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LAKE ERIE REGIONAL ICE COVER ANALYSIS: PRELIMINARY RESULTS

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CONTENTS

FIGURES

TABLES

LAKE ERIE REGIONAL ICE COYER ANALYSIS: PRELIMINARY RESULTS[1]

Raymond A. Assel

A 20-year (1960-79) digital ice concentration data set for Lake Erie was divided into nine half-month periods, starting the last half of December and ending the last half of April. Observation density, average regional ice cover, and percentage ice cover exceedance were calculated for three regions of the lake: region l--the entire lake; region 2--the lake east of Long Point, Ont.; and region 3--the lake east of Port Colborne, Ont. Results of the analysis are presented in tables and graphs of percentage of region observed, average ice cover, and percentage exceedance from average ice cover. Seasonal and regional trends in ice cover extent are discussed.

1. INTRODUCTION

The objective of this study is to provide improved information on Lake Erie ice cover through the use of average regional ice cover and ice cover exceedance calculations. This study was undertaken in response to a need for more detailed data on Lake Erie ice cover probabilities for use in ongoing investigations of the effects of the Niagara River ice boom on the local climate in the vicinity of Buffalo, N.Y.

A 20-year (1960-79) digital ice concentration data set with a 5- x S-km grid cell structure, described by Assel (1983), was used for the ice cover analysis. The percentage exceedance calculations are similar to those described for wave data (Aubert and Richards, 1981). The study area is composed of three overlapping regions of Lake Erie: (1) the entire lake; (2) the lake east of Long Point, Ont.; and (3) the lake east of Port Colborne, Ont., as shown in figure 1. Regions 2 and 3 represent approximately 22 percent and 2 percent, respectively, of the lake's total surface area.

The analysis consists of calculating for each lake region: (1) observation density, (2) the average regional ice cover, and (3) the percentage exceedance from the average regional ice cover for discrete percentage ice cover values. The results are summarized in tables and graphs, and discussed in terms of seasonal and extreme values of ice cover extent for nine half-month periods. This procedure was used because it facilitates presentation of many historic ice cover data in a relatively compact, easy to understand format.

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[1] GLERL Contribution No. 381.

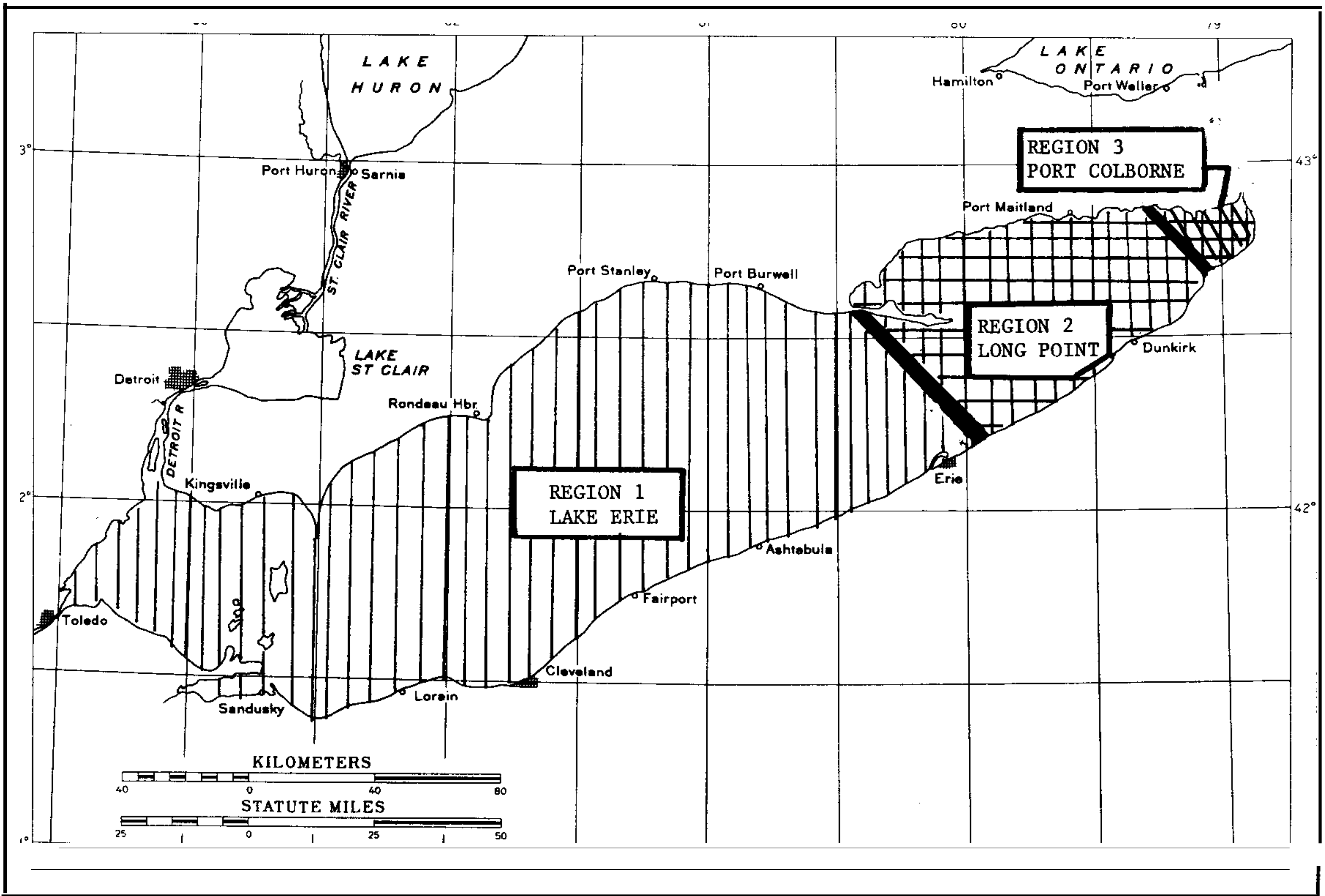

FIGURE 1.--*Lake regions.*

2. ANALYSIS PROCEDURES AND RESULTS

2.1 Observation Density

The density of data in each lake region was calculated to evaluate the feasibility of making an ice cover exceedance analysis. The 20-year Lake Erie data set was partitioned into the following nine half-month periods: December 16-31 (D2), January l-15 (J1), January 16-31 (J2), February l-14 (F1), February 15-28 (F2), March l-15 (Ml), March 16-31 (M2), April l-15 (Al), and April 16-30 (A2). The data for each half-month were then subdivided into the three lake regions and the percentage of each lake region observed (i.e., the number of cells with data divided by the total number of cells in the region) was calculated for each of the 20 years of the data base. Results are summarized in table 1. Summary statistics at the bottom of table la-c show that half-month periods D2, J1, and A2 contain less than 15 years of data, while the remaining six half-month periods contain 16 years or more of data. Figure 2 shows that the observation density, i.e., the percentage of a region with data, increases as the size of the region decreases; region 1 has the lowest percentage of its total area observed and region 3, which is only 2 percent of region 1, has the highest percentage of its area observed. The analysis to follow will therefore be less reliable for half-months D2, J1, and A2 than for the other half-months and for region 1 than for regions 2 and 3.

2.2 Average Regional Ice Cover

Equation (1) was used to an average regional ice cover for each half-month for each year with data.

$$\overline{X}iH = \frac{1}{NiH} \sum_{ic=1}^{NiH} XicH \qquad (1)$$

where NCH = number of grid cells with data for year i, half month period H and

$XicH$ = ice concentration for cell c, year i, and half-month period H.

