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WHAT DO SATELLITE AND OTHER DATA SUGGEST ABOUT PAST AND FUTURE FLORIDA FREEZES?[1]

J. DAVID MARTSOLF, JOHN F. GERBER, ELLEN Y. CHEN
Fruit Crops Department, IFAS,
University of Florida, Gainesville, FL 32611

JOHN L. JACKSON, AND ANDREW J. ROSE
Cooperative Extension Service, IFAS,
Tavares, FL 32778; Inverness, FL 32650

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Abstract. **Three major freezes have occurred in Florida during the last 4 winters. The third freeze in this series, Christmas 1983, may go into history as the worst freeze of this century. Do these winters constitute a change in the climate in Florida or are they simply random occurrences? Cold winters have occurred in Florida in the past in "spells" of a series of closely spaced winters followed by periods of relatively mild winter weather. The past record is compared with recent observation made by standard and remote sensing techniques. An objective analysis of recent data indicates that there are significant local differences in the climate of minimum temperatures and that grove management may alleviate some of the minimum temperatures. Comparison of grove thermometer and thermograph data with the satellite temperatures on Christmas morning reveals that the latter are often 4 to 5°F higher than those registered by the grove thermometers in the Lake County area, i.e., the satellite data fails to disclose the seriousness of the freeze on Christmas morning. Under radiant frost conditions, the surface cools more rapidly than the air adjacent to it and the satellite data has been found to be a very good estimate of grove temperatures. But when the air is much colder than the surface, as in an advective freeze, there is a lag of the surface temperature fall relative to that of the air temperature. So the satellite view (being that of the surface) also lags the air temperature fall in advective freezes preceeded by warm and wet weather.**

The contents of this paper originated as two efforts, combined at the request of the Sectional Vice President. The purpose of the first effort, Part 1, is to document an explanation of why the satellite-sensed surface temperatures may be expected to be several degrees above air temperatures measured in typical orchard shelters. This explanation is termed thermal inertia. Another problem with the satellite data collected during the 1983 Christmas Freeze, i.e., cloud cover, is mentioned only briefly because it is not expected to be a problem in most frosts and freezes.

Severe damage to citrus from cold weather occurred in 1835, 1886, 1899, 1962 and in 1983. From weather records it appears that cold winters cluster around these severe winters. In other words there is some evidence of clumping of cold winters or "spells" of cold winters. During the 30 yr before 1910 and from 1940 to 1970, a freeze occurred on average every other year. From 1910 to 1939 freezes averaged 1 every 3 to 4 yr. Since 1970 freezes have averaged about 1 every 3 to 4 yr but most of them have occurred since 1980. When the Federal State Frost Warning Service was established in 1935 many new observing stations were added. In the mid 1970's the satellite observations of minimum temperatures added new locations. Thus, the temperature records contain information from various sources which are not strictly comparable. One thing that tends to confuse the issue is the measurement of minimum temperatures. The point is that it is difficult to make accurate comparisons of small differences because of changes in the manner temperatures were measured or in the station locations. Another compounding factor is the changing face of the citrus industry (1). When fresh fruit was the major commerce, durations below certain temperatures were measured and reported because they were crucial temperatures at which fruit froze. With the advent of concentrate, temperatures which damage trees are the issue. Damage to trees is highly dependent upon prior weather conditions but fruit freezes at the same temperature. Severe advective freezes are a part of the climate of the northern one-third of the state.

Materials and Methods, Part 1

Satellite data. Infrared data were acquired from GOES-East with the Satellite Frost Forecast System (4). The presence of cloud cover over significant portions of the Florida Peninsula during the December 25-26, 1983, freeze precluded a direct comparison with satellite data collected during the 1981 and 1982 freezes. However, the coldest temperatures in the satellite data occurred at 7:30 AM EST December 25 and at 7:00 AM EST on the 26th, both of which were relatively clear. This included Lake, Orange, and portions of surrounding counties. This area sustained tremendous damage. These 2 data sets were selected for comparison with ambient air temperature observations by growers.

