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THE ROLE OF WINTER CLIMATIC ZONES IN FLORIDA FREEZES

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Abstract. **The Florida peninsula stretches for 5° latitude covering temperate to subtropical climatic zones. It is not uncommon to find maximum temperatures greater than 27°C (80°F) occuring somewhere in Florida during the winter months of December, January, and February. Thus, each winter Florida becomes a meeting ground beetween intruding polar air masses and native, warm and humid subtropical air masses. As a result, crop survival each winter depends not only on the temperatures of the intruding air masses but also on the preconditioning from the native subtropical air masses; and finally, the interaction between the two. One step towards solving this complex problem is to determine if a zone exists in the peninsula; south of which the subtropical climate is tenacious enough to provide natural "freeze protection", and north of which the subtropical environment is too weak to guarantee protection during winters. Records of monthly winter climatic extremes (1930-1979) suggest that such a zone may be present in central Florida. Minimum temperatures collected in agricultural areas were used to characterize the zone. Satellite thermal data from the 1985-86 winter provide supportive evidence that this zone exists and may be located between 28° and 29° latitude.**

The peninsula of Florida is oriented in a north-northwest to south-southeast direction, which is approximately parallel to the paths of intruding cold air masses. The peninsula is long (5° latitude) and narrow, no place is more than about 97 km from salt water (6). The highest elevation is about 105 m in north Florida, decreasing to about 75 m in central Florida, and to less than 30 m in south Florida. The Central Florida Ridge, which is part of this region of highest elevation, is marked by numerous limestone depressions, some of which are lakes, but many are dry depressions. This relatively flat terrain does not form a physical barrier impeding the flow of cold air to southern latitudes. However, the land surface of the peninsula does produce more frictional resistance to the air mass flowing over it than the surrounding sea surface because a land surface is generally rougher than a water surface. Since there is no physical barrier which could stop the southward progression of the air mass and frictional resistance acts linearly, the atmospheric forces are expected to carry the air mass through the length of the peninsula, slowing to a stop only when the energies providing the forward motion are expended. If this simple premise is true then a preferential location or an extremely narrow zone separating the incoming cold air mass from the warmer, native subtropical air mass is not expected. On the other hand, if the maritime subtropical air mass plays an important role in blocking the incoming cold air, then perhaps we could expect a buffered, narrow stopping zone for the cold air. In fact, there is no good method to estimate the stopping place of an air mass except indirectly, through events occurring at the surface as a result of the passage of the air mass, which then allow us to infer some properties of the air mass. An example of this is the freeze of 21 January 1985 in which "Interstate 4" appeared to be the "dividing line" (zone): north of which citrus was severely damaged (Lake County) and south of which citrus was relatively undamaged (Polk County). Hence, we inferred from the damages at the ground (citrus) that the boundary of the incoming cold air mass appeared to be so distinct as to cause the damage zone to be well defined. If this premise is also not true, then acclimation and preconditioning of citrus would have to be examined carefully as a factor producing the extensive damage north of "Interstate 4". It is most likely a combination of the two factors.

This paper examines historical climate records to determine if there is indeed a buffered stopping zone for intruding cold air mass, to identify its location, and to evaluate the margin of difference in the temperature north and south of this zone. If indeed the subtropical climate plays a role in checking the southward progression of the air mass, then the native subtropical air mass provides a "natural protection" benefiting crops south of this zone, and the possibility exists to apply freeze protection north of the zone to emulate conditions south of the zone. Satellite infrared data of the surface were also used to determine if such a zone can be visualized and quantified more clearly for each incoming air mass so that this zone can be monitored more closely with present day technology.

Materials and Methods

In addition to the satellite data, two sets of climate data are used in this paper: the highest and lowest daily maximum and minimum temperature of each winter month (5), and the minimum temperatures from agricultural areas of peninsular Florida during winter seasons from 1936-67 (3). The latter is a set of minimum temperatures collected by growers and the Extension Service. This set of data has not been published since about 1979. Also, efforts to collect these data have diminished through the years.

