rapidly, especially when in the proximity of strong jet streams. Active portions of Cb elements and their associated rainfall often move at a different direction and speed as compared to the cirrus debris. As mentioned previously, rainfall in extratropical cyclones tends to be concentrated along convective cloud bands; these bands are often observed in the high resolution visible imagery and occasionally in the IR pictures. For synoptic scale systems without deep convection, a variation of the scheme and of the enhancement curve must be developed for estimating precipitation.

7. SUMMARY

This paper does not present a tested/finalized scheme for estimating rainfall from synoptic scale disturbances. Also, this paper represents only one case and various assumptions were involved in making these estimates.

However, this paper does suggest the possibility that by taking necessary precautions, such as filtering out cirrus debris associated with jet streams or thunderstorms and by locating cloud bands, that a synoptic scale rainfall estimation scheme with embedded deep convection could be developed to supplement radar observations and rain gauge measurements.

REFERENCES

Heckman, Brian E., 1976: A Limitation to the Enhanced IR Data. *Satellite Applications Information Note 76/12*, NESS, Washington, D.C., 3 pp.

Houze, Robert A., Jr. and Hobbs, Peter V., Biswas, Kumud R. and Davis, William M., 1976: Mesoscale Rainbands in Extratropical Cyclones. *Monthly Weather Review*, V 104, pp. 868-878.

Scofield, Roderick A. and Oliver, Vincent J., 1977a: A Scheme for Estimating Convective Rainfall from Satellite Imagery. *NOAA/NESS Technical Memorandum 86*, National Environmental Satellite Service, Washington, D.C., April, 47 pp.

Scofield, Roderick A. and Oliver, Vincent J., 1977b: Using Satellite Imagery to Estimate Rainfall From Two Types of Convective Systems. *Preprints 11th Technical Conference on Hurricanes and Tropical Meteorology (Miami)*, American Meteorological Society, Boston, MA, in press.

ON THE INTER-SEASONAL RELATIONSHIPS AMONG MINIMUM TEMPERATURES AND DAMAGING FREEZES IN THE CENTRAL FLORIDA CITRUS BELT

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I. INTRODUCTION

A statistical summary of the Tampa, Florida and Orlando, Florida seasonal absolute minimum temperatures are presented for the winter seasons from 1884-1885 through 1976-1977. The occurrences of significant freezes in the Florida citrus belt are also included for this period. There were 34 seasons in which one or more freezes produced moderate or greater damage to citrus crops. The distribution of the seasonal minimum temperatures and of the freeze seasons throughout the time period, and to some extent of the periods within these seasons when freezes occurred, appear not to be randomly related. Of the 33 freeze seasons that occurred prior to last season (1976-1977) 22 contained significant freezes in the month of January. Of these 22 seasons, 18 of them (82 percent) were coupled with freezes that occurred in either the previous or the following seasons. Of the 4 seasons not so coupled, 2 of them contained freezes which occurred in other portions of the same season. Consequently then, in 20 of 22 seasons (91 percent) in which a freeze caused moderate or greater damage to Florida citrus, significant freezes occurred in either the prior or subsequent seasons or at some other time within the same season. The severe freeze of January 1977 was neither preceded by a significant freeze in 1976, nor accompanied by a significant freeze within the same (1977) season. The implications of this statistical set is that the chances for a significant freeze to occur in the Florida citrus belt during this coming season (1977-78) are considerably greater than a ran-

domly derived probability of .37 (34 in 92 seasons) and may be greater than .75.

2. CLIMATOLOGY

Following is a table of absolute monthly minimum temperatures for Tampa and Orlando, Florida for the winter seasons from 1897-98 to 1976-77. The absolute minimum temperature recorded for each season is listed in the first two columns followed by the monthly minimum temperatures for each month of the season from November through March. Freeze periods which are marked with an asterisk refer to freezes which caused significant damage to citrus corps. Such occurrences are further delineated in the last column with a notation of the severity ... MDT = moderate, SVR = severe, MDT+ = moderate to severe.

