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The 1997 ENSO event and implication for North American Laurentian Great Lakes winter severity and ice cover

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Abstract. Mild winters and below-average annual maximum ice cover for the Laurentian Great Lakes occur during strong warm ENSO events. During the six strongest warm ENSO events since 1950 a Great Lakes winter severity temperature index and simulated annual maximum ice cover averaged 1.2°C above and 15% below a 1950-1994 average, respectively. The observed differences between the average of the strong ENSO event years and the base period average are statistically significant.

1. Introduction

The 1997 ENSO event is shaping up to be one of the strongest since1982. It has established a new high for the Multivariate ENSO Index (MEI) during this past summer and early autumn (see Climate Diagnostics Center's Internet page http://www.cdc.noaa.gov/ENSO/enso.mei_index.html and *Wolter and Timlin*, 1993). If it continues to intensify during winter (1997-1998), typically the time when the effect of El Nino on the Northern Hemisphere extratropics reaches its maximum, the 1997 ENSO may become stronger than the record 1982 event, which is the strongest ENSO during this century. This paper presents the results of a preliminary evaluation of the affect of the six strongest MEI events over the past half century (1957, 1965, 1972, 1982, 1986, and 1991) on Great Lakes winter severity and ice cover. The MEI prior to 1950 was not available. The Great Lakes regional extremes and average winter severity and ice cover extent for the six strongest MEI events are identified and compared with the extremes and average values for the remaining winters during the 45-year period from 1950-1994.

2. Great Lakes Ice Cover and Winter Severity

Assel et al. (1985) found that the 1982-1983 ENSO event had a major impact on the severity of the winter and on the ice cover of the Great Lakes. A winter severity index [WSI] (the November through February average monthly temperature averaged for four sites in the Great Lakes: Duluth, Minnesota, Saulte St. Marie, Michigan, Detroit. Michigan, and Buffalo, New York) was used to 1) compare winter severity with previous winters, and 2) model lake-averaged annual maximum ice cover for the combined area of the five Great Lakes. The model was based on a regression analysis of a 21-winter record of annual maximum Great Lakes ice cover (winters 1963-1983). The correlation coefficient of the model was -0.83, and the standard error of estimate is 11.6 % ice cover.

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2.1. Historical Perspective of WSI and Ice Cover

Winter 1983 was the tenth mildest over the Great Lakes region during the previous 200 winters (*Assel et al.*, 1985). The 1983 annual maximum ice cover was the lowest of the 21 winters of record. Using their ice cover model, *Assel et al.*, (1985) found that the WSI for the warmest 10% of winters between 1783 and 1983 ranged from +0.1°C to -3.4°C, this translated to ice cover ranging from 0% to 41%. The coldest 10% of the winters had WSI's of -6.0°C to -9.0°C, corresponding to ice covers ranging from 73% to 100%. Note the minimum WSI (+0.1°C) which corresponds to a mild winter has a higher numerical value (more positive) than the maximum WSI (-9°C), which corresponds to a severe winter.

3. Comparison of the WSI and Ice Cover for Strongest MEI Events

The WSI and modeled ice cover for the 1950-1994 base period is portrayed in Figure 1. The WSI and observed ice cover for the six strongest MEI event winters (Table 1) shows that the WSI is below-average, and that both the modeled and the observed ice cover are below a 28-winter (1963-1990) average (59%) of observed annual maximum ice cover. Thus, each of the six strongest MEI events has produced milder winters and below-average ice cover relative to the average of the other winters in the 45-winter base period.

3.1. Comparison of Minimum WSI

The minimum WSI for the base period (winter 1952-1953) and for the ENSO with the lowest WSI (winter 1982-1983) is virtually the same (Table 2). During such extremely mild winters the deeper mid-lake areas of the Great Lakes remain primarily free of ice cover. Seasonal maximum ice cover during winter 1982-1983 was estimated as: 21% Lake Superior, 17% Lake Michigan, 36% Lake Huron, 25% Lake Erie, and less than 10% Lake Ontario (*Assel et al.*, 1985). The U.S. Coast Guard spent only 55 hours in support of winter shipping on the Great Lakes during winter 1982-*1983 (U.S. Coast Guard*, 1983), far below the average number of hours spent assisting shipping during a typical winter. Due to the mild air temperatures, a high percentage of the precipitation that fell on the southern portion of Great Lakes region in winter 1982-1983 fell as rain (Assel et al., 1985). This, likely, had economic impacts on winter sports activities associated with snow and municipal snow removal costs.

3.2 Comparison of Maximum WSI

The maximum WSI, corresponding to a severe winter is much lower (more negative) for the base period (winter 1976-1977, which was also an ENSO winter) than is the maximum WSI among the six strongest warm ENSOs (winter 1972-