The climate of Florida undergoes gradual changes from temperate (northern Florida) to maritime subtropical (southern Florida) in the 5° atitude of the peninsula. A gradual increase of the temperature in the peninsula is illustrated clearly by the use of isotherms (1). However, the use of isotherms shows only the changes in temperature, but does not illustrate the degree or intensity of the subtropical climate or its changes with latitude, nor does it show the progressive weakening of the winter freezes through the peninsula. Threshold values of the highest daily maximum temperature in each winter month (December, January, and February) are used to represent the extent of the subtropical climate and its changes with increasing latitude through the peninsula. The higher the

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threshold value which can be used to delineate the subtropical climate, the greater will be the strength of the subtropical climate. Threshold values using the lowest daily minimum temperatures for each winter month are used to represent the intruding cold air masses (winter freezes) and how they are moderated with latitude. The number of occurrences of the highest (lowest) daily maximum (minimum) temperature at specific threshold temperatures which occur during the winter months of a 50-year period (1930-1979) were summed. Omitting the 5 years from 1980-1985 from the analyses changes the percentage of occurrence by less than 5%. In the case of the high temperature, there were no significant changes in the highest daily temperatures during this period. In the case of the minimum temperatures, the greatest change would occur if 5 freezes had occurred in the 5 years (they did not). This number (5) is too small to change the percentile by a significant amount when the total number of months in the period is 150 (50 years, 3 months per year). In fact one reason we chose this set of parameters (the highest and lowest daily temperatures of each month) is because it yields a relatively stable climatic parameter. The percent monthly occurrence for the period is calculated for Tallahassee, Lake City, Ocala, Lake Alfred, Belle Glade, and Homestead to delineate the change with latitude. These are all inland cities and are approximately one degree latitude apart (Fig. 1).

Threshold values of 30.6°C, 29.4°C and 26.7°C were calculated for each city and the smoothed values are plotted (Fig. 1, dashed lines). Belle Glade shows some cooling effect from Lake Okeechobee at the 29.4°C threshold value. Homestead, at the southern tip of Florida, has ocean effects embedded in its climate year round. The 26.7°C threshold was used because in South Florida (subtropical)

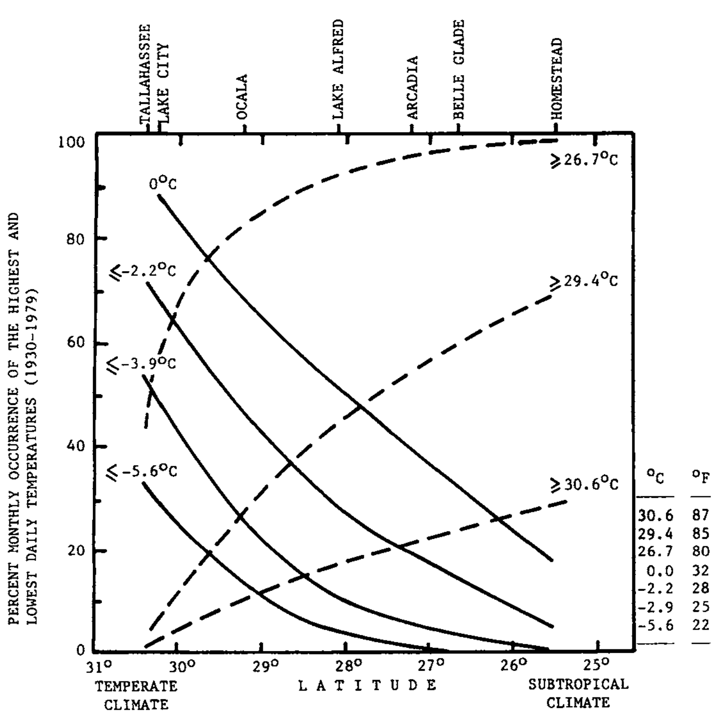

Fig. 1. The change of temperate to subtropical climate from north Florida (*Tallahassee*) to south Florida (Homestead) during winter months (D, J, and F) depicted by the percent monthly occurrence of the highest daily maximum (30.6°, 29.4°, and 26.7° C) and the lowest daily minimum (O°, –2.2°, –3.9°, and –5.6° C) temperatures (1930-79).