Relationships between the absolute minimum temperatures reported at Orlando and Tampa and the severity of the coincident freezes are difficult to generalize. During the 80-year period for which monthly records were available, the locations of both the Orlando and Tampa minimum thermometers were altered several times, sometimes significantly. Early in the period, Tampa temperatures were recorded in a downtown building location with readings which were made from heights that varied between 45 and 88 feet above ground level. Later in the period the thermometer was moved to a suburban location at the airport and lowered to near the standard height of between 5 and 6 feet above ground. At Orlando temperatures were measured in town at a height of 4 to 5 feet above ground early in the period. The instruments were moved to what is now Herndon Airport in 1943, still at a height of 4 feet above the ground. But in 1960 the equipment was moved to the administration building where readings were taken from a height of 16 to 18 feet above ground level. Since 1974 the official Orlando temperature records have been taken at McCoy Airport and from a height of 5 feet above the ground.

Other factors affecting a simple minimum temperature-freeze relationship during this 80-year period involve such elements as the changing character of the local environment, the slow southward shift of the citrus belt, and perhaps most important, the unique meteorological characteristics of each and every freeze. No two freeze patterns are identical; the loci of the isotherms, the magnitude of the temperatures, the strength of the winds and the duration of subfreezing temperatures are never exactly the same.

3. CROP DAMAGE ASSESSMENT

The vulnerability of the trees themselves vary from season-to-season and month-to-month as seasonal precipitation and temperatures affect the dormancy and resistance of the wood and foliage to cold weather. Temperatures of just under freezing which may be harmless in January can be very serious in late February or March when the trees are in bloom.

The determination of "significant" or "moderate or greater damage" is necessarily largely subjective, for some of the early dates we have have used the information contained in such sources as the monthly weather records of the climate and crop service of the U.S. Weather Bureau. Information from the IFAS Publication No. 9, *Minimum Temperatures in the Agricultural Areas of Peninsular Florida,* was used for middle years of the period. The Florida crop and livestock reporting service annual citrus summaries were referred to for the most recent occurrences. The classification criteria for freezes of moderate or greater proportions were assigned to those events that were believed to have reduced the previously anticipated crop by 5 percent or more.

The data is illustrated in Figures 1, 2, and 3.

4. LONG-TERM TEMPERATURE FLUCTUATIONS

Figure 1 represents a chart of the dates of the significant freezes which occurred between 1884 and 1977. The dots or short lines mark the periods within each season in which the most damaging temperatures were experienced. The chart clearly shows a bunching or grouping among some of the freeze dates which reveals three cold periods of a few to several years' duration. In the 80 years of record, 26 of the 34 freeze seasons (76 percent) occurred in these three clusters with 9 freezes in a period of 16 years (1894-1910), 5 in 9 years (1934-1943) and 12 in 14 years (1957-1971). Of the remaining 8 freeze seasons, 6 occurred in pairs (1916-17 and 1917-18, 1926-27 and 1927-28, 1946-47, and 1947-48). The other two seasons may not be totally isolated either. The major freeze in the 1885-86 season was not too far removed from one known to have occurred in 1884 (but not included in the detailed listing). The final ungrouped season was the most recent one, 1976-77. There were no significant freezes in the previous (1975-76) season and no other ones during the 1976-77 season. However, this season may still find a mate in the 1977-78 season. We will know within another few months.