Air temperature data. Minimum temperatures on minimum-indicating thermometers and from thermographs were acquired from the Federal-State Frost Warning Service, Ruskin, Florida, Mr. Fred Crosby and Mr. Dick Kamp and supplemented with grower observations, Mr. Bill Mathews, Winter Garden CGA; Mr. Hershal Hall, Golden Gem Growers; Mr. John Fiquette, Grower, Mr. Curtis Herd, Hi-Acres; Mr. Ed Barton, IMG; Mr. Franky Rogers, South Lake Apopka CGA: and Mr. Robert McAdams, Tilden Growers, (Table 1). The 30 minimum air temperature observations were plotted on a map of satellite pixel data. The satellite data was navigated by centering warm pixels associated with large warm lakes. A Macintosh personal computer was used to adjust the table of satellite values to fit the common map dimensions. These data arrays were superimposed. The differences, means, and standard deviation were computed using a spread sheet program on a microcomputer, which generated Table 1.

Materials and Methods, Part 2

Monthly mean minimum temperatures and daily maximum and minimum temperatures were retrieved with the Hydrologic Information and Retrieval System (HISARS) from climatic data sets in Northeast Regional Data Center at the University of Florida. Temperatures were supplemented and included data up to January, 1984 (6). Temperature departures were calculated and plotted with the FAST/CDC Cyber 730 computer.

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Table 1. Comparison of minimum temperatures (T min) observed by traditional thermometry with associated satellite pixel temperatures (Sat. Pixel T.) for the times indicated. The minimum temperatures were observed in °F so the satellite values are reported on the same scale.

Station	Dec. 25, 1983, 7:30 AM EST			Dec. 26, 1983, 7:00 AM EST		
	T min	Sat. Pixel T	Difference	T min	Sat. Pixel T.	Difference
Weirsdale 1	21	24.5	3.5	21	20.0	−1.0
Weirsdale 2	20	21.8	1.8	20	21.8	1.8
Lady Lake	18	21.8	3.8	18	17.3	−0.7
Fruitland Park	18	21.8	3.8	16	15.5	−0.5
Tavares	19	32.6	13.6	19	27.2	8.2
Leesburg ARC	18	26.3	8.3	17	23.6	6.6
Tangerine	21	29.9	8.9	20	21.8	1.8
Howey	21	26.3	5.3	21	21.8	0.8
Clermont	24	26.3	2.3	19	20.0	1.0
Umatilla	19	24.5	5.5	18	15.5	−2.5
Hartzog Rd	19	24.5	5.5	19	23.6	4.6
Lady Lake 2	19	23.6	4.6	19	17.3	−1.7
Plymouth	21	27.2	6.2	19	19.1	0.1
Mascotte	21	27.2	6.2	20	23.6	3.6
Pinehills	21	24.5	3.5	20	19.1	−0.9
IMG	19	26.3	7.3	19	26.3	7.3
Blueberries	19	27.2	8.2	18	21.8	3.8
Groveland	22	26.3	4.3	18	23.6	5.6
Montverde	21	27.2	6.2	21	23.6	2.6
Avalon	20	26.3	6.3	20	21.8	1.8
Shell Pond	21	26.3	5.3	22	23.6	1.6
Lake Ingram	22	26.3	4.3	21	23.6	2.6
Foundation Farm	19	26.3	7.3	19	23.6	4.6
Tilden Barn	22	27.2	5.2	22	24.5	2.5
Hi-Acres Barn	22	26.3	4.3	18	21.8	3.8
Oviedo	20	24.5	4.5	19	19.1	0.1
Stanford	21	26.3	5.3	22	21.8	−0.2
Apopka ARC	21	27.2	6.2	20	23.6	3.6
Kissimmee	22	24.5	2.5	21	23.6	2.6
Narcoosee	23	29.9	6.9	22	29.9	7.9
Mean	20.5	26.03	5.56	19.6	21.98	2.38
Standard deviation	1.53	2.32	2.32	1.54	3.23	2.86

Results and Discussion

Satellite comparison of air temperature. A comparison of 30 air temperature observations on December 25, 1983 with associated pixel radiant temperatures indicate radiant temperatures were 1.8°F to 13.6°F above observed air temperature with an average of 5.56°F. On December 26 the radiant temperature were both warmer and colder than air temperature from a −1.0°F to 8.2°F, and averaging 2.38°F. The satellite sensed radiant temperatures were much warmer on Christmas morning than air temperature and warmer than expected from previous experience with these satellite data, e.g. Fig. 3 (5), Fig. 2 (7), Fig. 2 (3). During previous freezes for which satellite data have been available, i.e., the 1981 and the 1982 freezes, the satellite temperatures were close enough to air temperature observed in groves that no differences were expected. A theory was developed to explain why the satellite temperatures were high in the advective freeze of 1983. This is due to the phenomenon termed "thermal inertia."