The distribution of average regional ice cover over the nine half-month periods and 20 years of the data base is given by region in table 2a-c. The average over the 20-year base period for each half-month average regional ice cover, as well as the maximum and minimum average regional ice cover, is given at the bottom of table 2 and in figure 3 and figure 4 for each lake region.

2.3 Percentage Exceedance From Average Regional Ice Cover for Discrete Ice Cover Values

The percentage exceedance of the average regional ice cover from a given value C for each half-month period H, based on y years of data is $P(C)H$.

TABLE la.--*Percentage of region observed, Lake Erie*

Year	Half-month period								
	D2	J1	J2	F1	F2	Ml	M2	Al	A2
1960	--	--	--	--	--	94	--	84	--
1961	--	--	77	67	--	99	99	99	--
1962	67	--	48	47	--	--	31	--	34
1963	15	--	70	73	46	85	66	97	37
1964	86	100	96	99	79	100	99	86	25
1965	--	33	96	98	99	98	78	100	81
1966	47	--	62	91	82	100	100	12	--
1967	--	78	86	99	72	95	98	99	--
1968	--	25	95	99	63	99	77	93	13
1969	--	43	29	79	48	80	100	19	--
1970	2	61	63	13	95	86	--	87	63
1971	72	68	27	17	66	20	99	94	--
1972	22	100	86	--	63	87	99	81	99
1973	63	75	100	97	99	100	71	--	--
1974	97	100	100	81	99	100	85	--	--
1975	60	65	100	96	99	99	99	73	--
1976	88	98	100	100	100	100	76	99	--
1977	--	99	77	78	85	90	97	75	18
1978	--	25	93	89	61	23	79	98	71
1979	--	--	67	58	66	65	86	53	--
Years	11	14	19	18	17	19	18	17	9
AVERAGE	56	69	77	76	77	85	85	79	49

TABLE 1b.--Percentage of region *observed, Long Point*

Year	Half-month period								
	D2	J1	J2	F1	F2	M1	M2	A1	A2
1960	--	--	--	--	--	100	--	100	--
1961	--	--	70	65	--	100	100	100	--
1962	70	--	99	72	--	--	40	--	100
1963	71	--	75	74	74	100	75	100	100
1964	92	100	98	100	93	100	100	100	100
1965	--	49	100	100	100	100	96	100	100
1966	46	--	79	99	69	100	100	57	--
1967	--	87	100	100	95	100	100	100	--
1968	--	19	100	100	100	100	100	100	61
1969	--	62	41	85	47	78	100	86	--
1970	11	76	97	30	100	97	--	100	94
1971	88	82	70	--	98	--	100	100	--
1972	--	100	85	--	73	100	100	100	100
1973	75	75	100	100	100	100	97	--	--
1974	100	100	100	81	100	100	100	--	--
1975	79	96	100	84	100	100	100	94	--
1976	98	100	100	100	100	100	100	100	--
1977	--	100	65	91	89	100	100	100	81
1978	--	25	87	93	70	--	89	100	100
1979	--	--	79	87	88	79	98	95	--
Years	10	14	19	17	17	17	18	17	9
AVERAGE	73	77	87	86	88	97	94	96	93

TABLE 1c.--*Percentage* of region *observed, Port Colborne*

Year	D2	J1	J2	F1	F2	M1	M2	A1	A2
	Half-month period								
1960	--	--	--	--	--	100	--	100	--
1961	--	--	41	16	--	100	100	100	--
1962	100	--	95	100	--	--	91	--	100
1963	100	--	100	100	100	100	100	100	100
1964	100	100	100	100	100	100	100	100	100
1965	--	91	100	100	100	100	100	100	100
1966	87	--	29	100	100	100	100	100	--
1967	--	100	100	100	100	100	100	100	--
1968	--	66	100	100	100	100	100	100	100
1969	--	100	83	79	41	66	100	100	--
1970	87	100	100	--	100	100	--	100	100
1971	100	79	100	--	100	--	100	100	--
1972	--	100	100	--	95	100	100	100	100
1973	100	100	100	100	100	100	100	--	--
1974	100	100	100	100	100	100	100	--	--
1975	100	100	100	91	100	100	100	100	--
1976	100	100	100	100	100	100	100	100	--
1977	--	100	91	100	100	100	100	100	100
1978	--	41	95	100	100	--	100	100	100
1979	--	--	41	95	100	100	100	100	--
Years	10	14	19	16	17	17	18	17	9
AVERAGE	97	91	88	93	96	98	99	100	100

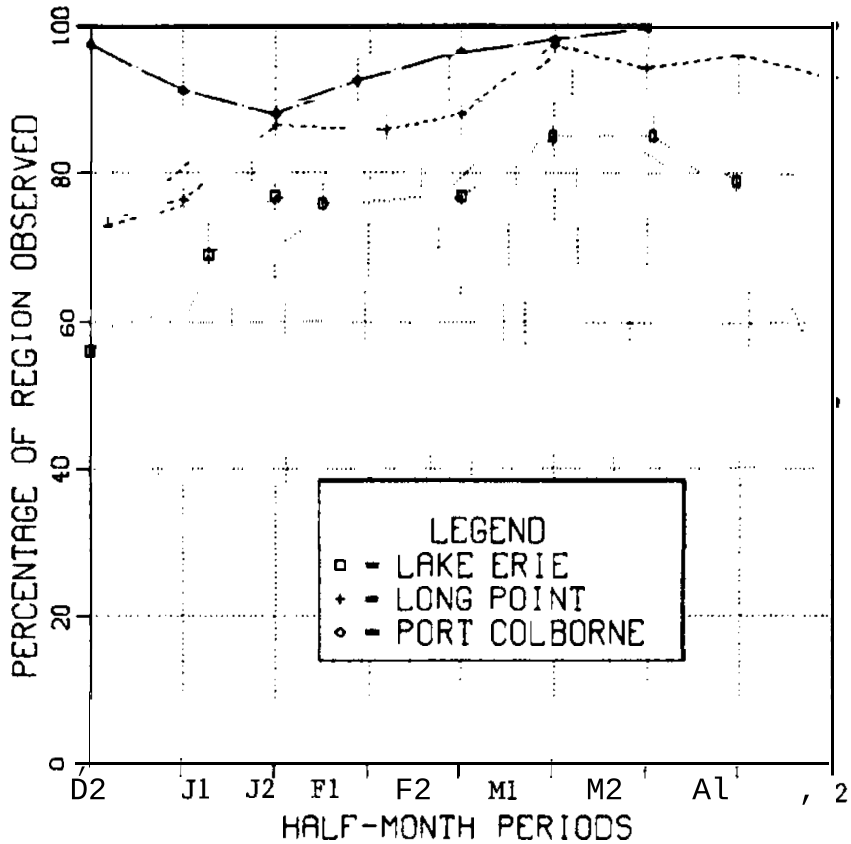

FIGURE 2.--*Average regional observation density.*

Equation (2) was used to evaluate $P(C)H$ for 10 discrete values of C, 10 percent to 90 percent in lo-percent increments and 95 percent. The percentage **exceedance values** for the 10 discrete values of C are given in table **3a-c** by half-month period.

$$P(C)H = \frac{F(C)H}{F(Y)H} \qquad (2)$$

where $F(C)H$ = number of years that average regional ice concentration was greater than C percent ice cover for half-month period H and

$F(Y)H$ = total number of years with regional ice concentrations for **half-**month period H.