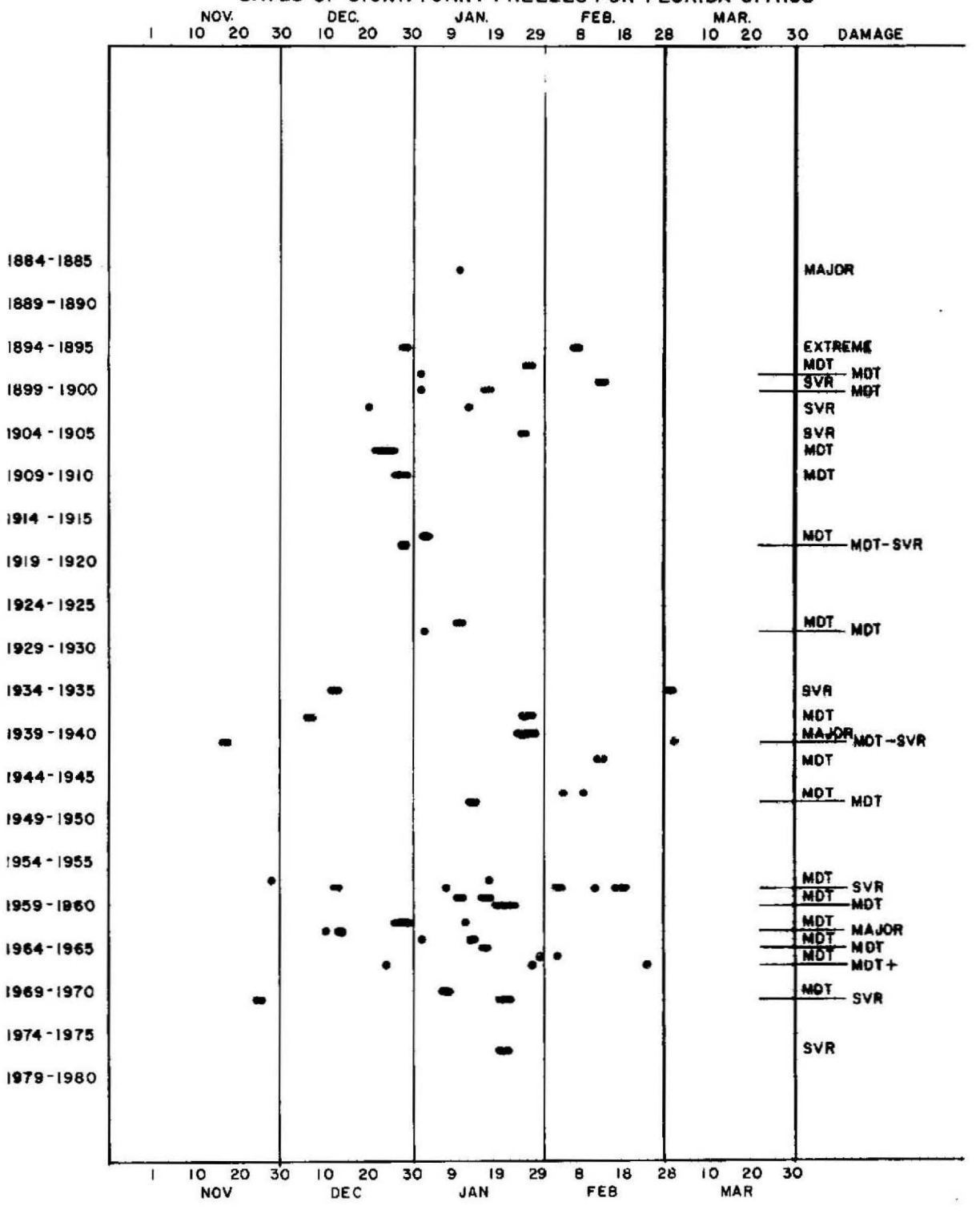
Figures 2 and 3 are graphs of the 5-year running means of the lowest temperatures for Tampa and Orlando respectively, plotted for each year of the 80-year period from 1897-1977. Notwithstanding the variations over the years due to relocation of the observing sites, a pattern of warm and cold regimes is clearly evident. Such patterns describe a characteristic of inter-seasonal persistence which often appears in long-term temperature records and which cannot be regarded as a random

