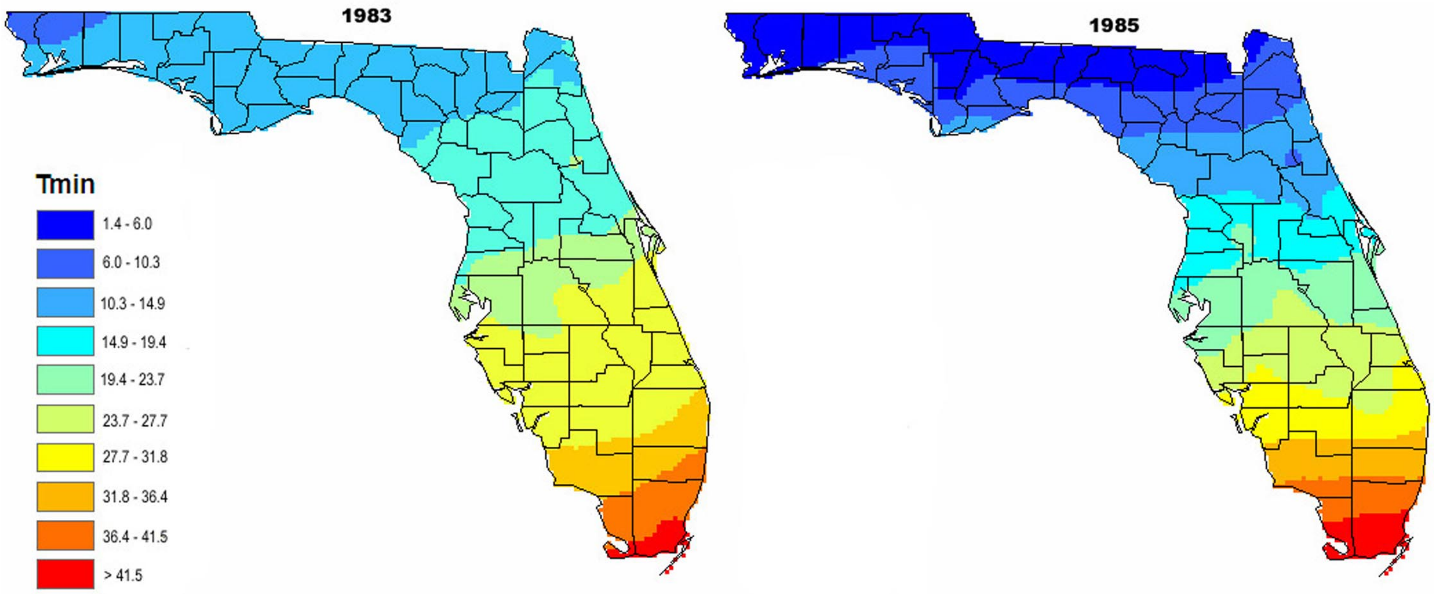

Fig. 4. Spatial distribution of observed minimum temperature during the freezes of December 25, 1983 (left) and January 21, 1985 (right).

Figure 4 shows the resulting statewide minimum temperatures for 25 Dec. 1983 and 21 Jan. 1985. Lower temperatures affected the state during the freeze of 1985, especially in the panhandle and the north central areas of the state.

Table 3 shows the area of citrus in each production zone affected by different ranges on minimum temperature during the freezes of 1983 and 1985. As expected, production areas in the northern production zone were impacted more severely during the 1983 and 1985 freeze events than the southern zones. Most of the citrus in the northern production zone, 70,575 acres in 1983 and 74,256 acres in 1985, were subjected to minimum temperatures in the range of -10 to -6.6°C (14 to 20°F). During the freeze of 1985, a substantial area, almost 2,000 acres, were subjected to minimum temperatures below -10°C (14°F). The southern production zone was the least impacted, with 70% (188,589 ac) and 76% (172,686 ac) of the production acreage subjected to minimum temperatures above -2°C (28°F) during the 1983 and 1985 freezes, respectively. According to Parsons and Boman (2003), oranges are usually damaged when the fruit are exposed to temperatures of -2°C (28°F) or lower for four hours or more. In that case, assuming that the observed minimum temperatures lasted more than 4 hours, it can be concluded that the percentage of the acreage with fruit damage caused by the freezes of 1983 and 1985 (Table 4) ranged from 1% in the southern zone during the 1983 freeze to 100% in the northern zone during the 1985 freeze. The greatest increase in impacted areas between 1983 and 1985 occurred in the Indian River production zone where 3% was affected during the 1983 freeze and 52% was affected during the 1985 freeze.