Table 2a.--*Average regional ice cover (%), Lake Erie*

	Half-month period								
Year	**D2**	**J1**	**J2**	**F1**	**F2**	Ml	**M2**	Al	A2
1960	--	--	--	--	--	89	--	29	--
1961	--	--	62	87	--	10	9	0	--
1962	23	--	87	100	--	--	41	--	1
1963	2	--	97	97	100	80	46	12	15
1964	13	42	68	62	89	52	22	9	9
1965	--	7	58	82	79	58	79	35	6
1966	15	--	23	74	84	50	7	29	--
1967	--	15	9	88	75	84	57	7	--
1968	--	95	94	83	96	81	33	15	6
1969	--	89	94	83	71	58	15	36	--
1970	0	94	88	96	82	58	--	16	4
1971	0	40	56	94	88	25	30	18	--
1972	13	6	3	--	86	91	57	21	4
1973	11	30	16	59	89	30	0	--	--
1974	0	37	12	73	92	20	2	--	--
1975	14	8	10	52	55	55	24	0	--
1976	36	35	72	83	42	19	7	1	--
1977	--	94	96	98	97	74	48	16	14
1978	--	78	90	99	99	90	82	44	13
1979	--	--	77	95	93	78	56	11	--
Average	11	47	60	83	83	58	34	17	8
Maximum	36	95	97	LOO	100	91	82	44	15
Minimum	0	6	9	52	42	10	0	0	0*

*Estimated.

TABLE 2b.--*Average regional* ice cover *(%)*, *Long* Point

Year	Half-month period								
	D2	J1	J2	F1	F2	M1	M2	A1	A2
1960	--	--	--	--	--	91	--	58	--
1961	--	--	36	91	--	26	24	2	--
1962	2	--	88	100	--	--	37	--	1
1963	2	--	97	100	100	87	84	48	26
1964	4	31	67	80	91	85	66	30	11
1965	--	1	33	91	90	61	82	66	23
1966	0	--	13	82	93	76	31	29	--
1967	--	3	5	87	78	90	74	24	--
1968	--	88	84	65	99	84	65	43	6
1969	--	66	92	87	84	69	54	36	--
1970	0	92	83	100	94	93	--	48	14
1971	0	27	32	--	96	--	88	70	--
1972	--	0	27	--	83	98	77	58	22
1973	1	14	6	34	94	31	0	--	--
1974	0	22	4	63	91	47	8	--	--
1975	0	0	4	31	31	47	25	0	--
1976	13	15	52	88	73	57	26	8	--
1977	--	93	93	100	100	100	64	26	14
1978	--	40	89	100	100	--	92	66	30
1979	--	--	75	100	92	75	74	25	--
Average	2	35	52	82	88	72	54	38	16
Maximum	13	93	97	100	100	100	92	66	30
Minimum	0	0	4	31	31	26	0	0	0

TABLE 2c.--*Average regional ice cover (%), Port Colborne*

Year	D2	J1	J2	F1	F2	M1	M2	A1	A2
	Half-month period								
1960	--	--	--	--	--	94	--	94	--
1961	--	--	60	100	--	69	90	20	--
1962	0	--	92	100	--	--	94	--	14
1963	0	--	100	100	100	97	100	86	81
1964	0	71	87	94	100	85	89	83	88
1965	--	0	76	100	98	87	97	85	65
1966	0	--	17	100	95	97	86	100	--
1967	--	0	7	100	39	95	87	42	--
1968	--	99	100	90	95	100	94	94	33
1969	--	90	100	96	100	91	100	90	--
1970	0	93	81	--	95	100	--	68	40
1971	0	59	52	--	100	--	97	90	--
1972	--	0	44	--	97	100	90	82	69
1973	0	17	30	56	96	8	0	--	--
1974	0	42	8	82	96	62	35	--	--
1975	0	0	7	47	59	64	48	0	--
1976	47	49	90	92	87	86	98	66	--
1977	--	100	92	100	100	100	73	83	70
1978	--	72	95	100	100	--	95	90	82
1979	--	--	99	100	98	87	92	71	--
Average	5	49	65	91	92	84	81	73	60
Maximum	47	100	100	100	100	100	100	100	88
Minimum	0	0	7	47	39	8	0	0	0*

*Estimated.

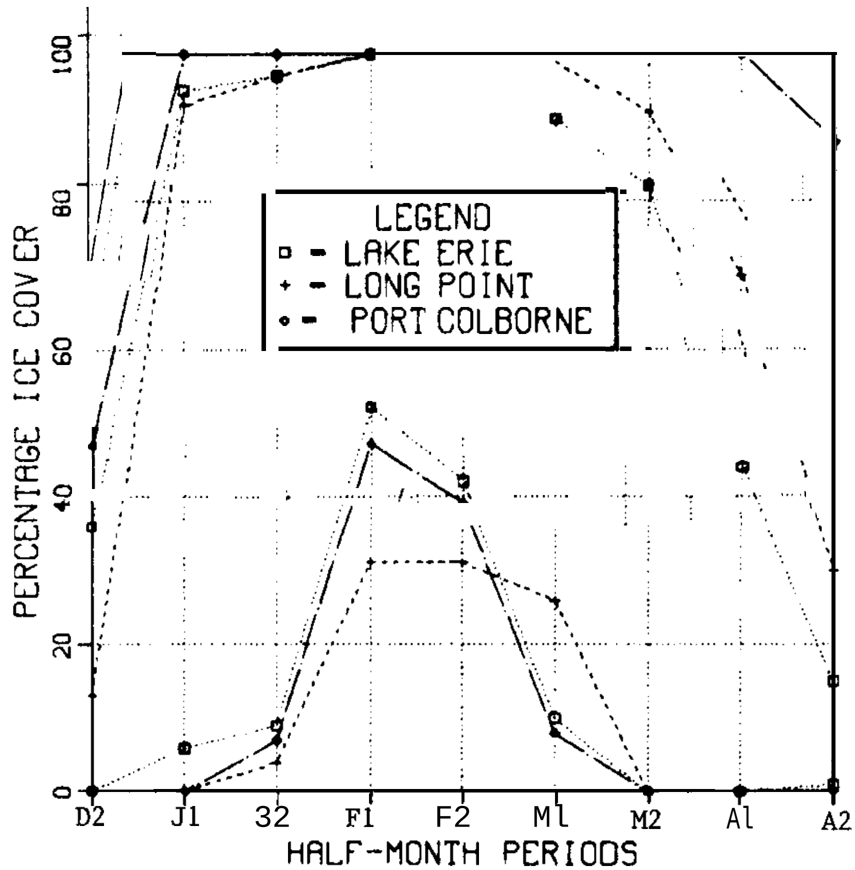

FIGURE 3.--*Maximum and minimum regional ice cover.*

2.4 Contour Analysis of Percentage Ice Cover Exceedance by Region

A coutour analysis of isopleths of Ice cover exceedance was performed on each regional data set in table 3. The resultant isopleth maps, figures 5a, b, and c, illustrate seasonal trends in average regional ice cover percentage exceedance. In addition, the isopleth pattern for pairs of regions was plotted (figures 5d, e, and f) to facilitate inter-regional comparisons of seasonal trends in average regional ice cover percentage exceedance.