Thermal inertia of satellite sensed temperatures in advective freezes. It was warm and moist prior to the Christmas 1983 Freeze. Both these conditions increase storage of heat. Since the freeze was advective the surface and vegetation were cooled by convection of heat from the warmer surface with the cooler air rushing over it by turbulent transport. Cloud cover frequently interrupted radiant cooling of the surface which is the primary cooling mechanism (Fig. 1). Consequently, the surface, i.e., lake surfaces, soil surfaces, and vegetation, were warmer than the air during of the freeze. It is the radiation that the satellite measures. When the surface is cooled by the air advection satellite temperatures lag air temperatures as they did during the Christmas 1983 freeze. During a typical frost situation, surfaces are cooled by radiation which cool the air. During radiant frosts the temperatures sensed through the satellite are similar to those air temperatures in groves. During advective freezes, especially when the weather preceeding the freeze has been warm and wet, the satellite temperatures will be warmer than those observed by thermometers and thermograph.

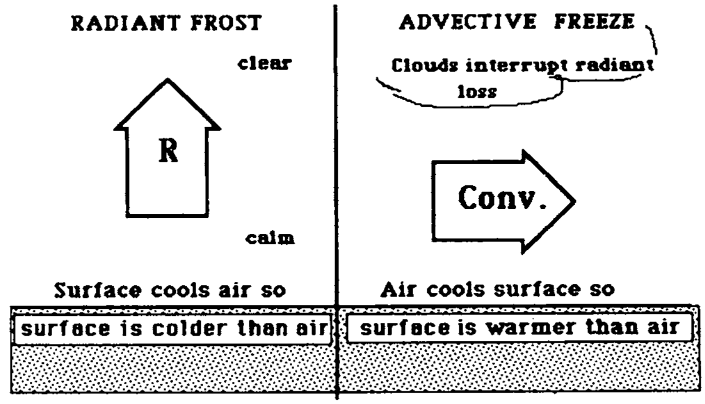

Fig. 1. Contrast in heat transfer mechanisms between radiant and advective (in which convective cooling (CONV) is the major mechanism) freezes showing that the surface temperature fall leads the air temperature fall in the radiant case and lags the air temperature fall in the advective case.

Climatological temperature departures. December and January mean monthly minimum temperature departures were calculated for the period 1930-1984 for Brooksville, Belle Glade, North Central and South Florida (Fig. 2). A prominent feature of December departures (Fig. 2 a, b) is the frequent oscillation from above average to below average temperature. Except for a 5-yr period (1959-1963) in Belle Glade, no more than 4 years were consecutively above or below average. Thus, a cold December one year could be followed by a warm December the next year, or 2-, 3-, or 4-yr. These oscillations are characteristic of December monthly minimum temperatures. One reason for the oscillation is the frequent passage of cold fronts of various degrees of severity through Florida. January temperature departures (Fig. 2 c, d) show less tendency to oscillate. Considering the 54-yr period as a whole, 55-60% of the years showed below average temperatures. However, for the 25-yr period from 1930-1954, only 20-40% of the years registered below average temperature; for the 29 years from 1955 to 1984, 67 to 80% of the years recorded below average temperatures. January departures strongly suggest a decline of the minimum temperatures. This decline is also found in other cities in Central and South Florida and suggests that peninsular Florida from south of Brooksville could be experiencing declining temperatures. At Brooksville and Lake Alfred, the last 9 yr were below average with 1980 nearest average. January of 1976 to 1979 were particularly cold, with negative departures of 6 to 10°F. Temperature records at St. Joseph, Louisiana, also indicate a trend of declining winter temperature from 1957 to 1980 (8). Our results agree with their findings, and suggests that the declining winter temperatures may be a regional phenomenon.