it occurs at near 100%, which means that each month 26.7°C was registered at least once. The use of a lower threshold value such as 25.6°C (78°F) probably would not yield more information because the slope of the threshold line would be more horizontal than the line for the 26.7°C threshold, and thus would merely indicate little change with latitude. The line delineating the 30.6°C threshold occurs at about the 5% level for Lake City (Fig. 1). Using a greater threshold value would only indicate even lower percentages, hence, it also would not add more information. Thus the 26.7° and 30.6°C thresholds were used to illustrate the subtropical climate of the peninsula and to show the variation with latitude. The 29.4°C threshold was chosen as a median value.

Invasions of cold air masses are indicated by the passage of fronts which interrupt this benign climate of Florida. The moderation of the air mass with latitude is summarized in the same manner as the subtropical climate, except that threshold values less than or equal to 0°C, –2.2°C, –3.9°C, and –5.6°C were used (Fig. 1, solid lines). The 0°C threshold was used to indicate the upper limit of winter climate and to show the possible changes in preconditioning of citrus with latitude. Since hardiness and acclimation are accumulated at low temperatures and repeated light frost, the 0°C line is the lower limit of preconditioning. The –2.2°, –3.9°, and –5.6°C thresholds are useful climatic indicators of the type of damages (such as ice in fruits and twig damage) which can be expected for citrus with changes in latitude. The –5.6°C threshold, for our purpose, is used to indicate the lower limit of winter climate in central and south Florida because its occurrence is less than 10% as far north as 29°N latitude. This is not to say that conditions worse than –5.6°C do not occur. In fact, they are expected to occur because of the naturally large daily and seasonal fluctuations of the weather, and climate is but the summation of the daily weather.

The summation of daily minimum temperatures of the winter months would produce only the gradual increase in temperature such as illustrated in climatic atlases (1). This is because such a summation of the daily minimum temperatures also included minimum temperatures which occur when the subtropical climate was dominant, that is, when there was no freeze present. We suggest then that the "buffered freezing zone" occurs only when the freezes are dominant. Hence it can be located only through parameters which document the freezes. The total number of hours below a threshold temperature is such a parameter. Records of the number of nights and hours below a minimum threshold value in agricultural areas (Johnson, 1970) were used to test the climatic parameter which can best delineate the southern edge of the "buffered freezing zone" so that such a parameter can be updated and systematically recorded to monitor the climate.

However, records of hours below a threshold value were collected on a voluntary basis and therefore continuity of data in area and in time are not guaranteed, also, spatially they are not statistically well represented. Therefore another set of data having the necessary attributes is needed. Satellite data from 1985-86 were examined to determine if they corroborate results from the historical climate data. The satellite data were used because they provide temperatures evenly across the land surface and eliminate statistical bias due to location. They increase the number of data points by 10 to 20 times, provide a temperature for every type of surface, and therefore yield information which are more objective than other types of climate data. Satellite infrared data collected during clear nights of the 1985-86 winter were examined to evaluate how the greater aerial density of the satellite data as compared to surface-collected station data can best be used to extract the necessary climatic information.

