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GREAT LAKES ICE CLIMATOLOGY UPDATE: WINTER 2006 – 2011 DESCRIPTION OF THE DIGITAL ICE COVER DATASET

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1. INTRODUCTION

A 6-winter digital ice cover data set consisting of 389 ice charts of total ice concentration (the fraction of a unit of surface area covered by ice), was downloaded from the National Ice Center (NIC) website, http://www.natice.noaa.gov/products/great_lakes.html. This report updates GLERL's 33-winter ice climatology dataset for total ice concentration (Assel 2003, Assel 2005). Data processing and quality control procedures, file structure, format, and naming conventions are described. The data are available as fixed formatted ASCII grids (2.55 km for winter 2006 and 1.275 km for winters 2007-2011) and has been converted to ArcMap feature classes for GIS users. Temporal distribution of the ice charts is summarized in tables. A planned companion report will contain an analysis of these data including spatial patterns of dates of first ice, last ice, ice duration, and ice concentration anomalies [relative to a 30-winter (1973-2002) base period] for each lake by winter season. It will also contain lake averages of total ice cover concentration that portray the seasonal progression of ice cover each winter.

Since the last updated ice atlas (Assel 2005), there has been significant change in ice cover on the Great Lakes. This update of the ice atlas should be useful to the research community as well as others who rely on Great Lakes ice data for planning purposes. The technical memorandum that updated the ice atlas for winters 2003, 2004, and 2005 (Assel 2005) did not include ArcGIS feature classes, so those are included here.

Lake ice cover is a sensitive indicator of regional climate and climate change (Assel et al. 1995; Assel and Robertson 1995; Magnuson et al. 1997, 2000). Seasonal ice cover repeats each year with large interannual variability. For example, the maximum ice coverage over all of the Great Lakes was 95% in 1979 and only 11% in 2002 (Bai et al. 2012). Possible contributors include interannual and interdecadal climate variability, and long-term trends (Assel 1990), some of which may be related to global climate warming. Even in response to the same climate forcing, Great Lakes ice cover may experience different spatial and temporal variability due to an individual lake's orientation, depth (i.e., water heat storage, Assel et al. 2003), and turbidity (i.e., albedo due to sedimentation). To predict seasonal and interannual variability of lake ice cover using statistical analysis, the first step is to investigate the predictability, which is measured by the ratio of the mean (climatology) to standard deviations (i.e., variability). In general, the larger the ratio between the two, the higher the predictability. In other words, if the standard deviation is larger than the mean, the mean is a poor predictor (Assel et al. 2004). In addition, under the same climate forcing, lake ice may respond differently in the upper and lower Great Lakes.

2. DISTRIBUTION OF ICE CHARTS BY WINTER SEASON

The number of ice charts per winter season, Table 1, ranged from 45 to 55, with the exception of the last winter, 2011, when it was 151. The NIC begin producing daily charts for GLERL in winter 2011 because of a request from GLERL's hydrodynamic modelers to provide daily ice chart analysis for their use. The dates of first ice charts range from the last week in November to the first week in December, and the dates of the last ice usually occur in early to mid May. Winter 2010 was mild, and the last ice chart occurred in mid-April. The number of days between the first and last ice chart ranges from 162 to 130, with a median value of 158. The average number of days between consecutive ice charts ranged from approximately 3.1 to 1.1 days, with a median value of approximately 3.25 days. The date of individual ice charts for each winter is given in Table 2.

Table 1. Summary of ice chart date statistics

Winter Season	No. of Charts	Date of First Ice Chart	Date of Last Ice Chart	Days Between First and Last Ice Chart	Average No. Days Between Ice Charts
2006	46	28-Nov	04-May	157	3.43
2007	46	04-Dec	10-May	158	3.46
2008	55	26-Nov	15-May	171	3.13
2009	45	08-Dec	07-May	151	3.38
2010	46	07-Dec	15-Apr	130	2.85
2011	151	02-Dec	13-May	162	1.08

3. NIC ASCII GRID FILES

The dates of NIC ASCII grid files are the dates these files were produced at NIC and not necessarily the date the data in these files was observed. This is discussed further in section 4.2. The following metadata for NIC ASCII grid files was abstracted from a file on the NIC web site at http://www.natice.noaa.gov/products/great_lakes.html under Category "Daily Ice Concentration," and Format "Metadata" for winter 2009: "Data for the analyses can go back 96 hours from when they are completed."… "They are based on an analysis and integration of all available data on ice conditions, including weather and oceanographic information, visual observations from shore, ship and aircraft, airborne radar, satellite imagery and climatological information." The reader is referred to that web site for more metadata details.

3.1 Spatial Resolution and Grid Size

National Ice Center ASCII grid files and NIC graphic ice chart files were downloaded from the NIC website for winters 2006 through 2011. As in Assel (2003, 2005) and as described in Norton et al. (2000) the ice data for winter 2006 was mapped into a Mercator projection and re-sampled to a 510×516 pixel grid covering the Great Lakes area with a grid resolution of 2.55 km. The latitude of true scale is approximately 45° N, actual grid resolution varies with latitude, L ≈ (2.55*cosf/cos45), where f is the latitude. Starting in winter 2007, and for subsequent winters, the data was re-sampled to a 1024×1024 pixel grid. The grid spacing for the 1024×1024 grid is specified at the equator as 1.8 km. Actual grid resolution is d cosf, where d is the spatial resolution at the equator, and f is the latitude (Schwab et al. 1992). For example, the grid spacing for the 1024×1024 grid is 1.275 km at 45°N.

Table 2. Distribution of ice chart dates by winter season

Winter 2006				Winter 2007				Winter 2008				Winter 2009				Winter 2010			
Year	Mon	Day	Jday	Year	Mon	Day	Jday	Year	Mon	Day	Jday	Year	Mon	Day	Jday	Year	Mon	Day	Jday
2005	11	28	332	2006	12	4	338	2007	11	26	330	2008	12	8	342	2009	12	7	341
2005	12	1	335	2006	12	7	341	2007	11	29	334	2008	12	11	345	2009	12	9	343
2005	12	5	339	2006	12	11	345	2007	12	3	337	2008	12	15	349	2009	12	14	348
2005	12	8	342	2006	12	14	348	2007	12	6	340	2008	12	18	352	2009	12	17	351
2005	12	12	346	2006	12	18	352	2007	12	10	344	2008	12	22	356	2009	12	21	355
2005	12	15	349	2006	12	21	355	2007	12	13	347	2008	12	25	359	2009	12	24	358
2005	12	20	354	2006	12	25	359	2007	12	17	351	2008	12	29	363	2009	12	28	362
2005	12	22	356	2006	12	28	362	2007	12	20	354	2009	1	1	366	2009	12	31	365
2005	12	26	360	2007	1	1	366	2007	12	24	358	2009	1	5	370	2010	1	5	370
2005	12	29	363	2007	1	4	369	2007	12	27	361	2009	1	8	373	2010	1	6	371
2006	1	2	367	2007	1	8	373	2007	12	31	365	2009	1	12	377	2010	1	7	372
2006	1	5	370	2007	1	11	376	2008	1	3	368	2009	1	15	380	2010	1	9	374
2006	1	9	374	2007	1	15	380	2008	1	7	372	2009	1	19	384	2010	1	10	375
2006	1	12	377	2007	1	18	383	2008	1	10	375	2009	1	22	387	2010	1	12	377
2006	1	16	381	2007	1	22	387	2008	1	14	379	2009	1	26	391	2010	1	13	378
2006	1	19	384	2007	1	25	390	2008	1	17	382	2009	1	29	394	2010	1	14	379
2006	1	23	388	2007	1	29	394	2008	1	21	386	2009	2	2	398	2010	1	19	384
2006	1	26	391	2007	2	1	397	2008	1	24	389	2009	2	5	401	2010	1	21	386
2006	1	30	395	2007	2	5	401	2008	1	28	393	2009	2	9	405	2010	1	25	390
2006	2	2	398	2007	2	8	404	2008	1	31	396	2009	2	12	408	2010	1	28	393
2006	2	6	402	2007	2	12	408	2008	2	4	400	2009	2	16	412	2010	2	1	397
2006	2	9	405	2007	2	15	411	2008	2	7	403	2009	2	19	415	2010	2	4	400
2006	2	13	409	2007	2	19	415	2008	2	11	407	2009	2	23	419	2010	2	8	404
2006	2	16	412	2007	2	22	418	2008	2	14	410	2009	2	26	422	2010	2	15	411
2006	2	20	416	2007	2	26	422	2008	2	18	414	2009	3	2	427	2010	2	18	414
2006	2	23	419	2007	3	1	426	2008	2	21	417	2009	3	5	430	2010	2	22	418
2006	2	27	423	2007	3	5	430	2008	2	25	421	2009	3	10	435	2010	2	25	421
2006	3	2	426	2007	3	8	433	2008	2	28	424	2009	3	12	437	2010	3	1	426
2006	3	6	430	2007	3	12	437	2008	3	3	428	2009	3	17	442	2010	3	4	429
2006	3	9	433	2007	3	15	440	2008	3	6	431	2009	3	19	444	2010	3	9	434
2006	3	13	437	2007	3	19	444	2008	3	10	435	2009	3	24	449	2010	3	10	435
2006	3	16	440	2007	3	22	447	2008	3	13	438	2009	3	26	451	2010	3	11	436
2006	3	20	444	2007	3	26	451	2008	3	17	442	2009	3	31	456	2010	3	13	438
2006	3	23	447	2007	3	29	454	2008	3	19	444	2009	4	1	457	2010	3	14	439
2006	3	27	451	2007	4	2	458	2008	3	20	445	2009	4	2	458	2010	3	16	441
2006	3	30	454	2007	4	5	461	2008	3	25	450	2009	4	7	463	2010	3	17	442
2006	4	3	458	2007	4	9	465	2008	3	26	451	2009	4	9	465	2010	3	18	443
2006	4	6	461	2007	4	12	468	2008	3	27	452	2009	4	14	470	2010	3	23	448
2006	4	10	465	2007	4	16	472	2008	4	1	457	2009	4	16	472	2010	3	24	449
2006	4	13	468	2007	4	19	475	2008	4	2	458	2009	4	20	476	2010	3	25	450
2006	4	17	472	2007	4	23	479	2008	4	3	459	2009	4	23	479	2010	3	30	455
2006	4	20	475	2007	4	26	482	2008	4	8	464	2009	4	27	483	2010	4	1	457
2006	4	24	479	2007	4	30	486	2008	4	9	465	2009	4	30	486	2010	4	5	461
2006	4	27	482	2007	5	3	489	2008	4	10	466	2009	5	4	490	2010	4	8	464

Table 2. Distribution of ice chart dates by winter season

Winter 2006				Winter 2007				Winter 2008				Winter 2009				Winter 2010			
Year	Mon	Day	Jday	Year	Mon	Day	Jday	Year	Mon	Day	Jday	Year	Mon	Day	Jday	Year	Mon	Day	Jday
2006	5	1	486	2007	5	7	493	2008	4	15	471	2009	5	7	493	2010	4	12	468
2006	5	4	489	2007	5	10	496	2008	4	16	472					2010	4	15	471
								2008	4	17	473								
								2008	4	21	477								
								2008	4	24	480								
								2008	4	28	484								
								2008	5	1	487								
								2008	5	5	491								
								2008	5	8	494								
								2008	5	12	498								
								2008	5	15	501								