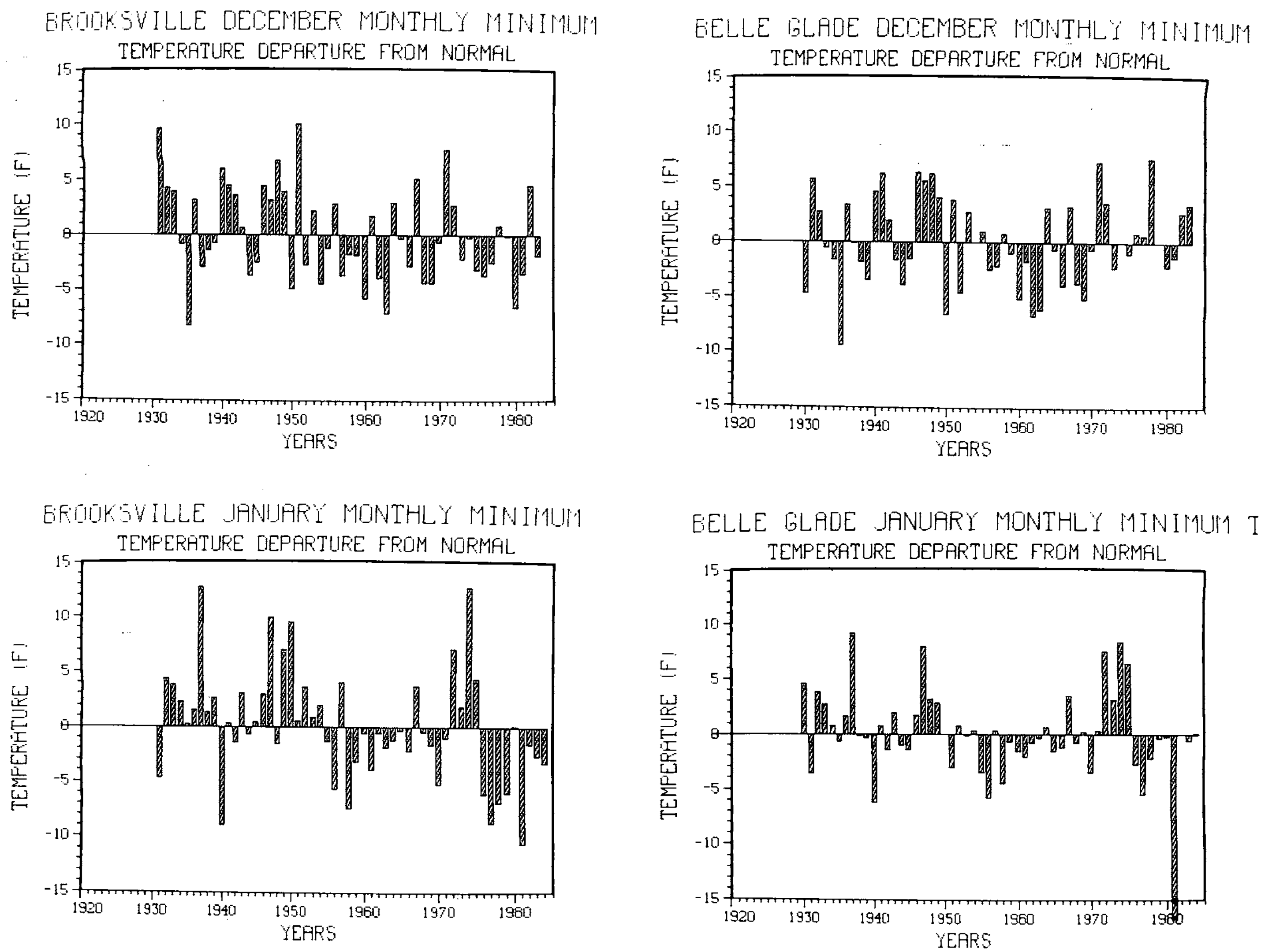

Fig. 2. December and January monthly mean minimum temperature departure for Brooksville and Belle Glade. Departures were calculated for the period 1920-1984.