Results and Discussion

The region of maximum exchange of air masses. In the temperate region of north Florida, the percent occurrence of the lowest daily temperatures in each winter month is highest (Fig. 1), from greater than 30% (–5.6°C threshold) to more than 90% (0°C threshold). The subtropical effect, indicated by the percent occurrence of the highest daily temperature for the winter (dashed lines), around latitude 30°, are less than 20% (29.4° and 30.6°C thresholds). Therefore, northern Florida is a region of temperate climate where the effect from the subtropical air mass is weak. On the other hand, in the subtropical region of South Florida, south of 27° latitude, the percent occurrence of freezing temperature is small, around 30% or less (0° through –5.6°C thresholds), whereas the effects from the subtropical air mass is large, from 70% (29.4°C threshold) to near 100% (26.7°C threshold). The 30.6°C threshold occurs nearly 30% of the winter months, or about once each winter. Therefore the benign climate of South Florida is only infrequently interrupted by freezes, but plants growing in this area are highly susceptible to damage should freezes occur, because in this truly subtropical climate the opportunity for acclimation is small. This is evident in the 0°C threshold, where the percent occurrence is less than 40% at 27° latitude, decreasing to less than 20% at 25.5° latitude (Homestead). However in Central Florida (27-29° latitude) the percent occurrence lies between 40 to 70%. Hence acclimation of citrus in south Florida is not the same as in central Florida. Also, because the annual range of temperature in a subtropical climate is relatively small when compared to the annual range of temperature in a more temperate region, the daily or short period fluctuations of a few days to weeks could more easily introduce spring-like conditions. After such warm periods, even mild freezes can be dangerous.

In central Florida between 27° and 29° latitude the percentages for both sets of threshold values (Fig. 1) are less than 50% except for the lower boundary for the subtropical air mass (26.7°C) and the upper limit of the cold air mass (0°C). This is interpreted to mean that in Central Florida the protective shield provided by the subtropical air mass and the intruding cold air mass (winter freezes) are approximately balanced and this balance can be easily upset by an intruding cold air mass. Therefore, one would expect this region to experience maximum exchanges between the cold air mass and the warm and humid subtropical air mass. It is in this region that the "buffered freezing zone" should be found if it is present. However, this region spans more than 200 km from Lake Okeechobee to northern Lake County and must be narrowed to locate the zone more exactly.

The "Buffered Freezing Zone." Graphical data compiled by Johnson (3) show that in little more than 1.5° latitude from 30°N latitude south to the Lake/Polk county area there were about 2500 hours in 30 seasons (1937-1967) which recorded temperatures below 0°C. However there were only about 1900 hours below 0°C from the Lake/Polk county line to Homestead (about 2.5° latitudes). Equivalently, there were about 400 hours below the –4.4°C (24°F) threshold north of the Lake/Polk county area but only about 100 hours south of the Lake/Polk county area. Therefore, there were not only more hours below the two threshold values (0°C and –4.4°C) in the northern zone but because the hours were spread over only 1.5° latitude, the change with latitude, or the gradient is greater in the northern area. On the other hand, south of the Lake/Polk county area, there are not only less hours below the thresholds, but the gradient is also smaller. In practical term, if one is at point A and moves 50 km south to point B for a warmer location (Fig. 2), all things being equal, the relief from the cold will be approximately 600 hours less of temperatures below 0°C spread over 30 seasons. On the other hand, if one moves the same distance from point C to point D, the relief from the cold is only about 350 hours less of temperatures below 0°C. Hence, a move in the northern zone provides more relief from low temperatures than an equivalent move in the southern zone, all things being equal. Such small changes probably would not be critical in mild freezes, but in extremely severe situations, such as the cumulative effects of the 4 freezes between 1980 and 1985, the few extra hours above a certain threshold mean reduced levels of damage in many cases.