Winter 2011				Winter 2011 (cont.)				Winter 2011 (cont.)			
Year	Mon	Day	Jday	Year	Mon	Day	Jday	Year	Mon	Day	Jday
2010	12	2	336	2011	1	12	377	2011	2	12	408
2010	12	7	341	2011	1	13	378	2011	2	13	409
2010	12	9	343	2011	1	14	379	2011	2	14	410
2010	12	14	348	2011	1	15	380	2011	2	15	411
2010	12	16	350	2011	1	16	381	2011	2	16	412
2010	12	17	351	2011	1	17	382	2011	2	17	413
2010	12	18	352	2011	1	18	383	2011	2	18	414
2010	12	19	353	2011	1	19	384	2011	2	19	415
2010	12	20	354	2011	1	20	385	2011	2	20	416
2010	12	21	355	2011	1	21	386	2011	2	21	417
2010	12	22	356	2011	1	22	387	2011	2	22	418
2010	12	23	357	2011	1	23	388	2011	2	23	419
2010	12	24	358	2011	1	24	389	2011	2	24	420
2010	12	25	359	2011	1	25	390	2011	2	25	421
2010	12	26	360	2011	1	26	391	2011	2	26	422
2010	12	27	361	2011	1	27	392	2011	2	27	423
2010	12	28	362	2011	1	28	393	2011	2	28	424
2010	12	29	363	2011	1	29	394	2011	3	1	425
2010	12	30	364	2011	1	30	395	2011	3	2	426
2010	12	31	365	2011	1	31	396	2011	3	3	427
2011	1	1	366	2011	2	1	397	2011	3	4	428
2011	1	2	367	2011	2	2	398	2011	3	5	429
2011	1	3	368	2011	2	3	399	2011	3	6	430
2011	1	4	369	2011	2	4	400	2011	3	7	431
2011	1	5	370	2011	2	5	401	2011	3	8	432
2011	1	6	371	2011	2	6	402	2011	3	9	433
2011	1	7	372	2011	2	7	403	2011	3	10	434
2011	1	8	373	2011	2	8	404	2011	3	11	435
2011	1	9	374	2011	2	9	405	2011	3	12	436
2011	1	10	375	2011	2	10	406	2011	3	13	437
2011	1	11	376	2011	2	11	407	2011	3	14	438

Jday is the Julian Date.
Shading indicates dates that were adjusted one day earlier than downloaded from NIC.

Table 2. Distribution of ice chart dates by winter season

Winter 2011 (cont.)				Winter 2011 (cont.)				Winter 2011 (cont.)			
Year	Mon	Day	Jday	Year	Mon	Day	Jday	Year	Mon	Day	Jday
2011	3	15	439	2011	4	1	456	2011	5	2	487
2011	3	16	440	2011	4	2	457	2011	5	3	488
2011	3	17	441	2011	4	3	458	2011	5	4	489
2011	3	18	442	2011	4	4	459	2011	5	5	490
2011	3	19	443	2011	4	5	460	2011	5	6	491
2011	3	20	444	2011	4	6	461	2011	5	9	494
2011	3	21	445	2011	4	7	462	2011	5	10	495
2011	3	22	446	2011	4	8	463	2011	5	11	496
2011	3	23	447	2011	4	9	464	2011	5	12	497
2011	3	24	448	2011	4	10	465	2011	5	13	498
2011	3	25	449	2011	4	11	466				
2011	3	26	450	2011	4	12	467				
2011	3	27	451	2011	4	13	468				
2011	3	28	452	2011	4	14	469				
2011	3	29	453	2011	4	15	470				
2011	3	30	454	2011	4	16	471				
2011	3	31	455	2011	4	17	472				
				2011	4	18	473				
				2011	4	19	474				
				2011	4	20	475				
				2011	4	21	476				
				2011	4	22	477				
				2011	4	23	478				
				2011	4	24	479				
				2011	4	25	480				
				2011	4	26	481				
				2011	4	27	482				
				2011	4	28	483				
				2011	4	29	484				
				2011	4	30	485				
				2011	5	1	486				

During the 2007 season, 23 ice charts were given in the 510×516 pixel grid, and 23 ice charts were in the 1024×1024 pixel grid. Software was developed at GLERL to transpose the 510×516 grid ASCII files to the 1024×1024 grid, see Appendix A-1. A comparison of lake-averaged ice cover for the 1024×1024 grid and 510×516 grid for winter 2007 (23 ice charts) is given in Appendix A-2. There is a bias for slightly greater lake-averaged ice cover for the 510×516 grids, but as seen in Appendix A-2, the maximum differences are 2%, and differences are less than 2% in most cases.

3.2 File Structure, Record format, Ice Codes, and File Names

The first six records of each ASCII grid file contain header information in the following order: 1) the number of columns, 2) number of rows, 3) xllcorner, the X coordinate (longitude) of the lower-left corner of the grid, expressed in meters from a reference meridian, 4) yllcorner, the Y coordinate (latitude) of the lower-left corner of the grid expressed in meters from the equator, 5) the cell size in meters, and 6) the code for no data (-9999). Records 7 through 516 (for the 2.55 km grids), 1030 (for the 1.275 km grids) contain the ice concentration data in fixed I3 format. Ice concentration values are 0, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, and 100 and have units of percent. Land grid cells have a code of -1. File names encode the year (four digits), month (two digits), and day (two digits) of the ASCII grid and are proceeded with a "g" for Great Lakes and have a file extension of ".ct", indicating total ice concentration. As an example, the file for December 2, 2004 is given as "g20041202.ct".

4. QUALITY CONTROL PROCESSING

4.1 Ice Codes and Land Mask

The NIC ice codes on the ASCII grid files were converted to GLERL's ice concentration codes and then processed through GLERL's land mask, Appendix A-3, to produce a file with ice concentration codes and a consistent set of over-water grid cells. Recall that for winter 2006, NIC still produced 510×516 ASCII grids, so the old GLERL land mask (GLmask2.txt) was applied to these data to be consistent with the NOAA Great Lakes ice atlas data from 1973 to 2005. GLERL developed a new land mask for the 1024×1024 grid (for winters 2007-2011) based on the NOAA Great Lakes CoastWatch land mask to be consistent with grid data produced by the GLERL CoastWatch node. Applying the GLERL land mask, the old 510×516 mask for winter 2006 and the new 1024×1024 mask for winters from 2007 forward, resulted in a number of over-land grid cells on the NIC ASCII file being over-water grid cells in the GLERL ASCII file. These grid cells were given a code for missing data [-99], and software was written to estimate the ice concentration for these cells using over-water cells in the proximity of the missing data cells. These inconsistencies are due to minor differences in the NIC and GLERL [raster] shoreline in the NIC and GLERL ASCII files. Software similar to that given in Appendix 1 (see "apply the cw mask to standardize land and water grid cells" in program tran5.for) was developed to fit the NIC 1024×1024 ASCII grid data to GLERL's 1024×1024 land mask, and a computer program similar to fillx07.for in Appendix 1 was used to estimate ice cover concentration for over water grid cells with -99 codes.

A count of the number of grid cells with a code of -99 was calculated for each ASCII grid file after the land mask was applied. The ASCII file was compared to the original NIC graphic file. If the number of cells with a code of -99 were small, corrections were applied to the GLERL version of the ASCII file in a text editor. An example of this occurred on the ASCII file for December 8, 2009 where a small area on Lake Erie at the head of Long Point was coded 0% ice cover in the ASCII file, and the NIC graphic file indicated it should have been 100% ice cover.

If there were a large number of cells with a code of -99, that file was not included for further analysis. This was a relatively rare occurrence. In some cases, the NIC was informed of a questionable raw data file, and they provided a corrected version of the ASCII file. An example of this occurred for a polygon in Lake Huron for January 22, 2007 that was coded 30% ice cover, while it should have been 0% ice cover. The NIC provided a corrected version of that ASCII grid.

4.2 Ice Chart Dates

Spatial distribution patterns of ice concentration were compared between graphic files produced on the NIC web site and GLERL graphic files produced from NIC ASCII files downloaded from the NIC web site. The objective of this comparison was to see if the NIC Graphic and NIC ASCII file had the same date for the same spatial ice cover patterns. Dates were not always the same for the same spatial patterns. When dates were different, the graphic file date (which was always a day earlier than the ASCII grid file date) was used to correct the date on the ASCII file. The rationale for making that adjustment is that since the graphic file existed a day earlier, it is likely that the ASCII grid file, which is a raster product produced from ARC/GIS coverage, was created the next day. Lending credence to this rationale is the fact that the Canadian Ice Service (CIS) and NIC each produced one ice chart each week during the winter and exchange data during the season in near real-time. The CIS ice chart file is used by NIC to produce special products such as the ASCII grid file for GLERL's use and different products for other users. Thus, it is likely that sometimes the CIS ice chart vector coverage is converted to ASCII raster grid coverage a day after they are received at NIC from CIS. The changed dates on ASCII grid files are summarized, indicated by shading, in Table 2. Note that no changes were made for winters 2006, 2007, and 2011. In winter 2011, there were 12 cases when the NIC ASCII file dates were 1 day later than the NIC graphic files, Table 3. The frequency of 1-day difference in 10 of these 12 cases occurred every 7th day, indicating that it was CIS data. However, it was not possible to adjust the dates on these 12 NIC ASCII grids, because there were already other NIC ASCII grid files on these dates. The reason for this is not known at this time but may be related to the NIC production of ice charts each day instead of twice per week as was the case in other winters.

Table 3. Winter 2011 similar ice cover patterns	
NIC ASCII	NIC Graph
Dec. 28	Dec. 27
Jan. 04	Jan. 03
Jan. 06	Jan. 05
Jan. 11	4an. 10
Jan. 18	Jan. 17
Jan. 25	Jan. 24
Feb. 01	Jan. 31
Feb. 08	Feb. 07
Feb. 15	Feb. 14
Feb. 22	Feb. 21
Mar. 01	Feb. 28
Mar. 08	Mar. 07

5. ArcGIS FEATURE CLASSES

5.1 Preprocessing

In order to complete the update of the Great Lakes ice atlas, graphic images (.jpg files) and GIS feature classes were created for all 389 ice charts for winters 2006 through 2011. In addition, since feature classes (also known as shapefiles) were never produced for the period 2003-2005 (Assel 2005), those 143 grid files also needed to be converted to complete the climatology for 1973-2011. It should be noted that the 1973-2002 original Great Lakes ice atlas included products that were based on different ice attribute files such as ice form and ice age. The 2003-2011 additions to the ice atlas are based on a single ASCII grid file from the NIC, total ice concentration. For the 2003-2005 ASCII grid files, only 'observed data' files for total ice concentration ending with '2.ct' were used from the ftp download site: http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-135/Appendix2/DailyGrids

The first step in the process was to add the geographic location to each of the ASCII grid ice concentration values. This was accomplished by one of three IDL programs, depending on the year, since the formats of the ASCII grids are somewhat different.

ASCII grid	IDL conversion program
2003-2005	LatLon.pro
2006	Cwmap_auto.pro
2007-2011	Cwmap1024_auto.pro

For the 2003-2005 files, the latitude and longitude are read in from a file (Assel 2005). For all other input files, a subroutine is called that associates each grid pixel with its corresponding latitude and longitude coordinates. All of these programs were designed to process a year of ASCII grid files at a time. Once the ice concentration values were associated with location coordinates, they were ready to be brought into ArcGIS. The IDL program, Cwmap1024_auto.pro is found in Appendix A-4.