2.5 Regression Analysis of Percent Ice Cover Exceedance
by Half-Month and Region

A linear least square regression analysis was made on the half-month percentage exceedance values in table 3a-c for each region, with percentage ice cover as the independent variable. If the percentage exceedance value for a given region and half-month period remained constant over a range of percentage ice cover values, only the last one or two values of the unchanged percentage exceedance were used in the regression analysis. And if there was more than one string of constant percentage exceedances for a given half-month period, only pert of the data from the first string was deleted. The purpose of the above editing procedure was to provide a better linear fit to the remaining data. A logical reason for this editing procedure is that one may consider the first string of constant percentage exceedance values over a

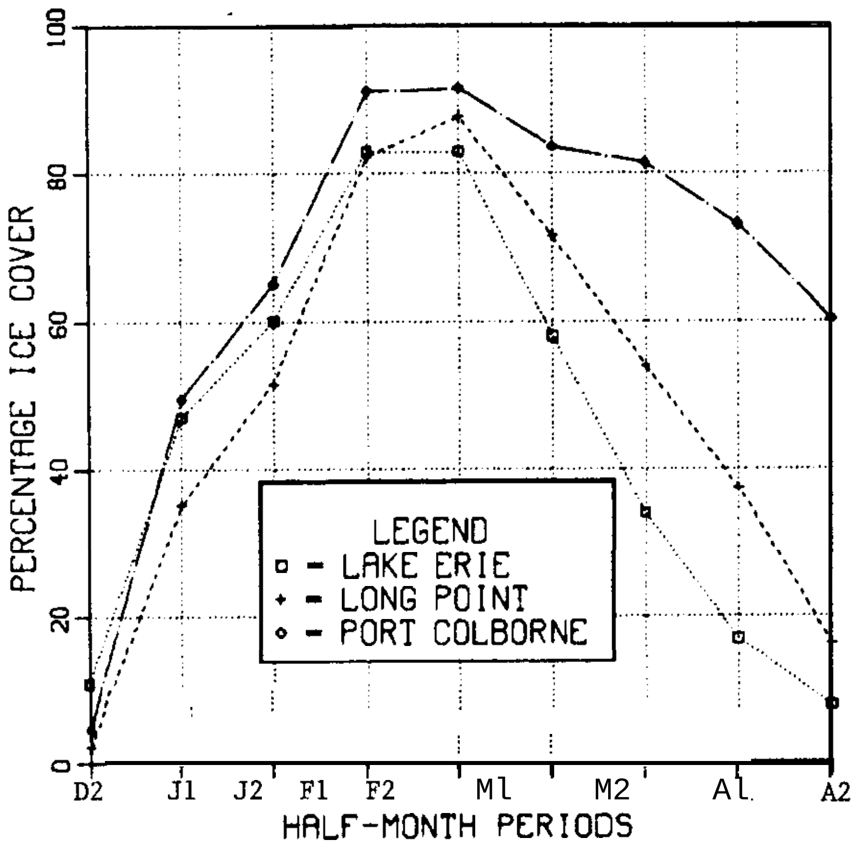

FIGURE 4.--*Average regional ice cover.*

TABLE 3a.--*Percentage ice cover exceedance, Lake Erie*

Percent ice	Half-month period								
	D2	J1	J2	F1	F2	Ml	M2	Al	A2
10	63	78	89	100	100	94	72	70	33
20	18	71	78	100	100	84	66	35	0
30	9	64	73	100	100	73	50	5	0
40	0	42	68	100	100	73	44	0	0
50	0	35	68	100	94	68	27	0	0
60	0	35	57	88	88	42	11	0	0
70	0	35	47	83	88	42	11	0	0
80	0	28	36	72	70	26	5	0	0
90	0	21	21	38	35	5	0	0	0
95	0	0	10	27	23	0	0	0	0

TABLE 3b.--*Percentage* ice cover *exceedance, Long Point*

Percent ice	Half-month period								
	D2	J1	J2	F1	F2	M1	M2	A1	A2
10	10	71	78	100	100	100	88	82	77
20	0	57	73	100	100	100	88	82	44
30	0	42	68	100	100	94	72	52	0
40	0	28	52	88	94	88	61	47	0
50	0	28	52	88	94	76	61	29	0
60	0	28	47	88	94	70	55	17	0
70	0	21	42	76	94	58	38	0	0
80	0	21	36	70	82	47	22	0	0
90	0	14	15	47	64	23	5	0	0
95	0	0	5	35	29	11	0	0	0

TABLE 3c.--*Percentage ice cover exceedance, Port Colborne*

Percent ice	Half-month period								
	D2	J1	J2	F1	F2	M1	M2	A1	A2
10	10	71	84	100	100	94	94	94	100
20	10	64	78	100	100	94	94	88	88
30	10	64	73	100	100	94	94	88	88
40	10	64	73	100	94	94	88	88	66
50	0	50	68	93	94	94	83	82	66
60	0	42	57	87	88	94	83	82	66
70	0	42	57	87	88	76	83	70	33
80	0	28	52	87	88	76	77	64	33
90	0	21	36	75	82	52	50	17	0
95	0	14	21	62	64	35	27	5	0

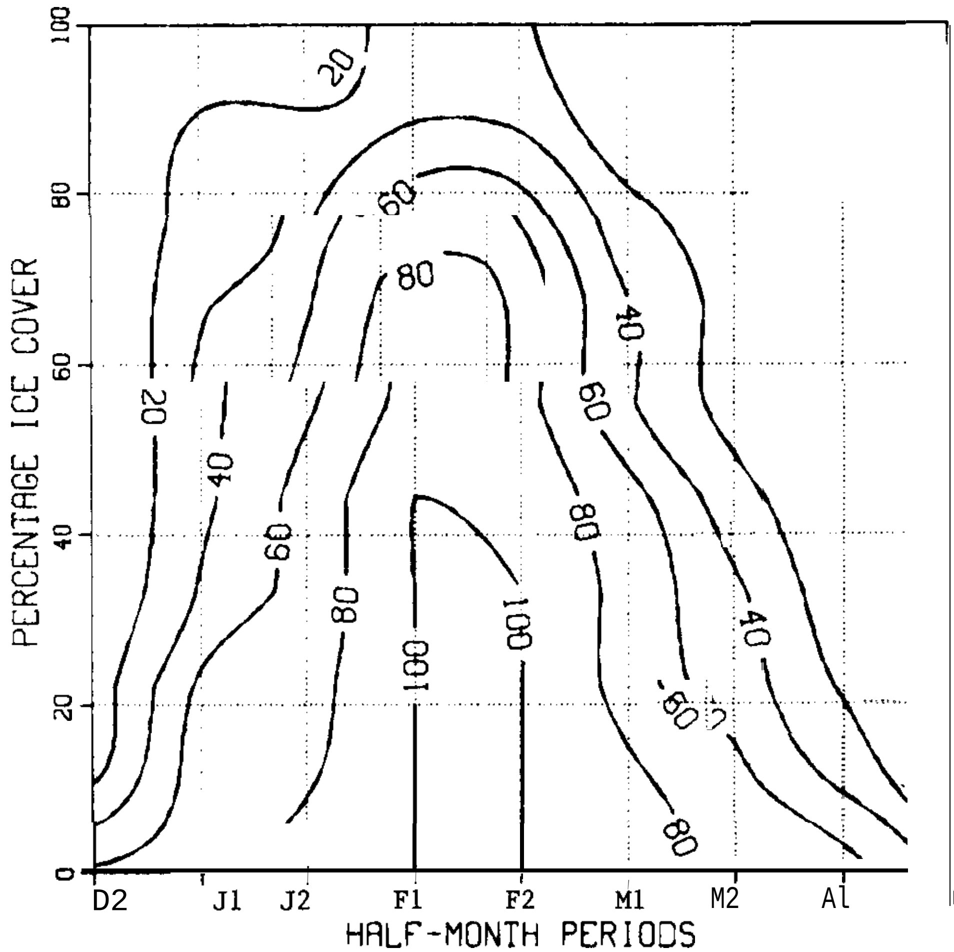

FIGURE 5a.--*Isopleths of percentage ice cover exceedance, Lake Erie.*

range of percentage ice cover values as a climatic limit of ice cover, based on the available data.

The form of the regression is given as equation (3). The number of observations, regression coefficients M and B, the coefficient of determination, and the standard error of estimate for each monthly regression equation are given in table 4.

$$P(C)H = M \cdot C + B \qquad (3)$$

where $P(C)H$ and C are es defined in equation (2).