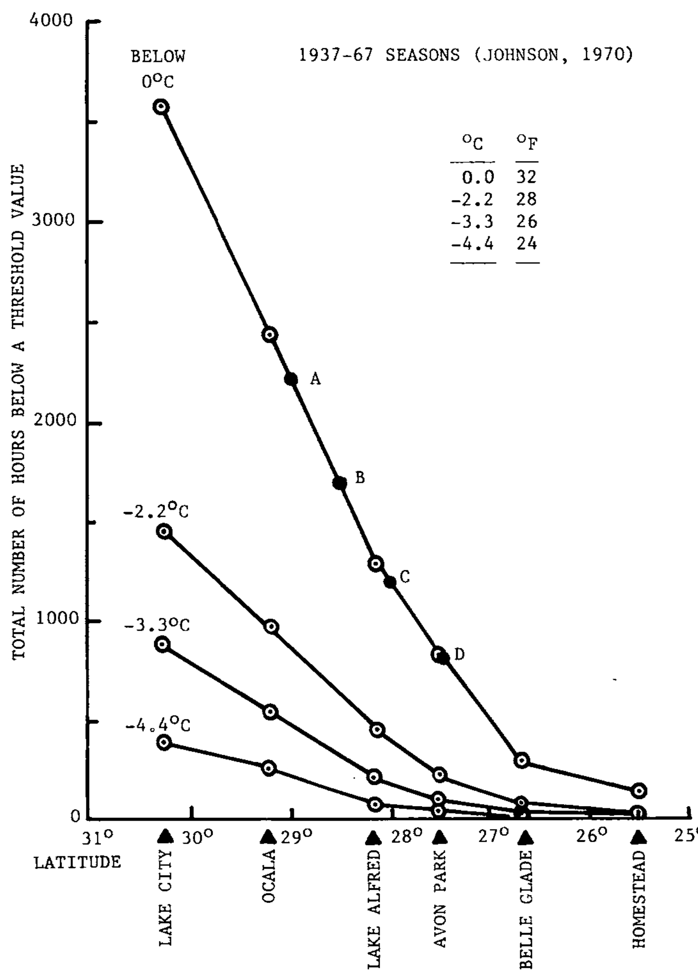

Fig. 2. The change in the total number of hours below threshold values of O°, –2.2°, –3.3°, and –4.4° C for 30 seasons (1937-67) from north Florida (Lake City) to south Florida (Homestead).

The *total number* of hours was not reduced to the number of hours per season because the variation from season to season is too great (Table 1).

Figure 2 shows that generally there is at least a doubling of the number of hours below thresholds –2.2°C, –3.3°C (26°F) and –4.4°C (24°F) for latitude 28° to 29° when compared to latitude 27° to 28°. The data suggest, but the evidence is far from conclusive, that the lower the threshold, to –4.4°C, the more natural protection for regions south of 28° latitude. The 30-year data therefore indicated to us that the "buffered freezing zone" is most likely between 28° to 29° latitude.

Application to cold protection. Because the data from Fig. 2 cannot be used to determine the difference in temperature north and south of the "buffered freezing zone", due mainly to the large year to year variation, the minimum temperatures and threshold values below –3.3° and –6.7°C (20°F) for two nights in two of the worst freezes in the period (12-13 Dec. 1957, and 13-14 Dec. 1962) were compared for Marion, Lake, and Polk counties (Table 2). With the exception of 13 Dec. 1957 freeze, the average minimum temperatures between the 3 counties are less than 2°C. The average difference of the minimum temperature between Lake and Polk counties is 0.6 0.5°C and is not significant. The average difference in the number of hours below the two threshold values of adjacent Lake and Polk counties is 1.5 hour. Such small differences, depending on the region, suggest that frost protection could be applied to alleviate temperature differences between adjacent regions if only to reduce the degree of freeze injury in extreme situations such as the recent freezes (1980-85). For example, in a worst case, if cold protection is applied successfully to hold temperature above –6.7°C, it could mean replacing major wood damage by branch or twig damages. Considering the cumulative loss of about 200,000 acres of citrus between 1980 and 1985 (2), and if the worst temperature thresholds in some areas could be eliminated through cold protection, the savings could be substantial. The situation may have been oversimplified by not taking into account preconditioning of trees or acclimation as factors in our estimates. However there has not been enough research on citrus acclimation to permit us to estimate the acclimation factor. As Fig. 1 illustrates quite clearly, acclimation depends not only on variation in latitude but also on the weather immediately before a freeze. Hence, both the acclimation factor and the freeze factor vary with latitude. Unless one factor can be held constant or is known, its effect on the other will be difficult to evaluate. If one factor is known, it can then be modeled and its effects predicted.