Severe cold events. From weather records since 1766 it is evident that cold weather has caused damage in a number of years (Table 2). There were times when the damage may have been worse than the temperatures indicated because tree dormancy or hardiness was low due to earlier freeze damage or warm weather. The winters of 1927 and 1934 were not extremely cold even though they were the coldest winters in those decades. From 1886 to 1909, 14 freezes occurred with minimum temperatures ranging from 6-15°F. In contrast, from 1910 until 1939 there were only 8 damaging seasons. The coldest temperatures during this period in the citrus producing region was 15°F at Gainesville and DeLand. In the major producing areas the coldest temperatures ranged from 20-22°F.

Temperature departures in December and January do not indicate a difference in the weather at Brooksville and Belle Glade, since there is no significant difference in the mean departures. A linear correlation of the departures shows a one to one relationship, with a correlation coefficient of 0.86. This suggests that cold fronts which sweep into the state are likely to pass through Brooksville and Belle Glade and influence the temperature of the entire peninsula. The difference in climate between Brooksville and Belle Glade is illustrated by a tabulation of extreme cold events (temperature less than or equal to 24°F) (Table 3). Approximately the same number of extreme events occurred in Brooksville, Lake Alfred, and Arcadia, indicating a similar climate in terms of extreme events. Belle Glade recorded significantly fewer cold events in both January and December. Thus, the climate of Belle Glade is more moderate. Therefore, the shift toward milder climate, such as Belle Glade, appears to occur south of *Arcadia*. Belle Glade is influenced by Lake Okeechobee and the ocean more

Table 2. Worst freezes during decades and the number of freezes during decades since 1966.

Date	Min (°F)	Year of worst freeze	Decade	No. of freezes
Jan	7-26	1766	1760-1769	1 (?)
?	?	1774	1710-1779	Snow
?	—	1799	?	—
Feb 7	7-?	1835	1830-1839	1 (?)
?	16-?	1850	1850-1859	1
Jan 12	12-20	1886	1880-1889	2
Feb 13-14	6-24	1899	1890-1899	6
Jan 26-27	16-24	1905	1900-1909	6
Feb 3-4	15-27	1917	1910-1919	1
Jan 11-16	18-30	1927	1920-1929	2
Dec 13-14	16-27	1934	1930-1939	2
Jan 28	10-23	1940	1940-1949	3
Jan 17	12-24	1958	1950-1959	7
Dec 13-14	9-24	1962	1960-1969	5
Jan 20	15-28	1977	1970-1979	2
Dec 24-25	12-26	1983	1980-198-	3

Table 3. December and January freeze events for each decade from 1930-1984 for Brooksville, Lake Alfred, Arcadia, and Belle Glade. Only daily minimum temperatures of 24°F or less were counted.

Decades	December				January			
	Brooksville	Lake Alfred	Arcadia	Belle Glade	Brooksville	Lake Alfred	Arcadia	Belle Glade
1930-39	1	1	2	—	—	—	—	—
1940-49	—	—	—	—	3	3	2	2
1950-59	1	2	2	—	1	—	—	—
1960-69	2	3	5	—	2	1	3	—
1970-79	—	—	1	—	7	4	3	1
1980-84	3	3	2	—	3	5	3	—
Total	7	9	12	0	16	13	11	3

than other cities. On the average, 70-80% of the cold events occurred after 1954.

The December 25, 1983 freeze. The December 1983 freeze was compared with historical freezes to determine if the recent freeze was more severe than past freezes, and how it was different. Considering the temperature factor alone, weather records show 3 historical freezes (Dec. 12, 1934; Dec. 13, 1957; and Dec. 13, 1962) at Lake Alfred with equivalent minimum temperature (22°F) (Fig. 3). Lake Alfred was used because records to 1925 were easily accessible from a computer. Also, the difference in air temperature between North Central Florida and Lake Alfred is small (2). Records of the historical freezes showed a mean minimum decline of 3-8°F per day for a period of 4 to 11 days prior to a freeze. However, there was an increase of 5°F from Dec. 13 to Dec. 23 in the minimum temperature prior to the 1983 freeze. The minimum temperature dropped from 60°F to 22°F on Dec 25. This was the warmest period prior to a severe freeze within the past 50 and maybe 100 yr, which makes it very unusual and unusually damaging.