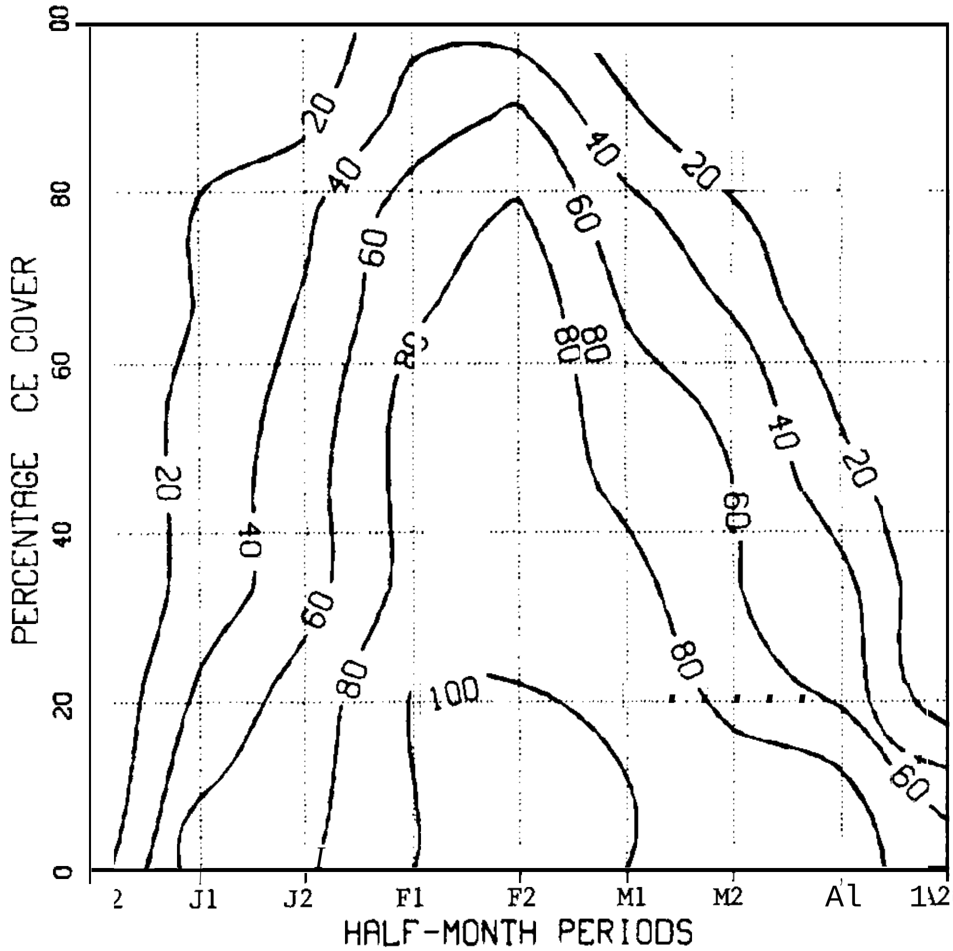

FIGURE 5b.--*Isopleths of percentage ice cover exceedance, Long Point.*

In most cases the coefficients of determination were above 0.80 and the standard error of estimates were less then 10, indicating a relatively high correlation and good fit for the data. The slope values of equation (3) (coefficient *M*) varied from -0.40 to -1.59 and represent the rate of decline in ice cover exceedance with increasing percentage ice cover. The intercept (coefficient *B*) values of equation (3) varied from 80 to 188 and they represent the percentage ice cover exceedance at zero percentage ice cover. For intercept values greater then 100, the regression equation is valid up to the percentage ice cover (*C*) that predicts loo-percent exceedance (*P(C)H*). Graphs of the regression equation for each lake region are given as figures 6a, b, end c.

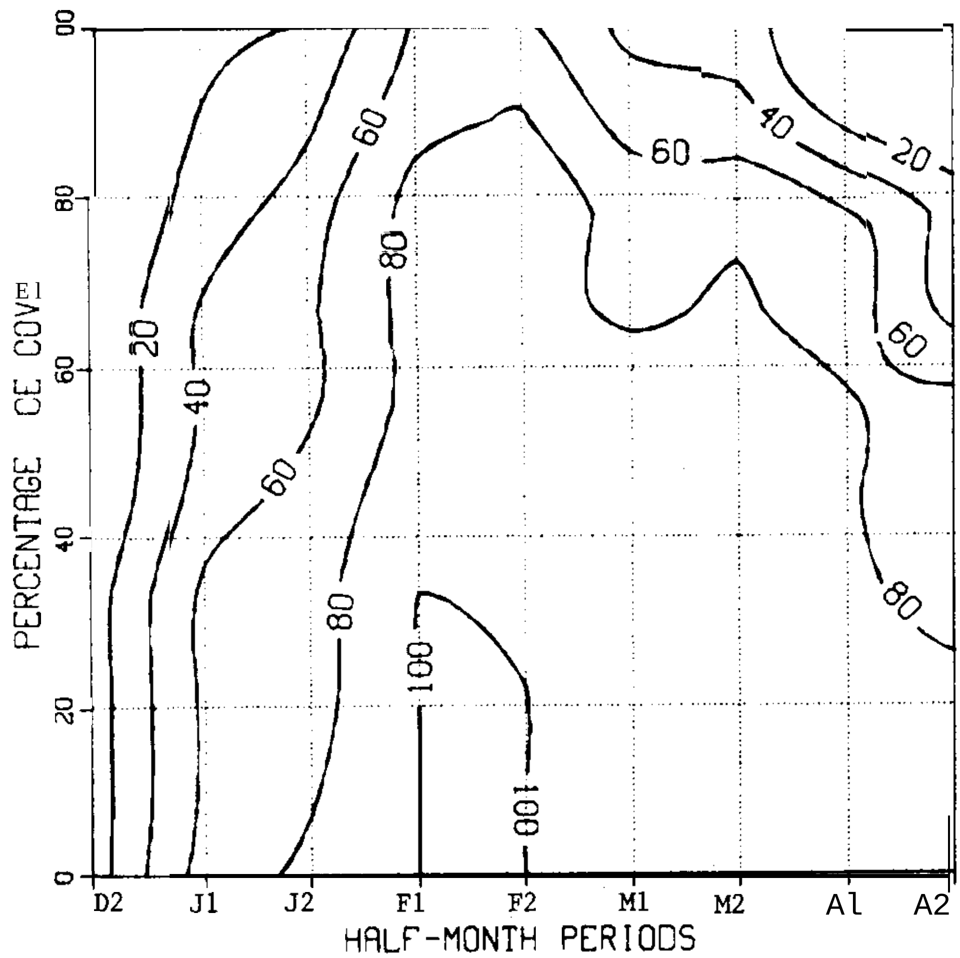

FIGURE 5c.--*Isopleths* of percentage *ice* cover *exceedance, Port Colborne.*

3. DISCUSSION OF RESULTS

3.1 General Pattern of Ice Formation end Decay

The average regional ice cover, illustrated in figure **4,** indicates **areal** trends in ice cover formation and decay on Lake Erie. During the ice formation period, half-months **D2** through **F1,** the percentage of the region covered by ice is usually greater in regions 1 end 3 (Lake Erie and Port Colborne eastward) compared to region 2 (Long Point eastward). This is apparently a direct result of the deeper water and associated greater heat storage in region 2. Starting the last half of February, **F2,** and lasting through the last half of April, A2, **areal** ice cover extent is greatest for region 3, followed by region 2; it is smallest in region 1. This pattern results because the ice cover normally first breaks up and is lost in the west lake basin. Ice cover loss gradually moves eastward across the lake in March and April, and it is common for wind to transport ice floes into the east end of