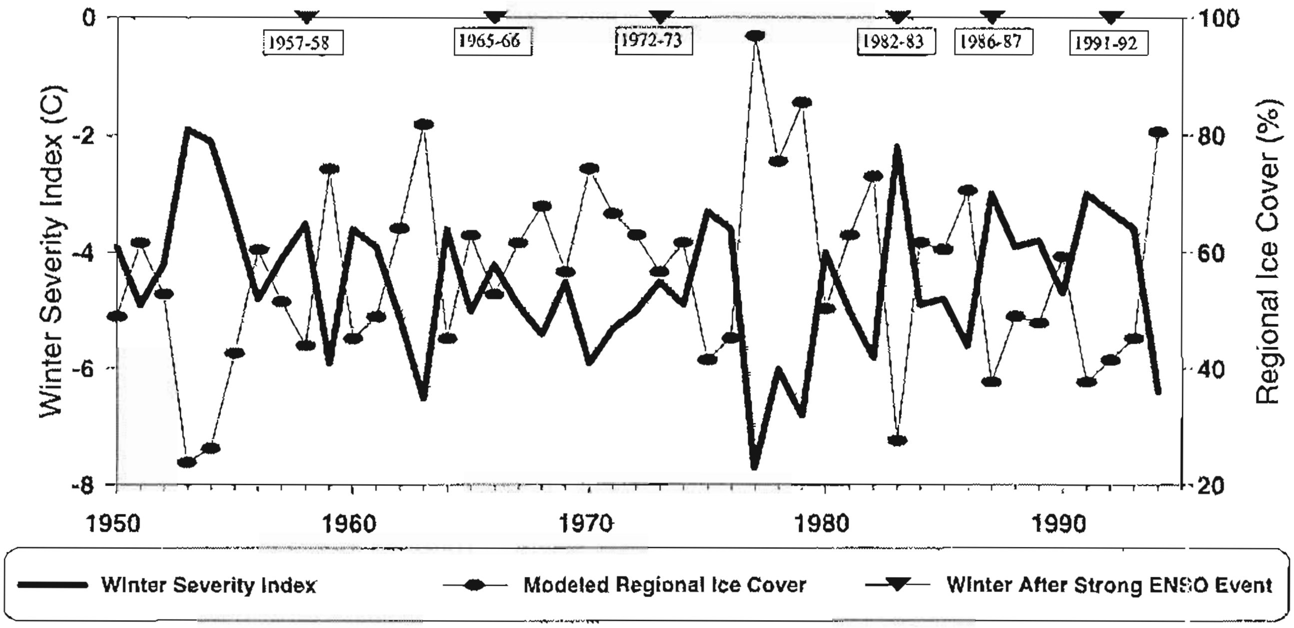

Figure 1. Observed Winter Severity Index, Modeled Regional Ice Cover (after Assel et al., 1985), and the six Strongest Warm ENSO Events Between 1950 and 1994.

1973). The ice cover and air temperatures for these two winters (1972-1973 and 1976-1977) are very different. Ice cover during winter 1976-1977 was much above average for the Great Lakes (*Quinn et al.*, 1978) and at a record level for Lake *Michigan (Assel and Quinn*, 1979). In contrast, seasonal maximum cover during winter 1972-1973 was near-to-below average on the Great Lakes (Assel, 1974). The difference in ice cover these two winters is perhaps most dramatically illustrated by the U.S. Coast Guard recorded assistance to shippers: 5,942 hours during winter 1976-1977, 1,341 hours during winter 1972-1973 (*DeWitt et al.*, 1980).

3.3 Comparison of Average WSI

The average WSI and average annual maximum ice cover for the 1950-1994 base period was significantly different (α =5%, two tailed students t test) than the average for the six strongest MEIs during that period (Table 2). Thus, *on average*, the average annual regional temperature is *likely* to be higher (approximately 1.2°C), and the annual regional maximum ice cover is *likely* to be less extensive (approximately 15%) during the winter following the onset year of a strong warm ENSO event. However, as indicated by winter 1972-1973 it is possible to have near-average maximum ice cover after a strong warm ENSO event. And as shown by winter 1952-1953, it is possible to have an extremely mild winter that does not occur with the mature phase of a strong warm ENSO event.

Table 1. Comparison of the WSI (°C) and Ice Cover (%) for the Six Strongest MEI Events

	WSI	Diff[1]	S-ICE[2]	O-ICE[3]	Diff[4]
1957-58	-3.5	1.2	44.1	ND[5]	-14.9
1965-66	-4.2	0.5	52.9	40.8	-6.1
1972-73	-4.5	0.2	56.7	49.9	-2.3
1982-83	-2.2	2.5	27.7	23.3	-31.3
1986-87	-3.0	1.7	37.8	30.3	-21.2
1991-92	-3.3	1.4	41.6	ND	-17.4

[1] The difference (strong ENSOs minus base period average) positive differences indicate milder winters;
[2] modeled ice cover;
[3] observed ice cover;
[4] difference (modeled minus the 28-winter average [59%] observed);
[5] ND, no data.

4. Discussion and Conclusions

The analysis shown here is preliminary, while it provides evidence that strong warm ENSO events have a statistically significant teleconnection with regional average winter temperature and regional *annual maximum* ice cover in the Laurentian Great Lakes, the sample size is likely too small for operational forecasting applications. The 1997 ENSO may be

Table 2. Comparison of the 1950-1994 WSI (°C) and Ice Cover (%) with the Six Strongest Warm ENSO Events During that Period

	Winter Severity Index			Great Lakes Ice Cover		
	50-94[1]	ENSO[2]	Diff[3]	50-94	ENSO	Diff
Minimum	-1.9	-2.2	-0.3	23.9	27.7	3.8
Maximum	-7.7	-4.5	3.2	97.0	56.7	-40.3
Average[4]	-4.7	-3.3	1.2	58.7	43.5	-15.2

[1] The 1950-1994 base period;
[2] the six strongest warm ENSO winters;
[3] the strong warm ENSO minus 1950-1994 value;
[4] the average for base does not include the strong ENSO winters.

among the strongest of this century if it continues to intensify during winter 1997-1998. The impact of strong warm ENSO events on the seasonal progression of ice cover (early winter, mid winter, late winter-to-early-spring) needs to be analyzed further. Early winter ice extent has implications for the Great Lake fishery (*Brown et al.*, 1993, *Taylor et al.*, 1987), late winter ice extent has implications for spring lake ecosystem processes (*Eadie et al.*, 1996), and the seasonal progression and extent of ice during strong warm ENSO winters has potential applications for long-range forecasts of ice *cover (Assel and Rodionov*, 1997), lake evaporation models (*Croley and Assel*, 1994), and winter navigation studies on the Great Lakes.

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