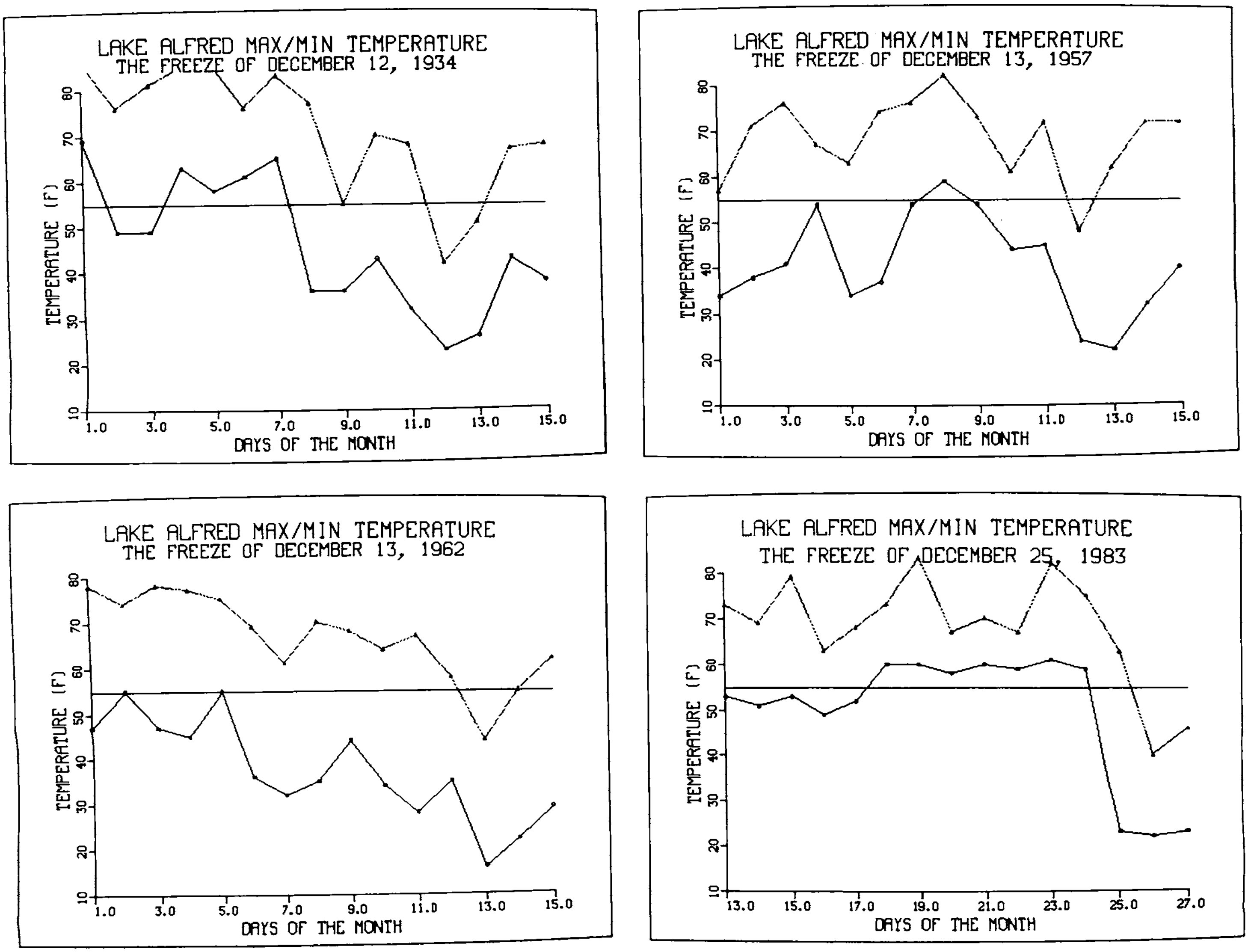

Fig. 3. Daily maximum and minimum temperatures for 12 days before freezes in December of 1934, 1957, 1962, and 1983. The upper and lower lines are maximum and minimum temperatures, respectively. 55°F is marked by a horizontal line.