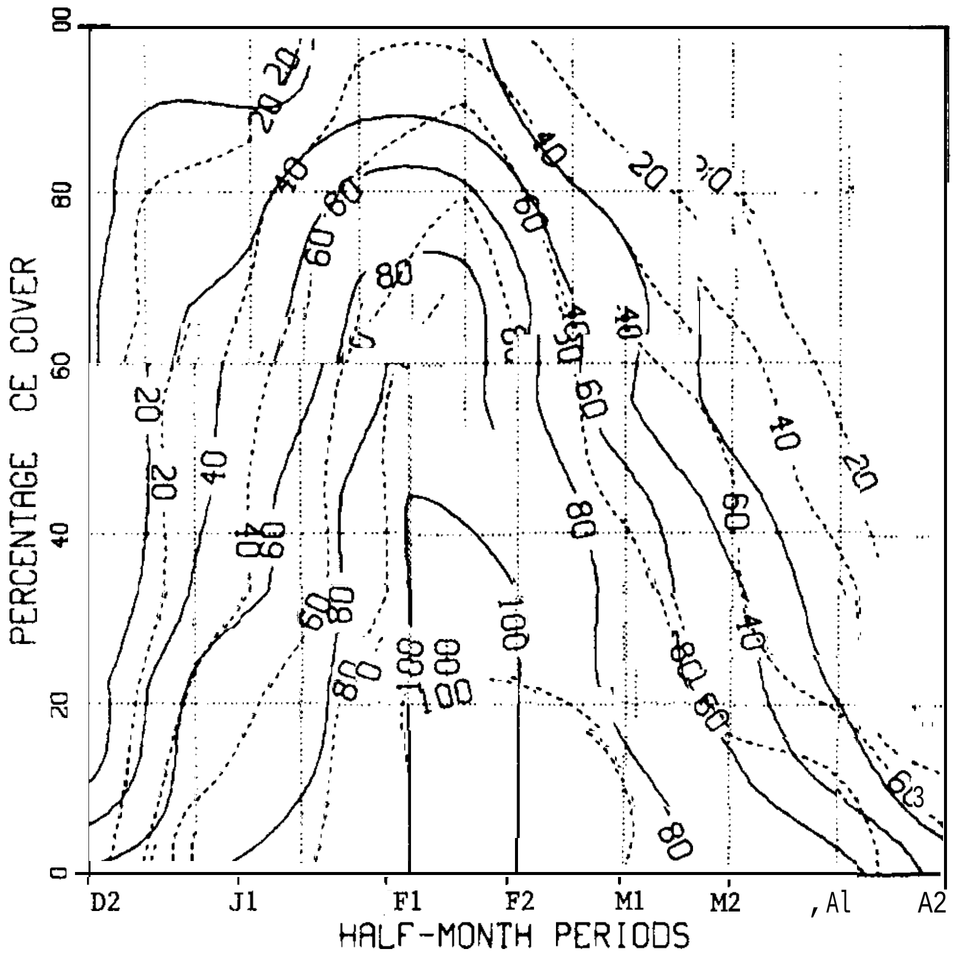

FIGURE 5d.--*Isopleths of percentage ice cover exceedance,* comparison *of isopleths Lake Erie and* Long *Point (dashed line).*

the lake in spring, resulting in the observed pattern of greater area1 coverage in regions 2 and 3 relative to region 1.

The isopleths of percentage ice cover exceedance shown in figure 5 also reflect the general seasonal end regional trends in ice cover noted above. A comparison of the 60-percent isopleths in figure 5d for Lake Erie and Long Point shows that the 60-percent isopleth occurs at a greater percentage ice cover value for Lake Erie relative to Long Point through half-month J2 and at a lesser percentage ice cover compared to Long Point for half-month8 F2 to A2, indicating a higher probability of greater ice cover extent for region 1 through the end of January and then a higher probability of greater ice cover extent for region 2 after that. Regional trends in ice cover probability during March and April are even more dramatically illustrated in figures 5e and f. These illustrations show that there is a higher probability of greeter ice cover in region 3 relative to either region 2 or region 1 in the spring.

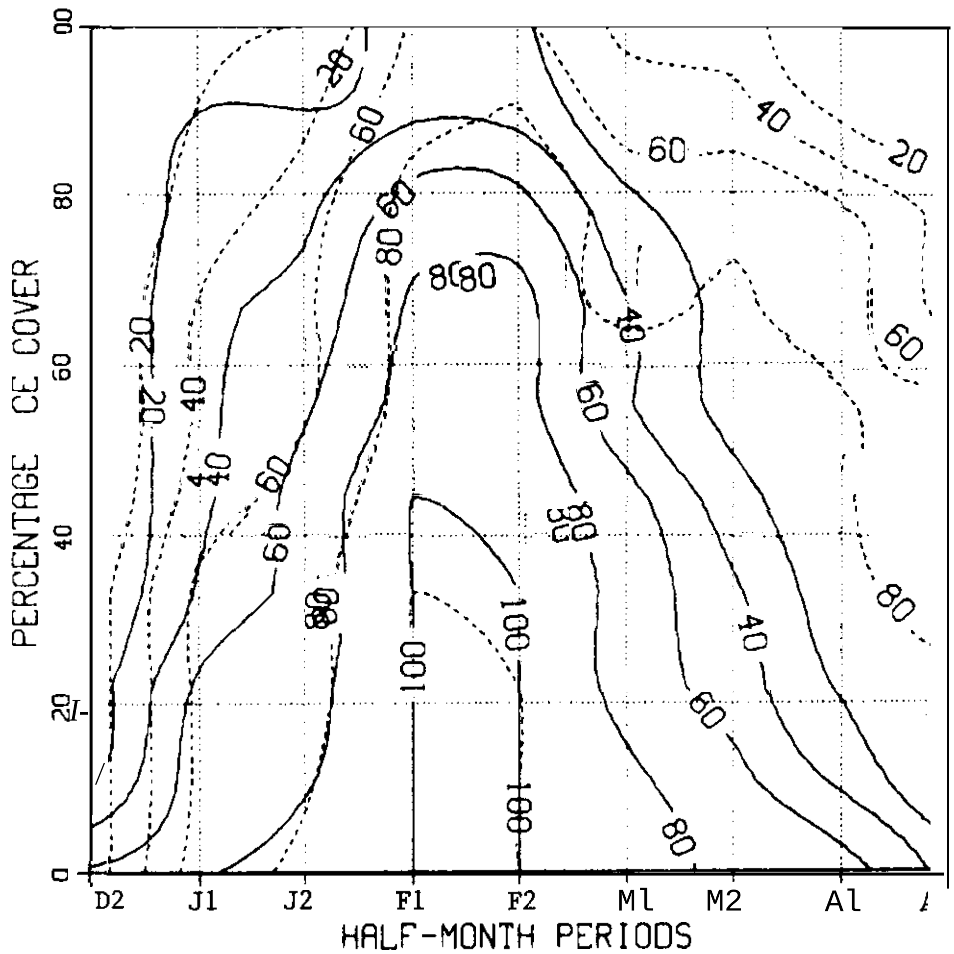

FIGURE 5e.--*Isopleths* of *percentage ice cover exceedance, comparison* of *isopleths Lake Erie and Port Colborne (dashed line).*

The graphs in figure 6 illustrate the general increase in ice cover extent through February and decrease in ice cover in March end April. Indications of that increase are the increase in intercept values and the migration of regression lines toward the higher ice concentrations values for January end February and the decrease in intercept values and the migration of regression lines toward lower ice concentrations in March end April.

3.2 Extremes in Ice Cover Extent

The maximum and minimum ice cover values given in table 2 and shown in figure 3 are estimates of the upper and lower annual limits of ice cover extent over the 20-year base period. A comparison of the maximum ice cover values for the three lake regions shows that during half-month periods J1, J2, F1, and F2 all three regions have maximum ice covers of close to 100 percent.