Summary and Conclusions

The spatial distributions of minimum temperatures observed during the freezes of 25 Dec. 1983 and 21 Jan. 1985 were estimated based on observations collected at individual weather stations across the State of Florida. Cubic polynomial trend surface equations were successfully used to model minimum temperatures using geographic coordinates as predictors. The main purpose of the trend analysis was to remove trends from temperature values before using a spatial interpolation process. The resulting minimum temperature maps were used in conjunction with land use maps to estimate the area of citrus production affected by different temperature ranges. The 21 Jan.1985 freeze had a greater impact across the state than the freeze of 25 Dec.1983. In 1985, 100% of the citrus production areas located in the northern production zone was subjected to minimum temperatures below -2°C (28°F). In the central, western, Indian River and southern zones, the fractions of the production areas affected were

Table 3. Acres affected by different minimum temperature (Min.T.) ranges during the 1983 and 1985 freezes.

Min. T. (°F)	North (acre)		Central (acre)		Western (acre)		Indian River (acre)		South (acre)	
	1983	1985	1983	1985	1983	1985	1983	1985	1983	1985
<10	0	789	0	0	0	0	0	0	0	0
10-14	139	1,172	0	0	0	0	0	0	0	0
14-20	70,575	74,256	2	18,323	214	4,277	2,028	7,446	0	0
20-25	5,509	7	113,815	120,845	81,188	95,949	5,420	112,193	1,458	14,425
25-28	0	0	84,819	59,468	112,968	94,143	188,206	98,286	56,797	59,732
28-32	0	0	0	0	0	0	36,618	14,347	161,925	149,539
>32	0	0	0	0	0	0	0	0	26,664	23,147
Total	76,223	76,223	198,635	198,635	194,369	194,369	232,272	232,272	246,844	246,844

Table 4. Percentage of the citrus production areas affected by minimum temperature ≤ -2°C (28°F).

Production zone	Fraction of the area affected by temperature ≤ -2°C (28°F) (%)	
	1983	1985
Northern	50.0%	100.0%
Central	57.0%	70.0%
Western	42.0%	52.0%
Indian River	3.0%	52.0%
South	1.0%	6.0%

70%, 52%, 52%, and 6%, respectively. During the freeze of 1983, the fractions of the production areas affected by minimum temperatures below -2°C (28°F) were 50%, 57%, 42%, 3%, and 1% for the northern, central, western, Indian River, and southern production zones, respectively.

The spatial interpolation techniques successfully used in this study can be automated to generate temperature maps for the State of Florida based on observed data collected at individual weather stations. The process can be used in combination with land use covers to generate rapid assessments of damage caused by weather extremes or to serve as input datasets for modeling other variables of interest to producers such as crop evapotranspiration and crop development and yield.

Literature Cited

Aerts, M. J. and O. N. Nesheim. 2000. Florida crop/pest management profiles: Citrus (Oranges/Grapefruits). University of Florida IFAS Extension, Circular EDIS CIR 1241.

Attaway, J. A. 1997. A History of Florida Citrus Freezes. Florida Science Source.

Bradley, J. T. 1975. Freeze probabilities in Florida. Publication no. 777. University of Florida Institute of Food and Agricultural Sciences, Gainesville.

Burrough, P. A. 1986. Principles of geographical information systems for land resources assessment. P. H. T. Beckett (ed.). Monographs on soil and resources survey No. 12. Claredon Press, Oxford.

Clark, I. and W. V. Harper. 2000. Practical Geostatistics 2000. Ecosse North America Llc, Columbus, OH.

Collins, F. C., Jr. and P. V. Bolstad. 1996. A Comparison of Spatial Interpolation Techniques in Temperature Estimation. Proceedings of the Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, NM.

Eckstein, B. A. 1989. Evaluation of spline and weighted average interpolation algorithms. Computers & Geosciences 15(1):79-94.

Hutchinson, M. F. and P. E. Gessler.1994. Splines—more than just a smooth interpolator. Geoderma 62:45-67.

MacEachren, A. M. and J. V. Davidson. 1987. Sampling and Isometric Mapping of Continuous Geographic Surfaces. The American Cartographer 14(4):299-320.

Myers, R. H. 1990. Classical and Modern Regression with Applications. PWS-Kent Publishing, Boston, MA.

Parsons, L. R. and B. J. Boman. 2003. Microsprinkler irrigation for cold protection in Florida citrus. University of Florida IFAS Extension, Fact Sheet EDIS HS-931.

Winsberg, M. D. 2003. Florida Weather. 2nd ed. University Press of Florida. Gainesville, FL.