5.2 GIS Processing

Each file was first imported into Excel and saved as a comma-delimited (.csv) file in order to be imported to ArcView 9.2 (later 10.0). Files were loaded, geographic coordinates set (GCS North American 1983), land points removed, and finally saved as feature classes (.shp). Symbology was set to match the previous ice atlas .e00 files as closely as possible. Once the feature class file was complete, the Great Lakes ice concentration map was exported as a graphic image (.jpg) file. ArcModelBuilder was used to semi-automate this process. Feature classes (.shp) and graphic image files (.jpg) are zipped together by winter season.

6. DATA AVAILABILITY

The data is available either for an individual winter season or for all winter seasons together. Instructions for obtaining data are on the next page. You can also find this data on the GLERL ice cover webpage: http://www.glerl.noaa.gov/data/pgs/glice/glice.html. This Technical Memorandum is available at http://www.glerl.noaa.gov/ftp/publications/tech_reports/glerl-155/.

Individual Winter Seasons. A total of 582 ice charts are available in ASCII grid files and in ArcGIS feature classes. The data are arranged by winter season from 2003 through 2011. Note that winters 2003-2006 are in the 510×516 grid format, and winters 2007 through 2011 are in the 1024×1024 grid format.

Each winter season contains the following files in Zip compression:
1) Graphic files of total ice concentration
2) ASCII grid files
3) ArcGIS feature classes

An example for winter 2009 is given below.

To view ice chart data for a winter season, place cursor on it and click.

2003   2004   2005

2006   2007   2008

2009   2010   2011

Period of Record. For those users who want a single zipped file for all winters, there is grid2003-2011.zip for ASCII grids and gis2003-2011.zip for ArcGIS feature classes.

ICE Charts – 2009 Winter
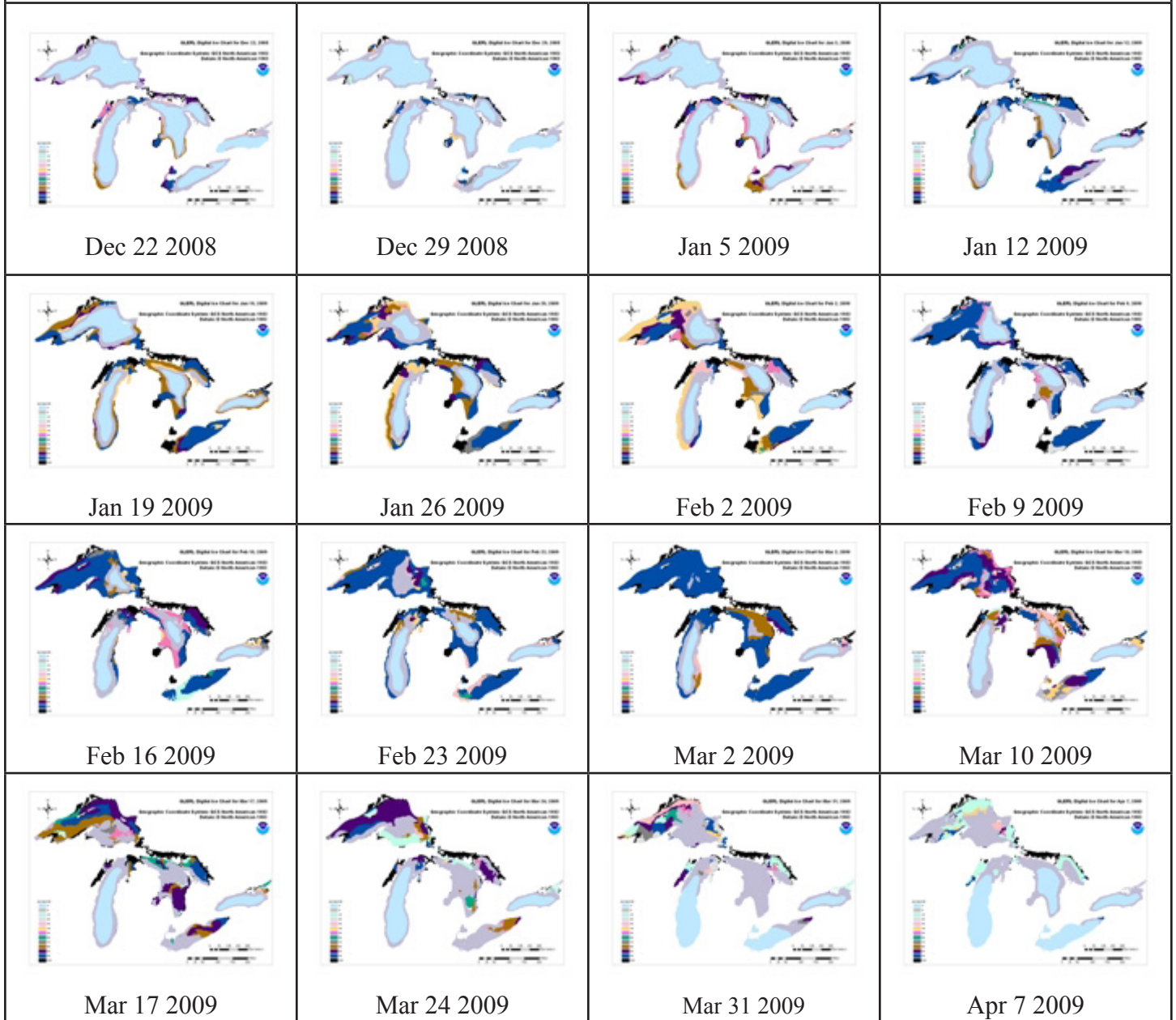
Click on thumbnails for larger images [note not all charts for 2009 are included in this example]
< back to winter season selection page

For 2009 winter data to be used with ArcGIS software, download gis2009.zip (32,260 KB)
For 2009 winter ASCII files, download grid2009.zip (1,156 KB)
For 2009 winter ice chart images, download jpg2009.zip (8,772 KB)

Dec 22 2008	Dec 29 2008	Jan 5 2009	Jan 12 2009
Jan 19 2009	Jan 26 2009	Feb 2 2009	Feb 9 2009
Feb 16 2009	Feb 23 2009	Mar 2 2009	Mar 10 2009
Mar 17 2009	Mar 24 2009	Mar 31 2009	Apr 7 2009

7. THE ANALYSIS USING THE UPDATED DATASET 1973-2011

7.1 Seasonal cycle

The spatial long-term (1973-2002) mean annual maximum ice cover in the Great Lakes was constructed using this dataset (Figure 1). The seasonal ice cover cycle (Figures 2-3) is computed based on the 1973-2011 data for the six lakes. The typical seasonal ice cycle of the Great Lakes consists of an initial formation (ice onset) period, followed by a growing period in which the annual maximum areal extent is reached, then a melting (break-up) period. The typical ice cycle has an ice-on date on all lakes occurring in December. The growth of ice cover is remarkably similar in all of the Great Lakes. Figure 2 also shows the progression of maximum ice cover for each lake.
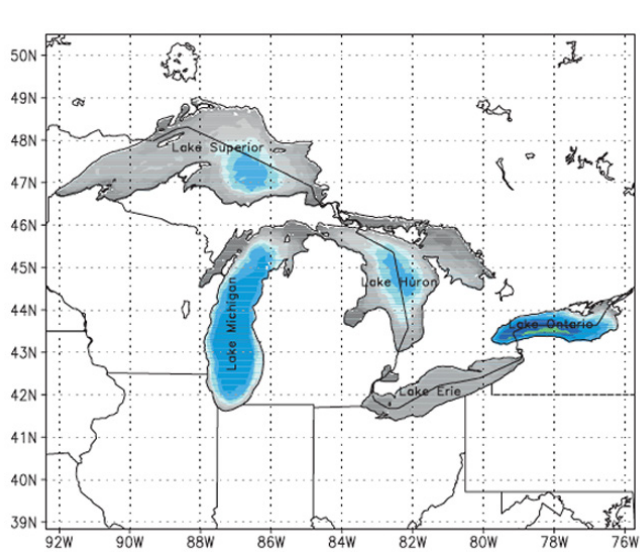

Figure 1. Long-term (1973-2002) mean annual maximum ice cover (in percent) in the Great Lakes. Note that ice cover (or concentration) ranges from 0% (ice free) to 100% (complete ice cover). (from Bai et al. 2011).
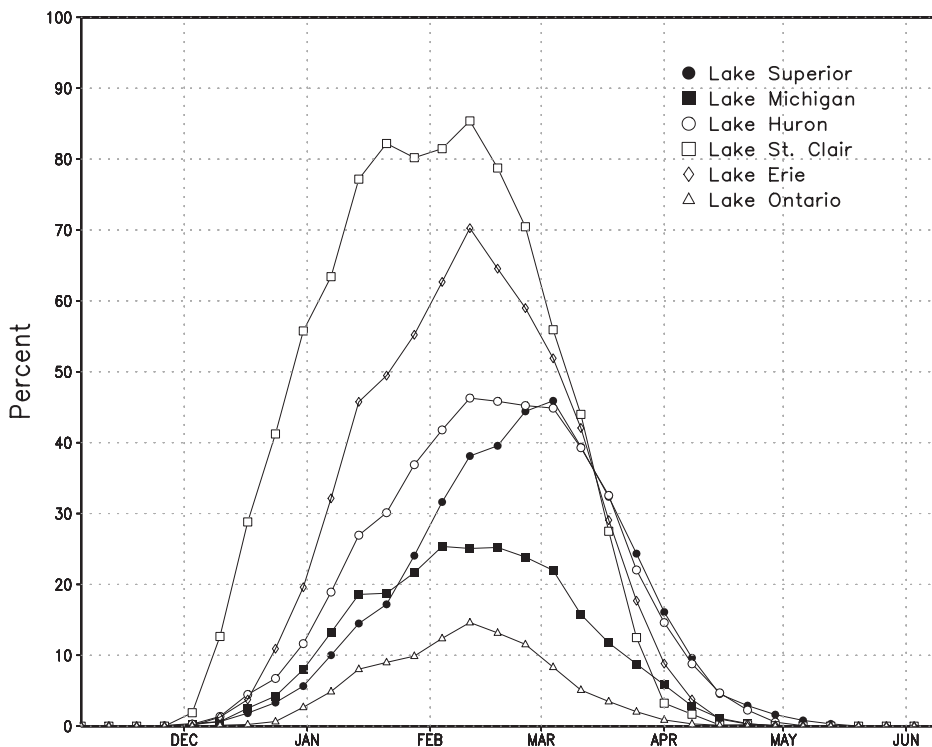