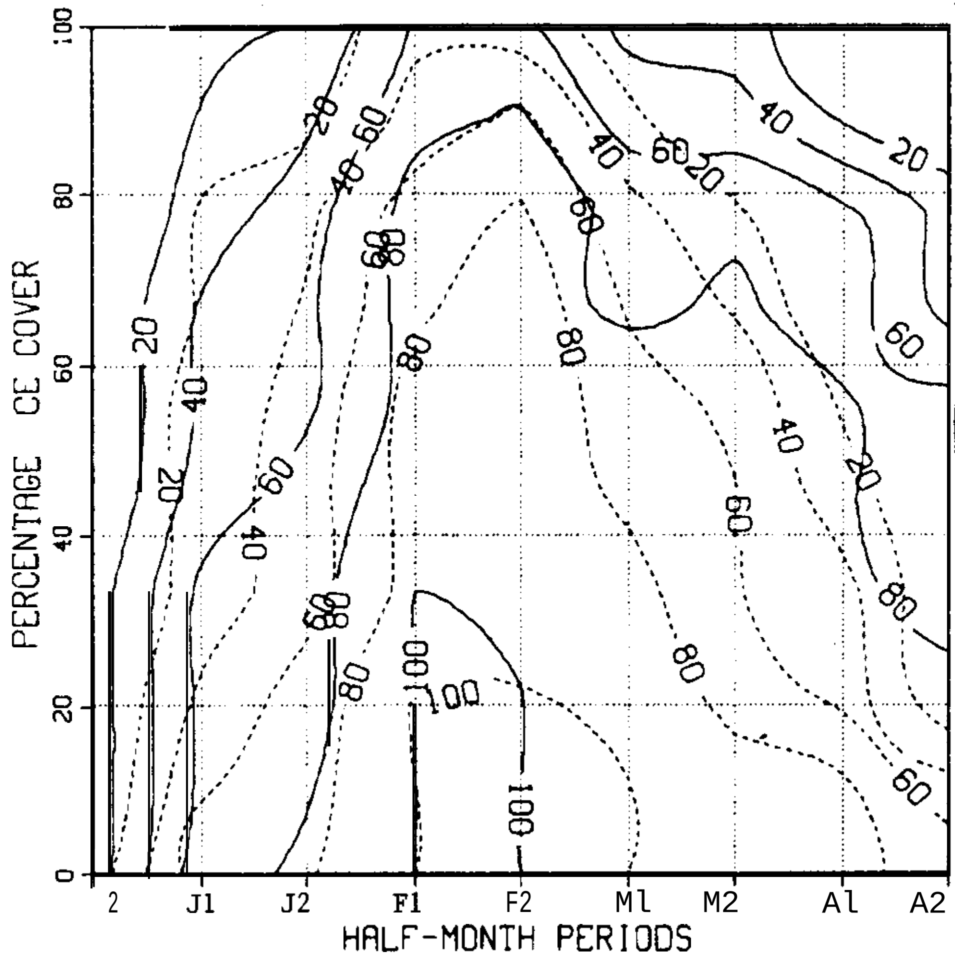

FIGURE 5f.--*Isopleths* of *percentage ice cover exceedance, comparison* of *isopleths Port Colborne and Long Point (dashed line).*

During half-month periods Ml, **M2,** Al, end **A2,** the upper annual limit in ice cover decreases greatly in regions 1 and 2, but is virtually unchanged in region 3 from its value during **F2.** This indicates that during some years region 3 has had much greeter ice cover in March end April than regions 1 and **2.** This trend is also illustrated in figures **5e** and **f.**

Minimum ice cover values indicate that all three lake regions **can** be virtually ice free in early and late winter some years, i.e., less than 10 percent ice covered through the end of January end less than 1 percent ice covered by the last half of March. During February, however, minimum annual ice cover extent varies from 30 percent to 50 percent over the three regions. In the first half of March, minimum annual ice cover in regions 1 end 3 is 10 percent or less, while in region 2 it is 26 percent. The greater minimum annual ice cover in region 2 during Ml may be a function of the observed breakup pattern end size of the region; i.e., es stated earlier, ice cover

TABLE 4a.--*Summary* of regression *analysis, Luke Erie*

	N	*M*	B	r^2	SE
J1	10	-0.77	83.12	0.95	7.6
J2	10	-0.85	100.83	0.94	6.6
F1	6	-1.59	186.30	0.91	9.7
F2	7	-1.36	165.40	0.84	13.3
Ml	10	-1.09	110.00	0.95	7.4
M2	9	-0.97	80.28	0.96	5.8
Al					
A2					

N = Number of observations.
M = Slope (coefficient 1).
B = Intercept (coefficient 2).
R^2 = Coefficient of determination.
SE = Standard error of estimate.

normally breaks up in the west end of the lake first and, under the influence of west winds, ice is often advected into the east end of the lake. Region 3 does not reflect this trend because it is much smaller than region 2.

Trends in maximum and minimum ice cover values are reflected in the contour charts of ice cover exceedance given as figure 5. The minimum ice cover values define the locations of the higher ice cover exceedance isopleths and the maximum ice cover values define the locations of the lower ice cover exceedance isopleths.

3.3 Concluding Remarks

A 20-year digital ice concentration data set was analyzed for observation density, average regional ice cover, and percentage ice cover exceedance for three overlapping regions of Lake Erie. The observation density analysis revealed a weakness in the data set for the early and late part of the ice season, i.e., from December 16 through January 15 and from April 16 to 30. The average regional ice cover and percentage ice cover exceedance analysis

TABLE 4b.--*Summary of* regression analysis, *Long Point*

	N	M	B	r^2	SE
J1	10	-0.66	67.05	0.88	7.5
J2	10	-0.77	89.17	0.93	6.5
F1	8	-0.88	131.11	0.86	9.0
F2	8	-0.81	133.80	0.64	15.6
M1	9	-1.14	130.99	0.95	7.6
M2	9	-1.12	111.45	0.96	6.5
A1	6	-1.52	106.36	0.97	5.5
A2					

N = Number of observations.
M = Slope (coefficient 1).
B = Intercept (coefficient 2).
R^2 = Coefficient of determination.
SE = Standard error of estimate.

revealed both seasonal and spatial trends in the distribution of ice cover and ice cover probabilities for Lake Erie on a regional basis. However, this analysis does not contain information on the spatial distribution of ice cover or ice cover probabilities within a given lake region. That type of analysis should also be made.

Because this analysis procedure, i.e.. regional ice cover and percentage exceedance from a regional average, facilitates presenting a large amount of historic ice cover data in a compact, coherent form, the same or a similar analysis should be made for other areas of the Great Lakes where more detailed ice cover information is needed. It is hoped that the data contained in this report will be of use to a broad spectrum of users concerned with ice cover on the Great Lakes.

4. ACKNOWLEDGMENTS

This work was performed under the general supervision of Dr. Frank H. Quinn, Head, Lake Hydrology Group, and at the request of Dr. Eugene J. Aubert, Director, Great Lakes Environmental Research Laboratory. The report was typed by Mrs. Barbara Lawton and edited by Mrs. Jeanne Kelley and her staff.

TABLE 4c.--*Summary* of regression analysis, *Port Colborne*

	N	M	B	r^2	SE
J1	10	-0.66	82.09	0.95	4.8
J2	10	-0.63	94.25	0.89	6.8
F1	7	-0.55	122.57	0.82	5.7
F2	8	-0.40	112.75	0.74	5.9
Ml	5	-1.54	188.18	0.91	8.0
M2	8	-0.81	125.57	0.71	13.3
Al	10	-0.91	116.89	0.72	17.7
A2	9	-1.13	116.25	0.91	10.3

N = Number of observations.
M = Slope (coefficient 1).
B = Intercept (coefficient 2).
R^2 = Coefficient of determination.
SE = Standard error of estimate.