The data in Table 2 depict only four nights of temperature differences, but they have revealed the size of the margin which separates the two zones. This difference between adjacent regions is quite small but because it is persistent and shows up distinctly in the 30-year summary (Fig. 2), it probably is real. The data also reveal the possible location of the "buffered freeze zone" and the magnitude of the temperature difference north and south of the zone. The satellite data from the 1985-86 winter showed that on four of the nights the isotherms outlining the worst conditions were delineated around northern to central Lake County (Chen, unpublished data). On another night, because of increasing dew point temperatures (National Weather Service data), the lowest isotherms did not advance beyond northern Lake County. This cursory examination of the satellite data appears to corroborate our findings using historical climate data and give credence to some of our inferrences. It appears that the satellite data will be useful in conducting further research on the climate zone and will be useful for extracting temperature differences north and south of the "buffered freeze zone".

Table 1. The greatest and least number of hours below 0°C which occurred in one season and the year(s) in which they occurred for a 30-year period (1937-67), from Johnson, 1970.

City	Greatest (Year)	Least (Year)
Lake City	234 (1939, 57)	12 (1948)
Ocala	220 (1957)	12 (1948)
Lake Alfred	154 (1957)	5 (1951, 53)
Avon Park	81 (1939	2 (1953)
Belle Glade	42 (1957)	0 (1951)
Homestead	16 (1955, 59)	0 (1938, 45, 47, 52, 58, 66)

Conclusion

Fifty years of climate data of seven stations from Tallahassee to Homestead indicate that there may be a zone from 27° to 29° latitude where the temperate climate of north Florida weakened sufficiently for the subtropical climate of south Florida to exert its influence in the region, and the two climatic types appear to be well-balanced. We inferred then that this is a region where an intruding cold air mass (freeze) is as likely as not to overcome the protection by the warm and humid subtropical air mass of south Florida. North of 29° latitude an intruding cold air mass

Table 2. Minimum temperatures and hours below –3.3°C (26°F) and –6.7°F (20°F) from Marion, Lake, and Polk counties for two freezes: 11-13 Dec 1957 and 12-14 Dec 1962. Subscripts indicate the number of stations averaged (4).

		Min temp (°C)			Hours below –3.3°C			Hours below –6.7°C		
Morning of		Marion	Lake	Polk	Marion	Lake	Polk	Marion	Lake	Polk
13 Dec 1962 (Windy)	Mean	$(-8.8)_{9}$	$(-7.8)_{13}$	$(-6.9)_{33}$	$(12.6)_{9}$	$(10.8)_{13}$	$(7.8)_{36}$	$(6.6)_{9}$	$(3.9)_{12}$	$(1.8)_{27}$
	SD	±0.8	±0·9	±1.3	±1.0	±1.0	±1.1	±1.1	±1.8	±1.0
13 Dec 1957	Mean	$(-7.6)_{17}$	$(-6.0)_{13}$	$(-4.9)_{42}$	$(11.9)_{17}$	$(8.6)_{13}$	$(7.0)_{38}$	$(7.5)_{14}$	$(3.2)_{4}$	$(2.3)_{7}$
	SD	±1.8	±1.1	±1.6	±1.6	±3.2	±3.8	±3.3	±2.1	±1.1
14 Dec 1962 (Calm)	Mean	$(-5.8)_{9}$	$(-5.6)_{13}$	$(-5.5)_{36}$	$(10.4)_{9}$	$(9.2)_{10}$	$(7.8)_{34}$	—	—	—
	SD	±1.2	±1.2	±1.2	±3.0	±2.1	±1.8	—	—	—
12 Dec 1957	Mean	$(-5.5)_{19}$	$(-4.6)_{13}$	$(-4.3)_{42}$	$(7.0)_{18}$	$(4.9)_{13}$	$(4.0)_{40}$	$(0.8)_{4}$	$(1.1)_{4}$	$(1.3)_{8}$
	SD	±0.9	±0.7	±0.8	±1.1	±1.8	±1.6	±0.7	±0.7	±0.8