Figure 2. The NIC twice-weekly climatology of ice cover (in percent) in the Great Lakes, averaged from the period 1973-2011.
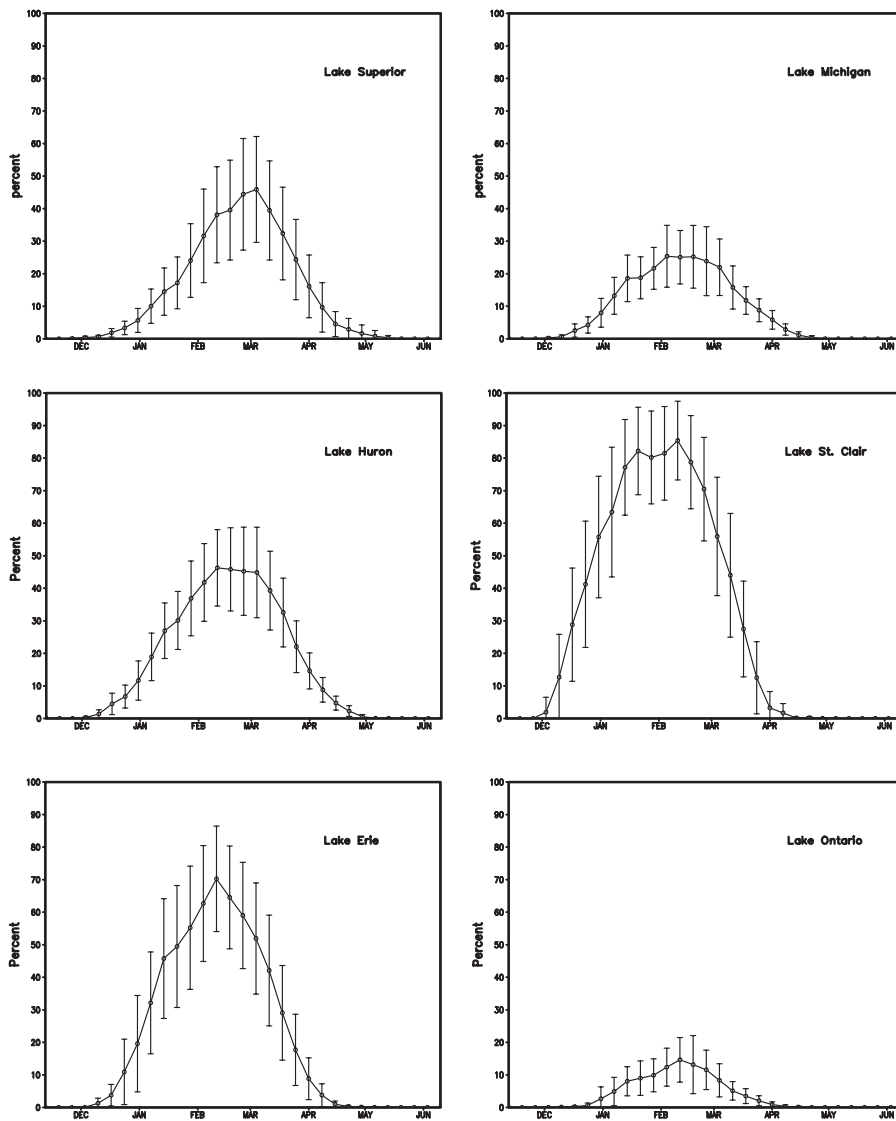
15

Figure 3. Variation of weekly ice coverage (in percent) of the six lakes for the period 1973-2011 with one standard deviation (SD) by the vertical bars.

7.2 Variations

The corresponding weekly variations, defined by standard deviations (SDs) of annual ice cover, are also shown in Figure 3. The months with the largest SDs are those most sensitive to atmospheric forcing, and the records with large SDs are the periods for better detecting interannual and decadal variability. One unique feature of Great Lakes ice cover, in contrast to Arctic sea ice cover (Wang and Ikeda 2001), is that the SDs are equivalent or even larger in magnitude than the means in the deep-water lakes, while SDs of sea ice are much smaller than the means in the Arctic Ocean (Wang and Ikeda 2001). This indicates that: 1) the natural variability of lake ice cover due to internal climate forcing is large (Wang et al. 2010a); and, 2) the predictability of lake ice cover using both statistical and numerical models is generally poor, particularly for interannual time scales. For example, Lake Ontario has the largest SDs compared to its mean, while Lake St. Clair has the smallest SDs. This implies that ice cover in Lake St. Clair has the best predictability, while ice cover in Lake Ontario has the poorest predictability among all the lakes, although the overall predictability in all lakes is poor.

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The reason for the poor overall predictability of ice cover is that the internal variability of natural climate patterns such as ENSO and AO/NAO are poorly predicted (Wang et al. 2010a, 2012). Bai et al. (2010, 2011, 2012) revealed that both ENSO and AO/NAO have impacts on lake ice; nevertheless, none of them dominates the Great Lakes. Using both ENSO and AO/NAO indices, lake ice can be projected on an intraseasonal time scale, but has poor predictability on the interannual time scales (from year to year). Thus, short-term numerical prediction based on short-term weather prediction is an alternative to provide relatively accurate prediction of lake ice on synoptic time scales (Wang et al. 2010b).

7.3 Interannual variability

Time series of weekly percent ice cover for all six lakes for the period 1973-2011 have been constructed (Figure 4), defined as the percentage of the total lake area that is covered by ice (Wang et al. 1994). All lakes have strong interannual variability of ice cover. However, there are two types of regional features: deep water and shallow water lakes. In the shallow water lakes such as Lakes St. Clair (3 m on average) and Erie (19 m on average), there is almost complete ice cover in winter except in 2005 for St. Clair, and 1983, 1991, 1998, 2002, 2005, 2006, and 2010 for Lake Erie. This indicates that using only lake ice area (in both percentage and square kilometers) is not sufficient to detect the climate signals in Lakes St. Clair and Erie, since the ice area is constrained by the bathymetry, the so-called boundary constraint (Wang et al. 1994). Under the boundary constraint, even though the ice area no long increases, ice thickness can still increase in winter. Thus, lake ice thickness must be used to study lake ice in response to a changing climate. However, in the deep-water lakes (Superior: 148 m; Huron: 59 m; and Ontario: 85 m), ice cover can be used to detect climate signals, since ice rarely completely covers the lakes. On Lake Erie, the least ice cover was found in 1983, 1991, and 1998, spaced by 7-8 years, but more frequently since 1998 with a period of about 3-4 years. This implies that interannual variability of the climate patterns tends to be greater in the Great Lakes in the past decade. In the deep-water lakes, it is possible to detect climate signals using the ice cover area, since the boundary constraint is weak.

To investigate interannual variability, the time series of annual mean lake ice coverage for each lake (Figure 4) is calculated by averaging over the ice season from the original data (Figure 4). There is large interannual variability with temporal correspondence among all the lakes, implying that the major response of lake ice to the climate forcing is basically uniform over the Great Lakes, since the spatial scale of the Great Lakes is small compared to the teleconnection patterns excited by phenomena such as ENSO and AO/NAO.

7.4 Long-term trend

Ice cover on the Great Lakes has been declining since 1973. Figure 4 and Table 4 show the linear trends for the six lakes. The linear trend was estimated using the least squares regression (LSR). The linear equation is in the form: x=a+bt, where x is the ice cover (in %), t is the year starting in 1973, a is the x-intercept constant (the value of x for t=0 (i.e.,1973), and b is the slope of the line (namely, the rate of change in x with a time increment of t).

Winter mean ice cover in all lakes shows a significant negative trend (Figure 5), indicating that the ice extent in the Great Lakes has been decreasing since the 1970s. The negative trends vary from lake to lake (-0.56%/yr to -1.96 %/yr, Table 4). Lake Superior has the largest negative trend (-1.96 %/yr), Lakes Ontario and Michigan place second (~-1.6%/yr), and Lakes Erie and St. Clair have the smallest negative trend: -0.74%/yr and -0.56%/yr, respectively. This translates to the total loss of winter lake ice coverage over the entire 39-year record (from 1973-2011) relative to 1973 in Table 4 (last row), which varies
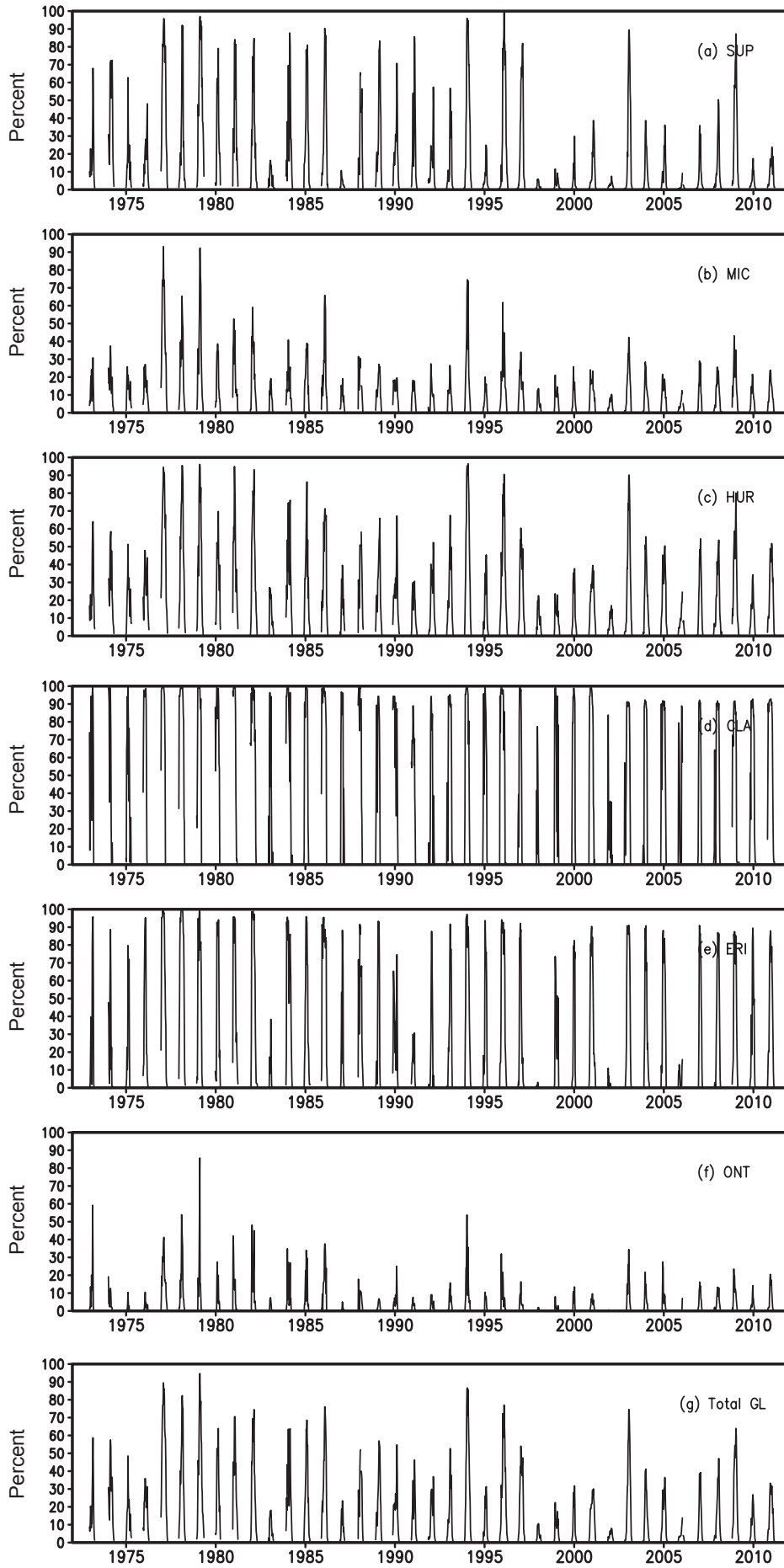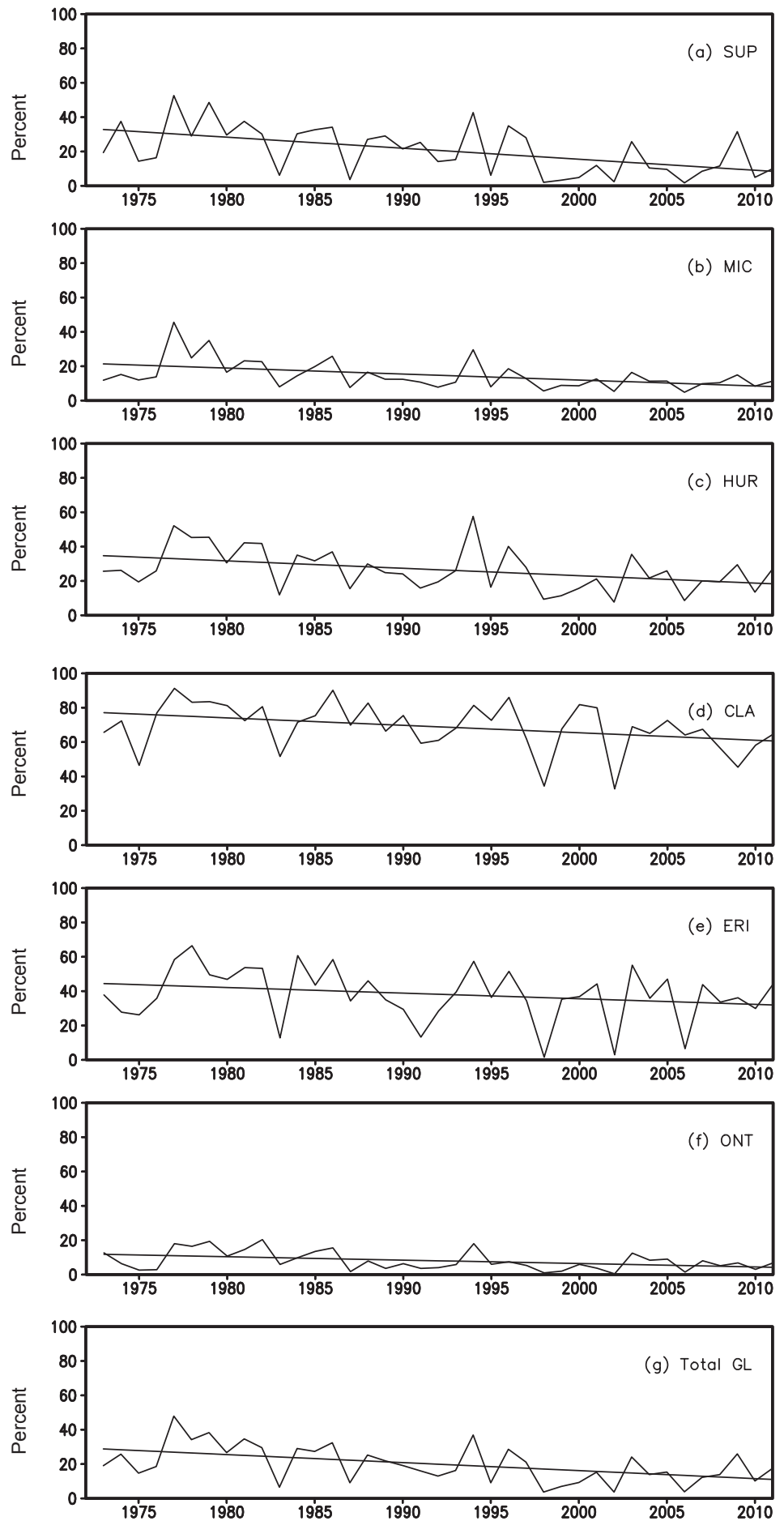
Figure 4. Twice weekly time series of ice cover (in percent) of all six lakes (a-f) and total Great Lakes (g) for the period 1973-2011.