SEASON	SEASONAL MIN TMP TPA	ORL	NOV TPA	ORL	MONTHLY MINIMUM TEMPERATURES DEC TPA	ORL	JAN TPA	ORL	FEB TPA	ORL	MAR TPA	ORL	FREEZE AND SEVERITY
1897-1898	27	23	50	48	40	36	27*	23*	31	30	46	40	MDT
1898-1899	22	20	43	45	36	35	42	42	22*	20*	34	33	SEVERE
1899-1900	27	26	50	47	34	33	27*	27*	28	26	45	45	MDT
1900-1901	31	32	42	40	47	40	37	35	31	32	34	33	
1901-1902	24	25	38	36	24*	25*	30*	26*	34	35	41	40	SEVERE
1902-1903	29	28	42	42	29	28	33	34	32	31	50	52	
1903-1904	32	28	32	28	33	31	37	32	37	33	50	46	
1904-1905	23	21	45	39	35	31	23*	21*	34	33	46	38	SEVERE
1905-1906	40	34	53	44	40	38	41	35	40	37	40	34	
1906-1907	28	25	39	34	28*	25*	45	44	37	35	53	49	MDT+
1907-1908	33	31	44	43	36	33	35	31	33	32	51	37	
1908-1909	27	28	43	36	41	33	30	28	27	28	42	37	
1909-1910	26	21	46	40	26*	21*	37	27	35	32	41	36	MDT+
1910-1911	31	29	46	37	34	29	31	32	37	29	47	38	
1911-1912	34	28	39	36	36	34	34	30	34	28	48	45	
1912-1913	41	35	43	40	41	35	45	37	44	39	49	48	
1913-1914	38	34	40	35	38	37	41	34	41	37	40	35	
1914-1915	32	30	32	30	37	33	41	36	41	38	40	34	
1915-1916	36	32	42	36	37	34	41	38	36	35	37	32	
1916-1917	26	22	39	38	38	31	37	35	26*	22*	40	37	MDT
1917-1918	27	26	36	29	27*	26*	41	26	42	37	56	51	MDT+
1918-1919	33	28	48	41	38	31	33	28	38	33	49	40	
1919-1920	35	28	55	44	39	36	35	30	38	31	36	28	
1920-1921	39	34	42	39	39	35	43	34	43	38	46	41	
1921-1922	35	30	49	42	48	39	37	30	35	33	44	39	
1922-1923	35	32	43	37	44	36	43	35	35	32	48	43	
1923-1924	34	31	45	34	42	35	34	33	38	31	41	36	
1924-1925	38	32	39	32	43	38	45	42	38	38	45	40	
1925-1926	33	31	40	33	33	32	37	31	38	29	36	32	
1926-1927	28	25	41	38	39	29	28*	25*	47	45	37	34	MDT
1927-1928	26	24	47	46	35	31	26*	24*	33	31	47	41	MDT
1928-1929	38	30	40	34	38	30	39	36	43	39	51	45	
1929-1930	33	30	39	43	33	30	42	38	41	34	39	34	
1930-1931	32	28	39	31	37	28	32	30	39	36	37	33	
1931-1932	35	27	48	46	53	47	41	35	52	39	35	27	
1932-1933	38	32	38	33	43	32	40	35	39	38	44	34	
1933-1934	34	32	46	40	43	39	34	32	43	37	40	33	
1934-1935	27	22	42	35	27*	22*	36	31	30*	29*	40	36	SEVERE
1935-1936	30	24	40	36	30	24	35	30	32	28	48	38	