would dominate, and protection from the warm air is minor. South of 27° latitude the warm air dominates and the cold air appears to be strongly weakened. The use of the parameter "the number of hours below a threshold value" indicates that the southern edge of this zone may be near the Lake/Polk county area (28° latitude) than 27° latitude. Existing data from 4 nights indicate that the average minimum temperature differences in agricultural areas between Lake and Polk counties are about 1°C. At the two threshold values (Table 2) Lake County has had 2 to 3 more hours than Polk County at the specified threshold value. This indicates the level of freeze protection which should be applied to emulate conditions in Polk County. However, we have not accounted for acclimation nor have we taken into consideration the large difference which can be generated by microclimates of terrain and slope differences. At this time there is no easy method to assess acclimation, either its variation with latitude or its variation with the weather immediately preceding a frontal passage. Finally, we conclude that the most important climate indicator for agriculture in Florida is the parameter "the number of hours below a threshold value". Unfortunately, efforts to collect temperatures for this parameter in agricultural areas have declined during the past decade because of financial and time constraints. One important alternative is to obtain the parameter from the satellite infrared data where comparative values for the entire peninsula are easily available. Also, the variation of acclimation with latitude, and with weather must be understood in order to apply freeze protection efficiently. We feel that only through the integrated use of both surface-collected climate data and the satellite thermal data can we begin to understand this complex problem.

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FREEZE PROTECTION POTENTIAL OF WINDBREAKS

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Abstract. **Recent advective freezes in Florida have raised questions within the horticultural industry regarding windbreaks for cold protection. Windbreaks obviously retard the wind and are expected to render cold protection methods more effective within their wake. However, frost hazard during radiative frosts may increase but this disadvantage may be tolerable or minimized. A review of windbreak literature regarding the effects of windbreaks on turbulent transport downstream of the windbreak leads to the special consideration of orchard covers. Interrogation of models for predictions of the amount of energy that is necessary to provide protection provides estimates of the potential effect of windbreaks at low windspeeds. The heating models break down as windspeeds approach 15 mph (25 Km/hr), but the sprinkling model provides reasonable estimates. A team approach to the evaluation of the windbreaks is reported, and may provide an answer to the advective freeze protection question.**

This paper describes, in part, a response to a question asked by growers concerning protection from advective freeze damage, such as the 1983 Christmas Freeze or the January 1985 Freeze, which were characterized by windspeeds as high as 30 mph (50 Km/hr). It is generally accepted that methods exist that protect young trees from such freezes (12, 17, 18, 19, 20, 26, 27, 28, 33, 34, 35). What can be done to protect larger trees?

It has been known, and appreciated, that wind disrupts conventional cold protection methods (e.g. 7, 16). Hume (16) advocates the use of artificial or natural windbreaks in his summary of frost considerations. But he mentions problems with "covered sheds," and may have been aware of experiences that the ancestors of the senior author of this paper had with a canvas grove cover that blew all through the little town of Candler in Marion County during one of the advective freezes at the turn of the century.

Growers have known for some time (7, 16) of instances in which the proximity of hammocks to groves has reduced the amount of damage from advective freezes, and especially when heaters were fired (10). It is well known that as a grove reaches full canopy, the effectiveness of heating systems is greatly increased (22)

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