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Figure 5. Winter mean lake ice cover (in percent) of all six lakes (a-f) and total Great Lakes ice cover (g) for the period 1973-2011. The linear lines are the trend in annual lake ice coverage calculated from the least squares fit method.

from 22% in Lake St Clair to 76% in Lake Superior. The total loss for overall Great Lakes ice coverage is 63% relative to the 1973 value. Another metric of loss of seasonal average ice cover over the 1973-2011 winters is the difference (1973 minus 2011) in the regression values for 1973 and 2011. The loss in seasonal average ice cover from 1973 to 2011 using this metric is 24.4% for Lake Superior, 12.9% for Lake Michigan, 15.5% for Lake Huron, 15.2% for Lake St. Clair, 11.1% for Lake Erie, 6.5% for Lake Ontario, and 14.9% for the entire Great Lakes basin.

Note that the trends calculated within a specific period of time such as 1973-2011 can only be applicable to the same period, and cannot be extrapolated to the future and back to the past. It should not be interpolated to a period shorter than the time series of the data from which the trends are derived, since there are decadal and multi-decadal changes in lake ice cover.

Table 4. Trends in winter lake ice coverage (in %) calculated by linear least squares fit for the period 1973-2011 (see text for detail). In row 2, a is the intercept constant (the value in year 1973) (in %); in row 3, b is the slope of the line (namely, the rate of change in ice area with time, % per year). Row 4 defines relative trend in winter lake ice coverage (% per year) = (b/ a) x 100%. Row 5 is the total loss of winter lake ice coverage over the entire 39-year record (from 1973 to 2011) relative to the 1973 value.

	Superior	Michigan	Huron	St. Clair	Erie	Ontario	Total GL
a	32.822	21.362	34.717	77.099	44.405	11.784	28.786
b	-0.642	-0.348	-0.431	-0.433	-0.327	-0.198	-0.467
b/a*100%	-1.955	-1.629	-1.242	-0.562	-0.737	-1.679	-1.622
Total loss (%)	-76	-63	-48	-22	-29	-65	-63

To search factors responsible for the lake ice trend, the winter surface air temperature (SAT) trend over the Northern Hemisphere was calculated for the period 1973-2010 (Figure 6). The SAT trend over the Great Lakes ranges from ~0.4 ℃ per decade over the lower lakes to ~0.6 ℃ per decade over the upper lakes, with Lake Superior being the highest (0.6 ℃ per decade). This is consistent with the upward trend of Lake Superior water temperature (Austin and Colman 2007). They found that summer (July–September) surface water temperatures have increased approximately 2.5°C over the period 1979–2006, significantly higher than regional atmospheric warming. This excessive warming of lake water temperature relative to the local surface air temperature has caused a positive ice/water albedo feedback (Wang et al. 2005) due to the declining ice cover (Austin and Colman 2007).

7.5 Periodicity

We further examined the spectral characteristics of the 38-year time series of the six lakes (Figure 7). The main periods are ~8 years and 3-5 years. Lakes Michigan, Huron, St. Clair, and Erie have two periods: 8 and 3.8 years. The former may be related to AO/NAO, and the latter may be related to ENSO, since both ENSO and AO have impacts on Great Lakes ice cover (Bai et al. 2010, 2011); and the AO/NAO has significant decadal to quasi-decadal time scales (7-8 years) (Wang et al. 1994; Mysak et al. 1996; Wang and Ikeda 2001; Wang et al. 2005), while ENSO basically possesses strong interannual time scales of 3-5 years.
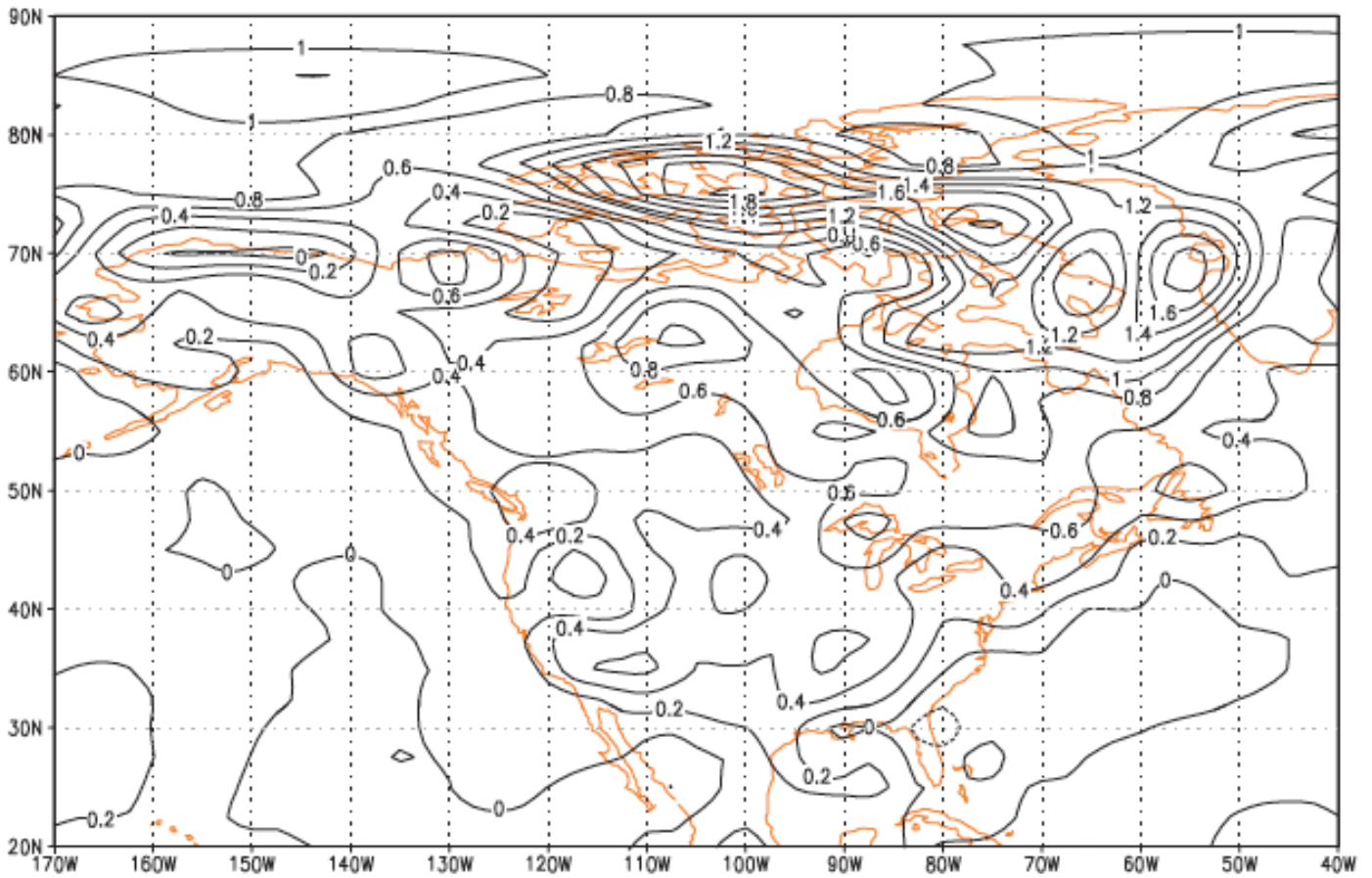
Figure 6. Winter surface air temperature (SAT) trend (°C per decade) for the period 1973-2010, calculated using the least squares fit. (from Wang et al. 2012)
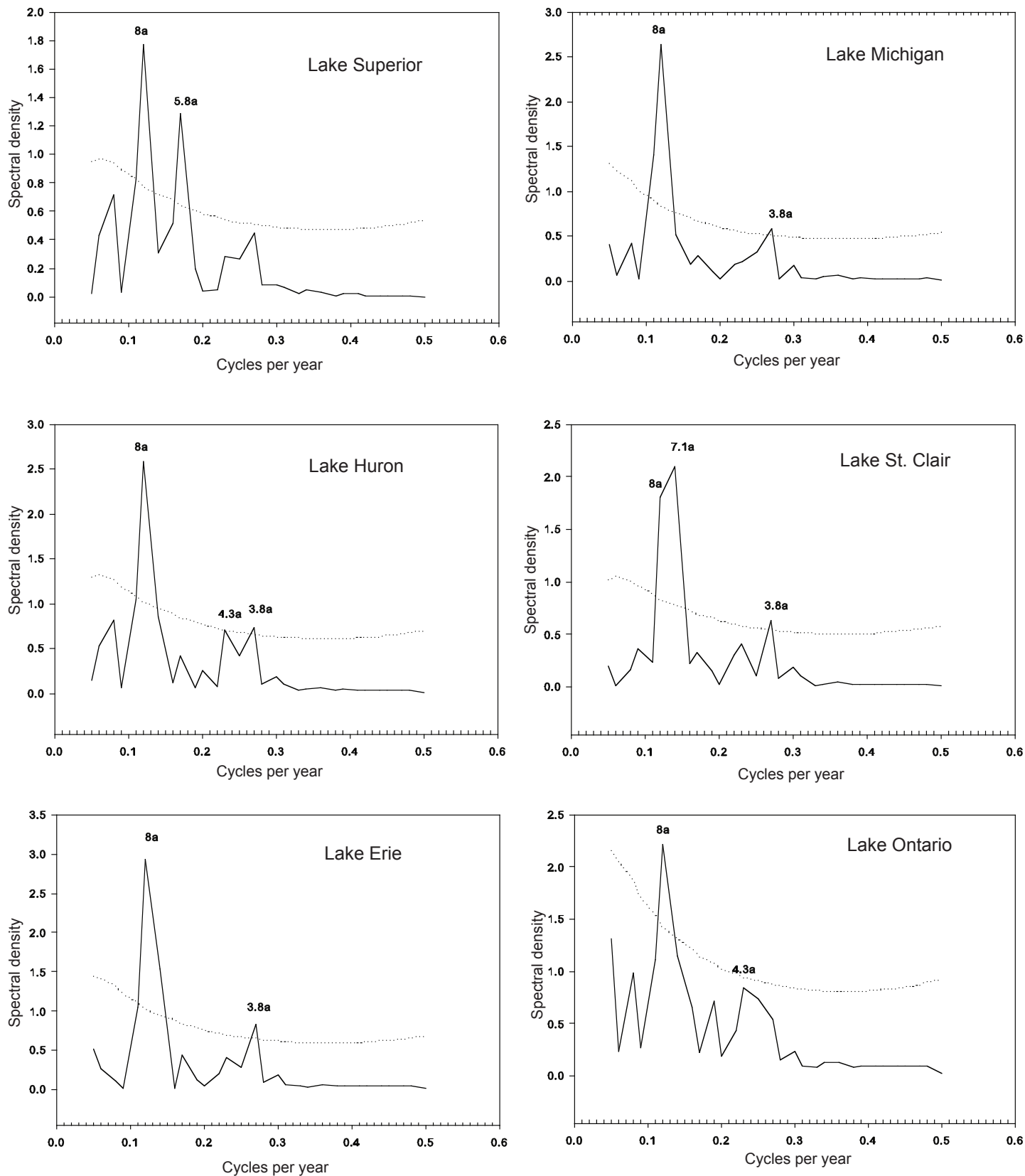
Figure 7. Spectral analysis of lake ice cover anomalies in all six lakes. The dotted curves are the 95% significance level. The peaks are marked with the corresponding periods in years.