1936-1937	33	31	33	32	43	32	56	50	41	31	40	38	
1937-1938	28	25	32	30	28*	25*	36	28*	43	32	52	43	MDT
1938-1939	34	29	34	31	40	29	40	29	35	30	51	44	
1939-1940	26	20	43	38	41	30	26*	20*	37	30	44	36	MAJOR
1940-1941	31	26	31	26*	42	35	38	31	38	28	39	27*	MDT+
1941-1942	31	28	47	38	45	38	31	28	37	34	40	31	
1942-1943	31	26	44	39	36	35	40	35	31*	26*	31	29	MDT
1943-1944	32	30	42	36	32	30	41	32	39	33	44	40	
1944-1945	33	30	43	41	33	30	41	40	36	34	53	46	
1945-1946	37	32	39	32	37	35	41	36	42	40	49	43	
1946-1947	32	29	51	52	42	44	37	36	32*	29*	34	32	MDT
1947-1948	27	26	44	42	44	41	27*	26*	38	38	44	45	MDT
1948-1949	38	32	48	47	44	36	38	32	48	48	44	41	
1949-1950	39	38	43	38	42	38	53	52	39	40	41	41	
1950-1951	31	29	31	29	35	33	33	30	31	31	45	42	
1951-1952	36	34	37	35	39	36	36	34	38	40	46	43	
1952-1953	35	32	43	39	35	32	39	37	41	38	46	46	
1953-1954	36	35	45	40	36	35	39	37	42	40	37	35	
1954-1955	31	30	39	36	35	30	33	33	31	31	41	39	
1955-1956	32	31	37	36	35	35	32	31	41	40	40	40	
1956-1957	35	32	35	32	39	35	35	34	44	44	40	38	
1957-1958	24	24	45	44	26*	24*	31	27	24*	28*	43	38	SEVERE
1958-1959	30	28	51	51	38	38	30*	28*	47	45	45	40	MDT
1959-1960	29	30	29*	32*	40	33	30*	30*	36	35	37	35	MDT
1960-1961	31	29	46	49	32	31	31	29	43	41	42	40	
1961-1962	29	31	45	49	33*	29*	29*	31*	42	41	39	33	MDT
1962-1963	18	20	37	41	18*	20*	35	34	37	35	43	43	MAJOR
1963-1964	27	27	35	39	31	33	27*	27*	33	39	39	42	MDT
1964-1965	29	30	41	46	32	38	29*	30*	33	35	40	39	MDT
1965-1966	24	24	37	45	32	40	24*	24*	27	35	38	40	MDT
1966-1967	27	28	36	40	31	33	30	37	27*	28*	46	47	MDT+
1967-1968	30	32	42	47	30	36	31	32	34	33	31	35	
1968-1969	27	29	35	36	27*	29*	36	38	32	34	38	39	MDT
1969-1970	24	25	34	33	33	37	24*	25*	32	28	41	41	MDT
1970-1971	23	28	23*	30*	33	35	23*	28*	32	32	35	39	SEVERE
1971-1972	34	37	45	46	50	52	36	38	34	37	45	47	
1972-1973	30	35	44	47	34	37	30	35	32	35	46	49	
1973-1974	30	31	37	46	30	31	57	56	30	32	45	44	
1974-1975	33	33	42	42	35	34	33	33	39	42	38	39	
1975-1976	28	30	37	37	30	32	28	30	36	33	43	43	
1976-1977	26	20	35	37	32	33	26*	20*	32	30	41	37	SEVERE