5. REFERENCES

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Aubert, E. J., and T. L. Richards (1981): *IFYGL--The International Field Year for the Great Lakes.* Ann Arbor, Mich.: National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory. 421 pp.

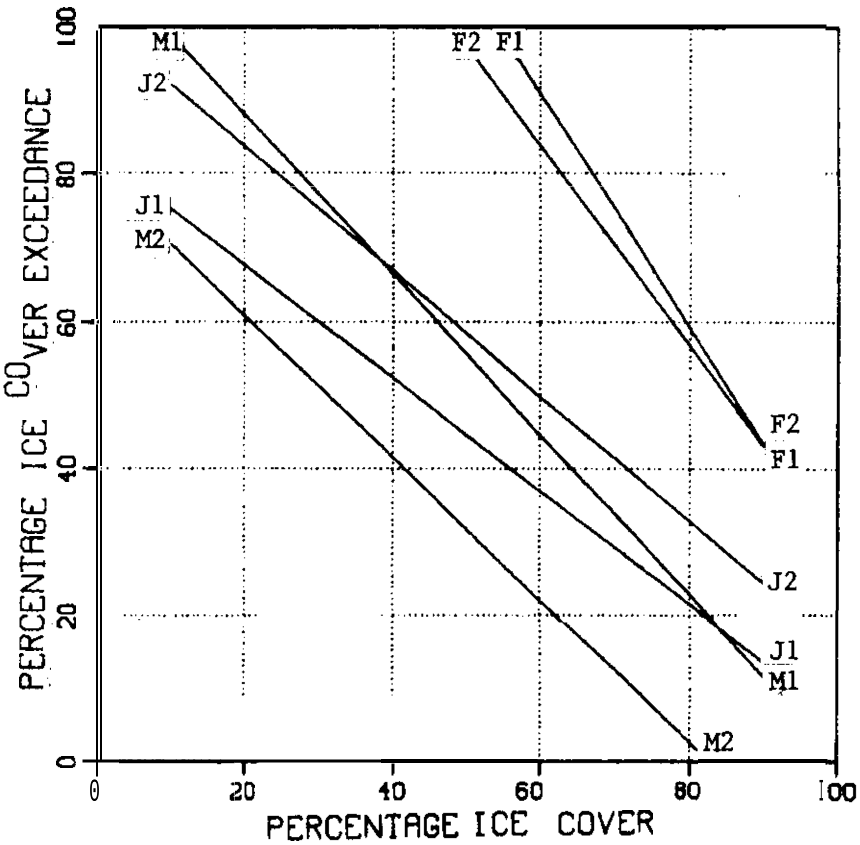

FIGURE 6a.--*Regression analysis, Lake Erie.*

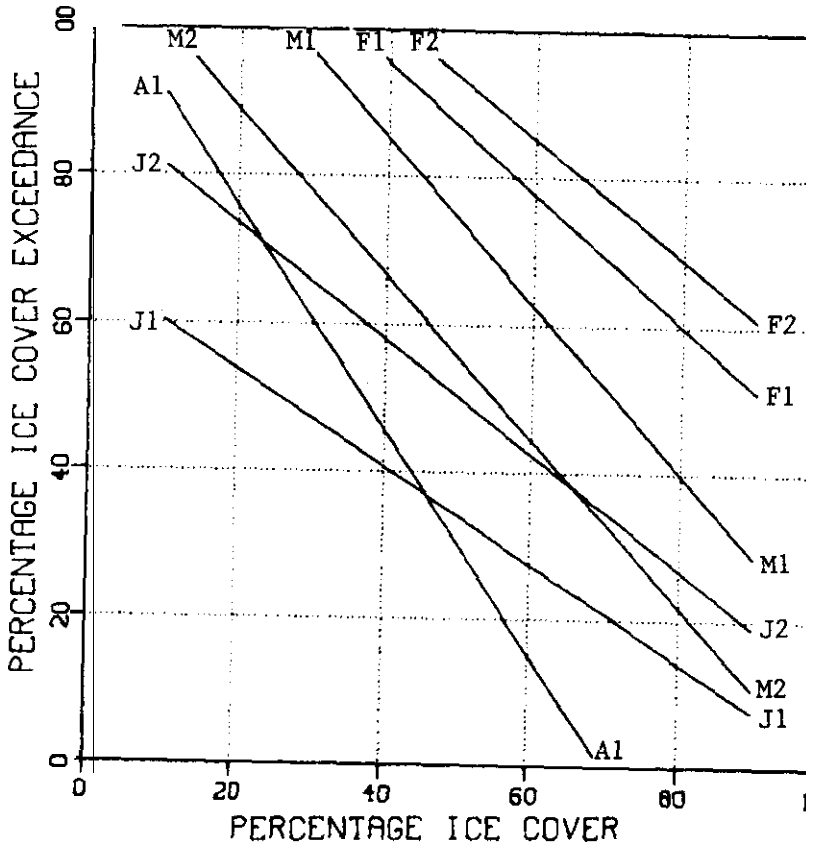

FIGURE 6b.--*Regression analysis, Long Point.*

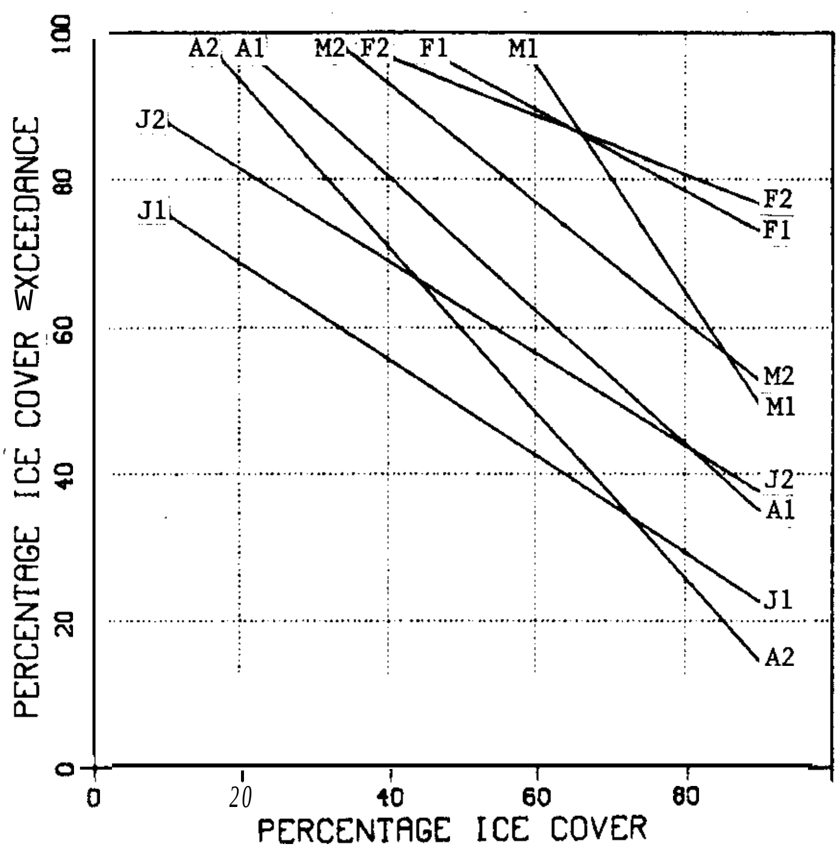

FIGURE 6c.--*Regression analysis, Port Colborne.*