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9. ACKNOWLEDGEMENTS

Appendix A-1

Software for converting 510×516 grids to 1024×1024 grids in CW format

Documentation of Standard Operating Procedure
1. Use the files created in fixed 516 record format with GLERL ice codes,
2. Run tran5.for, [function: transpose 510x516 array to 1024x1024 array].
3. Run the results of trand5.for through fillx07.for [function estimates the ice concentrations in cells with missing data].

```
c*************************************************************************
c  name tran5.for,  date  N0VEMBER 2010,  function to transpose 510x516 array to 1024x1024 array.
c FIRST transpose 510x516 to 1020x1032 array, NEXT transpose 1020x1032 array to 1024x1024 array,
c LAST,use CoastWatch [CW]  land mask to make standard land water grids for climatic analysis

     dimension ib(1020,1032),is(510,516),msk(1024,1024),ice(1024,1024)
     dimension ib2(1020,1032)
     character count(4)*30, inmap*20,outmap*15
c ib is the fine spatial resolution array
c is is the small low resolution array currently used in the NOAA ice Atlas
c msk is the CoastWatch land water mask array
c ice is the ib array with CW mask applied.
     data count/'mask and map both overwater',
    *'mask and map both land','mask land and map water',
    *'mask water and map land'/
     open(unit=1,file='tem07ctb', status='old')
     open(unit=2,file='tem07-1',status='old')
     open(unit=3,file='cw1024.txt',status='old')

c read in the cw mask of standardize land and water cells
     do i=1,1024
     read(3,12)(msk(i,j),j=1,1024)
     enddo
  12 format(1024i4)
c read in each of 23 maps
     do iouter=1,23
c read the input and output files
  29 format(a15)
 291 format(a20)
     read(1,291)inmap
     read(2,29)outmap
        open(unit=4,file=inmap,status='old')
        open(unit=6,file=outmap,status='unknown')
c set counters ict jct kct and Lct
     ict=0
     jct=0
     kct=0
     Lct=0
c fill in ib with missing data code
     do i=1,1020
     do j=1,1032
     ib(i,j)=-99
     enddo
     enddo
c read in the low resolution ice array
     do i=1,510
     read(4,10)(is(i,j),j=1,516)
     enddo
  10 format(516i3)
c fill ib with the data from array 'is'
     do i=1,510
     do j=1,516
     it=is(i,j)
     ib(i*2-1,J*2-1)=it
     ib(i*2-1,J*2)=it
     ib(i*2,j*2-1)=it
     ib(i*2,j*2)=it
     enddo
     enddo
c now shift ib (in ib2)
c************************
```

```
      nrows=7
      ncols=3
c************************
      do i=1,nrows
      do j=1,ncols
      ib2(i,j)=-1
      enddo
      enddo

      iend=1020-nrows
      jend=1032-ncols
      do i=1,iend
      do j=1,jend
      ik=ib(i,j)
      ib2(i+nrows,j+ncols)=ik
      enddo
      enddo
c apply the cw mask to standardize land and water grid cells
      do i=1,1024
      do j=1,1024
      ix=ib2(i,j)
      im=msk(i,j)
c if the mask is land then make ice array land
      if(im.eq.255)ice(i,j)=-1
c if the mask is water then test ib to see if it is land or water
c and set value of ice appropriately
      if(im.lt.255.and.ix.ge.0)ice(i,j)=ix
      if(im.lt.255.and.ix.eq.-1)ice(i,j)=-99
      if(im.lt.255.and.ix.lt.-1)ice(i,j)=-98
      if(im.lt.255.and.ix.lt.-1)print*,'error cell < -1 at grid',i,j
c mask and map both overwater
      if(im.lt.255.and.ix.ge.0)ict=ict+1
c mask and map both land
      if(im.eq.255.and.ix.eq.-1)jct=jct+1
c mask land and map water
      if(im.eq.255.and.ix.gt.-1)kct=kct+1
c mask water and map land
      if(im.lt.255.and.ix.eq.-1)Lct=Lct+1
  14  continue
      enddo
      enddo

  11  format(1032i3)
      do i=1,1024
      write(6,15)(ice(i,j),j=1,1024)
      enddo
c print out the counters
      if(iouter.eq.1)print51
      print52,inmap,outmap,ict,jct,kct,Lct, (ict+jct+kct+Lct),iouter
c this is end of outerdo
       enddo
  51  format(3x,
     *'infile      outfile      BOLA  BOWA  MLMPW  MWMPL TOTAL',
     *3x,'Map No.')
  52  format(1x,a20,1x,a15,2x,4(i6,1x),1x,i7,2x,i4)
  15  format(1024i3)
      end
```

```
c===================================================================
c modified from screen print statements for tran5.for
------------------------------------------------------------------------------------------------------
input file              out file           BOLA BOWA   MLMPW    MWMPL    TOTAL   Map
------------------------------------------------------------------------------------------------------
glgrd061204_2550.ctb glgrd061204.dat 147618 880500  19394     1064    1048576   1
glgrd061211_2550.ctb glgrd061211.dat 147618 880500  19394     1064    1048576   2
glgrd061218_2550.ctb glgrd061218.dat 147618 880500  19394     1064    1048576   3
glgrd061225_2550.ctb glgrd061225.dat 147618 880500  19394     1064    1048576   4
glgrd070101_2550.ctb glgrd070101.dat 147618 880500  19394     1064    1048576   5
glgrd070108_2550.ctb glgrd070108.dat 147618 880500  19394     1064    1048576   6
glgrd070115_2550.ctb glgrd070115.dat 147618 880500  19394     1064    1048576   7
glgrd070122_2550.ctb glgrd070122.dat 147618 880500  19394     1064    1048576   8
glgrd070129_2550.ctb glgrd070129.dat 147618 880500  19394     1064    1048576   9
glgrd070205_2550.ctb glgrd070205.dat 147618 880500  19394     1064    1048576   10
glgrd070212_2550.ctb glgrd070212.dat 147618 880500  19394     1064    1048576   11
glgrd070219_2550.ctb glgrd070219.dat 147618 880500  19394     1064    1048576   12
glgrd070226_2550.ctb glgrd070226.dat 147618 880500  19394     1064    1048576   13
glgrd070305_2550.ctb glgrd070305.dat 147618 880500  19394     1064    1048576   14
glgrd070312_2550.ctb glgrd070312.dat 147618 880500  19394     1064    1048576   15
glgrd070319_2550.ctb glgrd070319.dat 147618 880500  19394     1064    1048576   16
glgrd070326_2550.ctb glgrd070326.dat 147618 880500  19394     1064    1048576   17
glgrd070402_2550.ctb glgrd070402.dat 147618 880500  19394     1064    1048576   18
glgrd070409_2550.ctb glgrd070409.dat 147618 880500  19394     1064    1048576   19
glgrd070416_2550.ctb glgrd070416.dat 147618 880500  19394     1064    1048576   20
glgrd070423_2550.ctb glgrd070423.dat 147618 880500  19394     1064    1048576   21
glgrd070430_2550.ctb glgrd070430.dat 147618 880500  19394     1064    1048576   22
glgrd070507_2550.ctb glgrd070507.dat 147618 880500  19394     1064    1048576   23
------------------------------------------------------------------------------------------------------
```