variation of year-to-year fluctuations about a constant mean minium temperature. The problem in applying these curves to a multi-year long range forecast is that there is no obvious regular periodicity in the troughs and crests of the various regimes. One can recognize the presence of cold spells and warm spells and presume that freezes may occur more frequently during the colder periods; but the duration and magnitude of these periods cannot be accurately or consistently predicted.

The two temperature charts (Figures 2 and 3) show three major cold spells which encompass essentially the same time periods as noted in the freeze groupings above. There are other, briefer cold periods as well, such as 1916-1919 and 1926-1930 which included some of the "coupled" freeze seasons (1916-17 and 1917-18, 1926-27 and 1927-28). Some of the sytematic differences between the two temperature records can be explained by the variations in observation sites which occurred during the period. Note that until 1957 the

FIGURE - 1



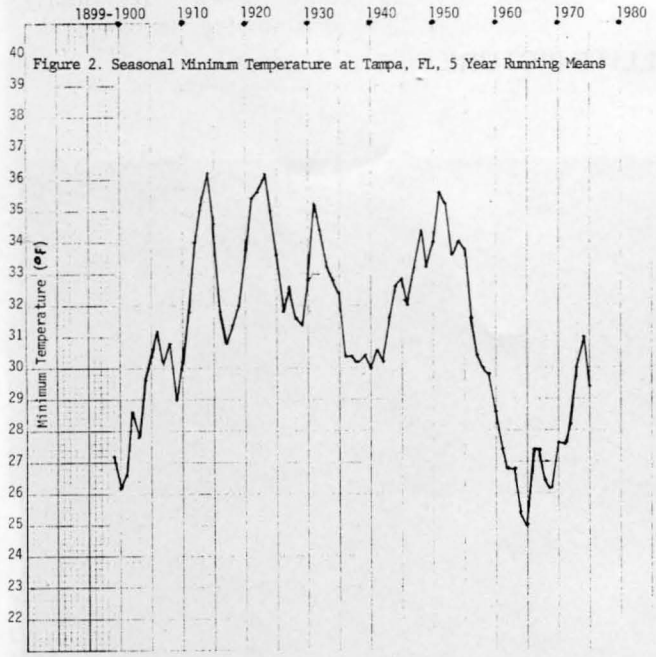


Figure 2. Seasonal Minimum Temperature at Tampa, FL, 5 Year Running Means

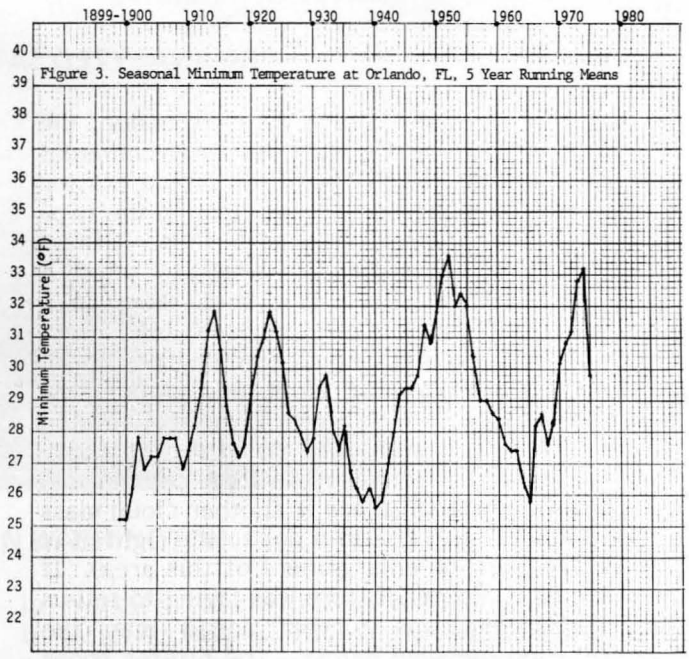


Figure 3. Seasonal Minimum Temperature at Orlando, FL, 5 Year Running Means

Orlando minimum temperatures were almost always colder than those at Tampa. This difference narrowed considerably when the Tampa thermometers were moved to the International Airport in 1946. The relationship was reversed after 1960 about the time the Orlando thermometer was elevated to 16-18 feet above ground level. Orlando continued to read higher than Tampa until 1974 when the Orlando thermometer was moved again, this time from Herndon Airport to McCoy Airport and lowered to 5 feet.

5. CONCLUSIONS

The conclusions one draws from reviewing the seasonal temperature records and the recent history of Florida freezes damaging to citrus are:

1. Very cold weather more often than not comes in couples or groupings of several seasons rather than in single seasons randomly distributed throughout the period of record.

2. There appear to be "cold regimes" and "warm regimes" in which the seasonal absolute minimum temperatures averaged over a five-year period vary substantially. These spells may last anywhere from 3 or 4 years to as many as 15 or more years. There is no obvious periodicity that is consistent for the entire period of record. The three cold groupings covering 39 seasons described above contained 26 freeze seasons. This means that 42 percent of the years (39 of 92) contained 76 percent of the freeze seasons (26 of 34).

3. The incidence of a January freeze that is not associated with a freeze in either the preceding or the following season, or with a freeze at some other time within the same season is a relatively unusual event. Of 22 January freezes between 1885 and 1976 only the freezes of 1886 and 1905 failed to be so coupled. This is a frequency of only 9 percent. If this statistical relationship is maintained, the chances of a freeze occurring in the forthcoming 1977-78 season are probably better than 70 percent and depending upon how one orders the statistics, may be as high as 91 percent.