This pattern was repeated for many locations in Central Florida (2). The minimum temperature rose about 10°F from Dec. 16 to Dec. 18 and remained at 60°F until Dec. 23. Most locations in Central Florida reported slight rainfall (6) from Dec. 18 to Dec. 23, showing that there was general cloudiness over the region. An extended spatial and temporal cloud cover suppressed nocturnal radiative cooling and helped to maintain warm nocturnal temperatures. The extended cloudiness most likely contributed to the high minimum temperatures observed from Dec. 18-23 prior to the freeze. The high temperature and the slight rainfall are conducive to plant growth. Also, acquired cold hardiness may have been lost during the warm period.

Severe advective freezes have occurred in Florida in 1835, 1886, 1894-95, 1899, 1909, 1940, 1962, and 1983, on average, once each 20 to 22 yr. These freezes are a part of the climate of the northern part of the citrus producing area.

Conclusions

Radiant temperatures may be expected to be higher than air temperatures during advective freezes following warm, wet periods. Since advective freezes are infrequent in comparison with radiant frosts this is expected to be an infrequent adjustment to be considered.

The temperatures analyzed show that there were a large number of years within the last 30 yr which recorded below normal temperatures. In addition, the occurrence of extreme cold events have also increased. The data suggest declining minimum temperatures for December and January from North Central to South Florida. Citrus received more damage from the December 1983 freeze *not because* of low minimum temperature alone, but because of a combination of low minimum temperature, temperature behavior prior to the freeze, cloud cover, and rainfall. The 4 factors occurring in tandem caused this freeze to be labeled by many as the freeze of the century.

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REVIEW OF EFFECTS OF CULTURAL PRACTICES ON FROST HAZARD[1]

A. H. Krezdorn and J. David Martsolf
University of Florida, IFAS,
Fruit Crops Department, Gainesville, FL 32611

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Abstract. **Severe advective freezes, such as occurred December 1983, are experienced infrequently. Most damaging freezes are of the radiation type where temperatures develop which are only a few degrees below those lethal to citrus leaves and branches. Cultural practices can be, under certain conditions, manipulated to enhance the tree's warmth and cold hardiness and thereby avoid or reduce freeze damage. Principles involved are maintenance of weed-free, moist, compact soil to furnish a reservoir of heat for the night, enhancement of air drainage, maintenance of a thick leafy canopy to intercept heat radiated from the soil, and development of maximum hardiness to cold. Severely freeze damaged trees are colder and less cold-hardy than those not damaged. Certain modifications of cultural practices are suggested for trees severely freeze damaged; however, the basic principles involved remain the same.**

Damage of freezes to citrus in Florida is well documented. For example, a temperature of 22°F, the temperature often used as approximating the temperature at which leaf damage occurs, or lower, occurred on the average of every 3.1, 8.0, and 10.8 yr, respectively, at Ocala-Weirsdale, Orlando and Avon Park from 1894-1958 (2).

Occasional dry, windy (advective) freezes, such as occurred December 1983, are so severe almost no existing method of protection is economically feasible; however, most damaging freezes are of the radiation type that develop on calm nights and damage trees at temperatures only slightly lower than 22°F. Cultural practices can be, in some instances, manipulated to attain this much protection and it is our purpose in this paper to examine their role in doing this. Unfortunately, much of the evidence is not based on precise experimentation in the field because of the difficulty in making some of the physical measurements needed, the nonuniformity of freezes, the fact that temperatures of the various part of a tree differ from air temperature and are cyclic rather than static, and because tree hardiness to cold varies with even short periods of warm and cold weather preceding the freeze.

Principles Involved

A knowledge of the development of freezes, the microclimate of the tree and factors that induce maximum tree hardiness are necessary to determine how cultural practices can be used to lessen damage.

Freeze development. There are advective freezes and radiation frosts. An advective freeze develops from an invasion of cold polar air. Air temperatures are below freezing and wind speed is 3 mph or much more. The freezes

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