BOLA = no. of CW base and lake map land cells agree
BOWA = no. of CW base and lake map water cells agree
MLMPA = no. of CW base land cells which are water cells on lake map
MWMPL = no. of CW base water cells which are land cells on lake map
TOTAL = total no. cells

```
c=================================================================================
c fillx07.for  NOVEMBER 2010
c function: estimate the ice concentrations for grid cells with missing data
c=================================================================================
c  code for cells with missing data is -99.
c Up to 30 iterations can be made to reduce the number of cells with missing data, missed by the previous iteration.
c A check will be made at the end of each iteration to count  the number of cells with missing data.

      character infi*15,outf*15,infis(23)*15,outfs(23)*15

      dimension ice(1024,1024),nice(1024,1024),isav(30,23),iter(30)
      dimension ifxr(21),ifxc(21)

      data ifxr/564,565,565,566,566,566,567,567,568,568,569,569,
     *570,570,570,571,571,571,572,572,573/

      data ifxc/1024,1024,1023,1022,1023,1024,1022,1023,1024,
     *1022,1024,1023,1024,1023,1022,1024,1023,1022,1023,1022,1022/

      open(unit=1,file='tem07-1',status='old')
      open(unit=2,file='tem07-2',status='old')
      open(unit=8,file='fillx07.out',status='unknown')

  10 format(a15)
  15 format(1024i3)

c the number of maps parameter has to be set each time
      num_maps=23

c read in the input and output file names
c**************************
      do imap=1,num_maps
c**************************
      read(1,10)infi
      infis(imap)=infi
      read(2,10)outf
      outfs(imap)=outf
      open(unit=3,file=infi,status='old')
      open(unit=7,file=outf,status='unknown')

c read in the data for one map
      do irow=1,1024
      read(3,15)(ice(irow,icol),icol=1,1024)
      enddo

c iterate through data 15 times
c nt = the number of times to estimate the nearest neighbor cell
      nt=3
      do itimes=1,nt
        iter(itimes)=itimes
c replace cells with missing data
      do irow=1,1024
      do ic=1,1024

c set the cell value in the new arrary equal to original cell vealue
        nice(irow,ic)=ice(irow,ic)
c if you have a land cell [code -1] do not interpolate
        if(nice(irow,ic).eq.-1)goto999

c next 4 ifs - if you are within 3 cells of edge of the array
c do not interpoate - as the grid search will produce
c bogus data because of the array dimension
        if(irow.lt.3)goto999
        if(irow.gt.1021)goto999
        if(ic.lt.3.)goto999
        if(ic.gt.1021)goto999

        if(ice(irow,ic).eq.-99)then
c here we estimate the value of the cell from the neighbor cells

              it2=ice(irow,ic-1)
              if(it2.ge.0)nice(irow,ic)=it2
```

```
if(nice(irow,ic).ge.0)goto998

it3=ice(irow,ic+1)
if(it3.ge.0)nice(irow,ic)=it3
if(nice(irow,ic).ge.0)goto998

it4=ice(irow+1,ic)
if(it4.ge.0)nice(irow,ic)=it4
if(nice(irow,ic).ge.0)goto998

it5=ice(irow-1,ic)
if(it5.ge.0)nice(irow,ic)=it5
if(nice(irow,ic).ge.0)goto998

it6=ice(irow-1,ic-1)
if(it6.gt.0)nice(irow,ic)=it6
if(nice(irow,ic).ge.0)goto998

it7=ice(irow-1,ic+1)
if(it7.ge.0)nice(irow,ic)=it7
if(nice(irow,ic).ge.0)goto998

it8=ice(irow+1,ic-1)
if(it8.ge.0)nice(irow,ic)=it8
if(nice(irow,ic).ge.0)goto998

it9=ice(irow+1,ic+1)
if(it9.ge.0)nice(irow,ic)=it9
if(nice(irow,ic).ge.0)goto998

it12=ice(irow,ic-2)
if(it12.ge.0)nice(irow,ic)=it12
if(nice(irow,ic).ge.0)goto998

it13=ice(irow,ic+2)
if(it13.ge.0)nice(irow,ic)=it13
if(nice(irow,ic).ge.0)goto998

it14=ice(irow+2,ic)
if(it14.ge.0)nice(irow,ic)=it14
if(nice(irow,ic).ge.0)goto998

it15=ice(irow-2,ic)
if(it15.ge.0)nice(irow,ic)=it15
if(nice(irow,ic).ge.0)goto998

it16=ice(irow-2,ic-2)
if(it16.gt.0)nice(irow,ic)=it16
if(nice(irow,ic).ge.0)goto998

it17=ice(irow-2,ic+2)
if(it17.ge.0)nice(irow,ic)=it17
if(nice(irow,ic).ge.0)goto998

it18=ice(irow+2,ic-2)
if(it18.ge.0)nice(irow,ic)=it18
if(nice(irow,ic).ge.0)goto998

it19=ice(irow+2,ic+2)
if(it19.ge.0)nice(irow,ic)=it19
if(nice(irow,ic).ge.0)goto998

it20=ice(irow,ic-3)
if(it20.ge.0)nice(irow,ic)=it20
if(nice(irow,ic).ge.0)goto998

it21=ice(irow,ic+3)
if(it21.ge.0)nice(irow,ic)=it21
```

```fortran
            if(nice(irow,ic).ge.0)goto998

            it22=ice(irow+3,ic)
            if(it22.ge.0)nice(irow,ic)=it22
            if(nice(irow,ic).ge.0)goto998

            it23=ice(irow-3,ic)
            if(it23.ge.0)nice(irow,ic)=it23
            if(nice(irow,ic).ge.0)goto998

            it24=ice(irow-3,ic-3)
            if(it24.gt.0)nice(irow,ic)=it24
            if(nice(irow,ic).ge.0)goto998

            it25=ice(irow-3,ic+3)
            if(it25.ge.0)nice(irow,ic)=it25
            if(nice(irow,ic).ge.0)goto998

            it26=ice(irow+3,ic-3)
            if(it26.ge.0)nice(irow,ic)=it26
            if(nice(irow,ic).ge.0)goto998

            it27=ice(irow+3,ic+3)
            if(it27.ge.0)nice(irow,ic)=it27
            if(nice(irow,ic).ge.0)goto998
          else
           nice(irow,ic)=ice(irow,ic)
          endif
  998 continue
c now for the median ice chart maps make the following estimates for
c noth east L. Ontario Bay of Quinte
     itont1=nice(588,958)
     itont2=nice(588,959)
     itont3=nice(589,956)
     itont4=nice(589,957)
     itont5=nice(590,955)
     itont6=nice(591,928)
     itont7=nice(592,926)
     itont8=nice(595,934)

     if(itont1.eq.-99.and.itont8.ne.-99)nice(588,957)=itont8
     if(itont2.eq.-99.and.itont8.ne.-99)nice(588,958)=itont8
     if(itont3.eq.-99.and.itont8.ne.-99)nice(589,955)=itont8
     if(itont4.eq.-99.and.itont8.ne.-99)nice(589,956)=itont8
     if(itont5.eq.-99.and.itont8.ne.-99)nice(590,954)=itont8
     if(itont6.eq.-99.and.itont8.ne.-99)nice(591,928)=itont8
     if(itont7.eq.-99.and.itont8.ne.-99)nice(592,926)=itont8
c now fill in data for one cell in Georgian Bay
     itg1=nice(531,787)
     itg2=nice(536,785)
     if(itg1.eq.-99.and.itg2.ne.-99)nice(531,787)=itg2
c now fill in data for 21 cells at west St. Lawrence River
     do kk=1,21
     itg3=ifxr(kk)
     itg4=ifxc(kk)
     istc=nice(itg3,itg4)
     istc2=nice(571,1017)
     if(istc.eq.-99.and.istc2.ne.-99)nice(itg3,itg4)=istc2
     enddo
  999 continue
        enddo
     enddo

c save a count of the No. of cells that have -99 (missing data)
       ict=0
     do km=1,1024
       do km2=1,1024
       item=nice(km,km2)
       if(item.eq.-99)ict=ict+1
       enddo
      enddo
      isav(itimes,imap)=ict
c save the results for the next iteration
```

30

```
      do KSA=1,1024
       do KSB=1,1024
        ice(ksa,ksb)=nice(ksa,ksb)
         enddo
        enddo
c this next do is for the itimes do loop
      enddo
c write out the results for one map
       do MM=1,1024
        write(7,15)(nice(mm,iicol),iicol=1,1024)
        enddo
c this next do is for all maps
      enddo
c print the number of cells that have -99 (missing data)
c on each ice chart for each iteration
      write(8,62)(iter(k),k=1,nt)
      print62,(iter(k),k=1,nt)
c************************
      do imap=1,num_maps
c************************
      print60,'completed map',imap,'inf=',infis(imap),'outf=',
     *outfs(imap), 'NO. of cell with -99 =',
     *(isav(itime,imap),itime=1,nt)
      write(8,60)'completed map',imap,'inf=',infis(imap),'outf=',
     *outfs(imap), 'NO. of cell with -99 =',
     *(isav(itime,imap),itime=1,nt)
      enddo
c234567
  62 format(78x,30(1x,i4))
  60 format(1x,a13,1x,i3,1x,a4,a15,2x,a5,a15,2x,a22,20(1x,i4))
      end
c====================================================================
c modified screen output from fillx07.for                    No. Iterations
c              input file           output file                 1  2  3
c completed map  1 inf=glgrd061204.dat  outf=glgrd061204.fil  NO. of cell with -99 =  11  1  0
c completed map  2 inf=glgrd061211.dat  outf=glgrd061211.fil  NO. of cell with -99 =  11  1  0
c completed map  3 inf=glgrd061218.dat  outf=glgrd061218.fil  NO. of cell with -99 =  10  0  0
c completed map  4 inf=glgrd061225.dat  outf=glgrd061225.fil  NO. of cell with -99 =   9  0  0
c completed map  5 inf=glgrd070101.dat  outf=glgrd070101.fil  NO. of cell with -99 =  10  1  0
c completed map  6 inf=glgrd070108.dat  outf=glgrd070108.fil  NO. of cell with -99 =  11  1  0
c completed map  7 inf=glgrd070115.dat  outf=glgrd070115.fil  NO. of cell with -99 =   7  0  0
c completed map  8 inf=glgrd070122.dat  outf=glgrd070122.fil  NO. of cell with -99 =   7  0  0
c completed map  9 inf=glgrd070129.dat  outf=glgrd070129.fil  NO. of cell with -99 =   7  0  0
c completed map 10 inf=glgrd070205.dat  outf=glgrd070205.fil  NO. of cell with -99 =   7  0  0
c completed map 11 inf=glgrd070212.dat  outf=glgrd070212.fil  NO. of cell with -99 =   7  0  0
c completed map 12 inf=glgrd070219.dat  outf=glgrd070219.fil  NO. of cell with -99 =   7  0  0
c completed map 13 inf=glgrd070226.dat  outf=glgrd070226.fil  NO. of cell with -99 =   7  0  0
c completed map 14 inf=glgrd070305.dat  outf=glgrd070305.fil  NO. of cell with -99 =   7  0  0
c completed map 15 inf=glgrd070312.dat  outf=glgrd070312.fil  NO. of cell with -99 =   7  0  0
c completed map 16 inf=glgrd070319.dat  outf=glgrd070319.fil  NO. of cell with -99 =   7  0  0
c completed map 17 inf=glgrd070326.dat  outf=glgrd070326.fil  NO. of cell with -99 =   7  0  0
c completed map 18 inf=glgrd070402.dat  outf=glgrd070402.fil  NO. of cell with -99 =   7  0  0
c completed map 19 inf=glgrd070409.dat  outf=glgrd070409.fil  NO. of cell with -99 =   8  1  0
c completed map 20 inf=glgrd070416.dat  outf=glgrd070416.fil  NO. of cell with -99 =  10  1  0
c completed map 21 inf=glgrd070423.dat  outf=glgrd070423.fil  NO. of cell with -99 =  10  1  0
c completed map 22 inf=glgrd070430.dat  outf=glgrd070430.fil  NO. of cell with -99 =  10  1  0
c completed map 23 inf=glgrd070507.dat  outf=glgrd070507.fil  NO. of cell with -99 =  11  1  0
c====================================================================
```

Comparison of lake averaged ice cover converted from 510×516 to 1024×1024 grid.
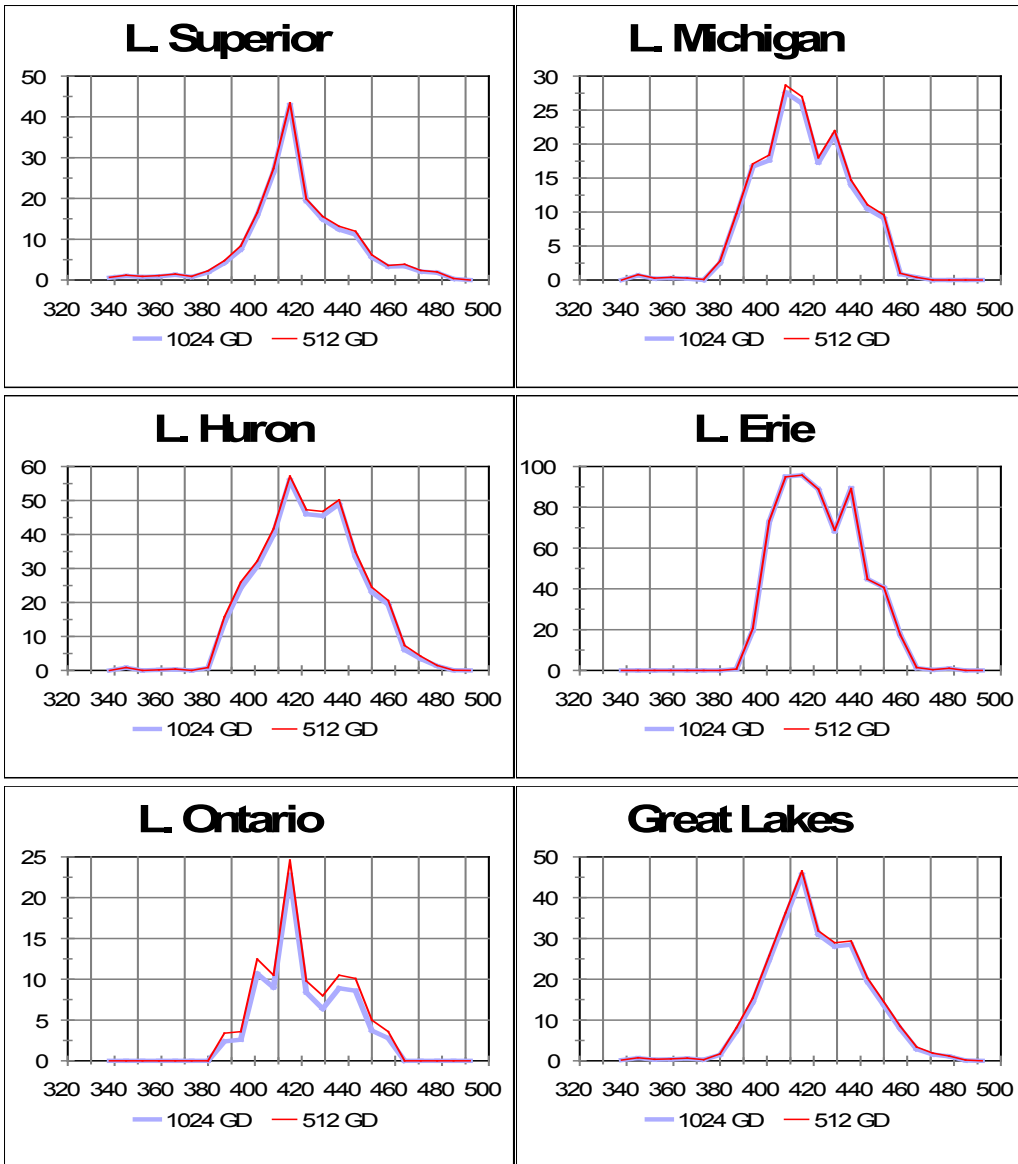
Lake averaged ice cover for 1024x1024 and 510x516 grid for winter 2007 (23 ice charts). Note the bias is for slightly greater lake averaged ice cover for 510x516 grid but as seen on next page differences are 2% or less in all cases. This is considered sufficiently accurate for climate studies.
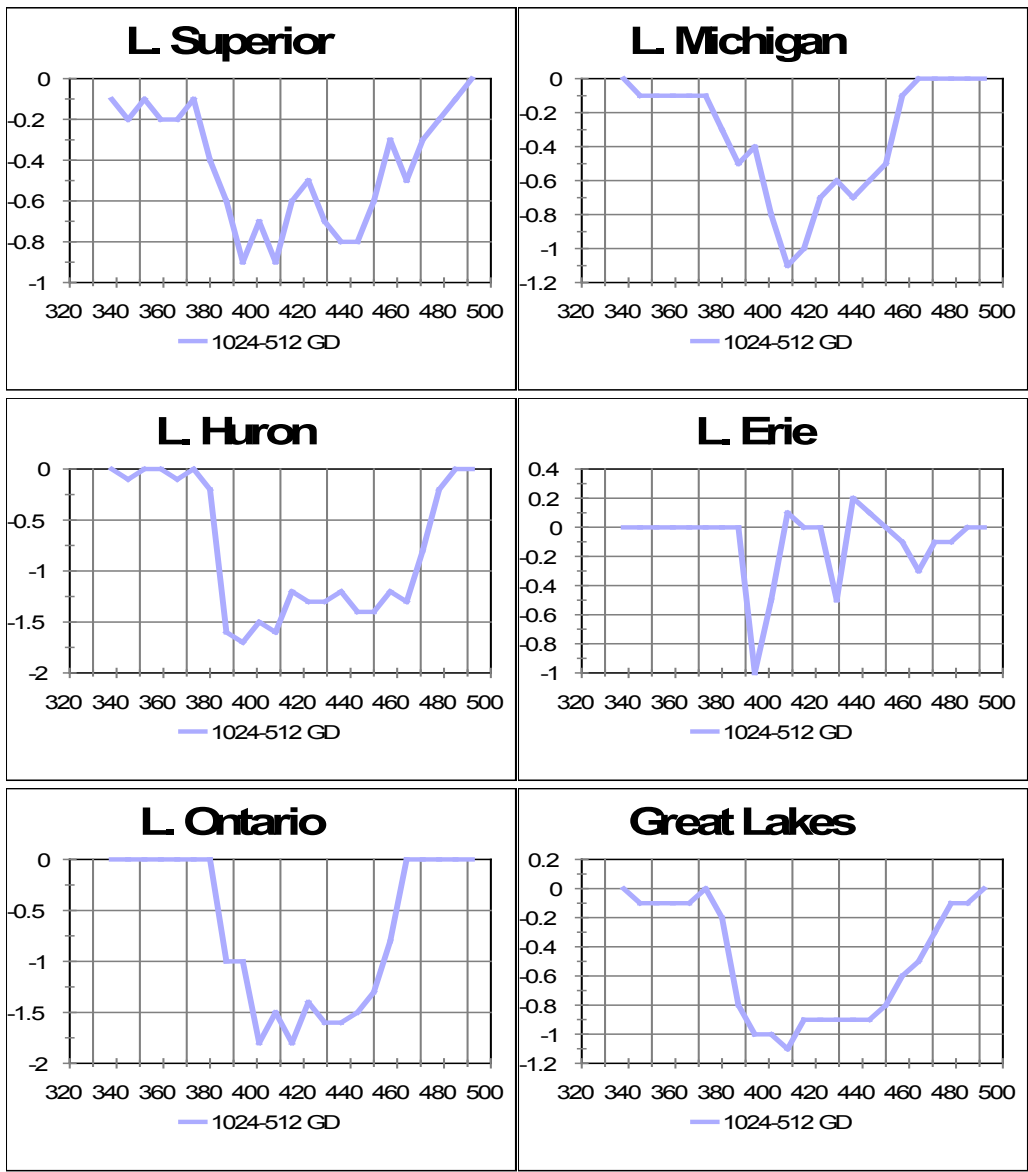
Differences of 1024 from 510×516 grid for winter 2007 (23 ice charts). Note differences are 2% or less in all cases. This is considered sufficiently accurate for climate studies.

Appendix A-3

Land mask applied to NIC ASCII files to create standard land-water grid cells

The land mask for the 510×516 grid. An ASCII land mask file is available by clicking on the following: GLmask2.txt. It is a fixed formatted text file with 510 records. Each record in that file has a format of 516 i1. Land grid cells have a code of 0 or 1, the grid cell codes for lakes and rivers are: Lake Superior = 4, Lake Michigan = 5, Lake Huron = 6, Lake Erie = 7, Lake St. Clair = 2, Lake Ontario = 8, St. Marys River = 9, Detroit River = 3.

The land mask for the 1024×1024 grid. An ASCII land mask file is available by clicking on CW1024a.txt.

File Structure

        Record Format (1024i4), 1024 records in this file

     Numeric codes for each grid cell by lake by region

         Lake Superior
01   Thunder Bay
02   Black Bay
03   Nipigon Bay
04   Western Lake Superior
05   Eastern Lake Superior
06   Whitefish Bay

         St Marys River
07   St Marys River North
26   St Marys River South

         Lake Michigan
11   Green Bay
12   Grand Traverse Bay
13   Northern Lake Michigan
14   Southern Lake Michigan

         Lake Huron
21   Georgian Bay
22   North Channel
23   Saginaw Bay
24   Northern Lake Huron
25   Southern Lake Huron

         Lake St. Clair
30   Lake St. Clair

<u>Detroit River</u>
31	Detroit River North
44	Detroit River South

<u>Lake Erie</u>
41	Western Lake Erie
42	Central Lake Erie
43	Eastern Lake Erie

<u>Lake Ontario</u>
51	Western Lake Ontario
52	Eastern Lake Ontario

-01	Western St. Lawrence River

255	Land

Appendix A-4

Software for adding geographic location to ice concentration values for conversion of ice grids to ArcGIS.

```
;------------------------------------------------------------------------------
pro cwmap1024_auto,ipx,jpx,lat,lon,conv
;------------------------------------------------------------------------
; Subroutine cwmap: Return pixel location, given latitude and longitude, or
;  latitude and longitude given pixel location within synoptic 1024x1024
;  CoastWatch image. (Approximate WGS-84 Mercator Projection - DJS 2007)


; Set conv to -1 for (lat, lon) to (ipx, jpx) conversion,
; anything else for inverse

slat  =  38.8744   ;  Southern latitude
wlon  = -92.4106   ;  Western longitude
elon  = -75.8690   ;  Eastern longitude

f1 = 0.99664  ; N-S scale adjustment for WGS-84

; Constants

alon0 = -wlon
a1    = 1023. / (!dtor * ( elon-wlon ) )
y0    = a1 * alog(tan (!dtor * (45.0 + slat / 2.) ))

; Calculate latitude and longitude if conv = -1, else calculate ipx and jpx

if(conv eq -1) then begin
 ipx=fix(a1*!dtor*(alon0-lon)+0.5)
 jpx=fix(f1*(a1*alog(tan(!dtor*(45.+lat/2.)))-y0)+0.5)
end else begin
 lat = 2.0 * ((( atan ( exp ( (jpx/f1 + y0) / a1) )) / !dtor) - 45.0)
 lon = -1.0*((ipx / (a1 * !dtor)) - alon0)
end


return
end
;----------------------------------------------------------------
;
; calculate lat and lon of ice concentration pixels
; this version is for the 1275m grid (2007 and later)

header=STRARR(1,6)
conc=intarr(1024,1024)
iceconc=intarr(1024,1024)
lat=fltarr(1024,1024)
lon=fltarr(1024,1024)
infile=""
outfile=""
dirstrng=""
datestrng=""

print,"Enter the absolute path of the directory containing the .ct files"
read,dirstrng
cd,dirstrng
file_conversion_index=0L
file_list_array = findfile("*.ct")
file_count = N_ELEMENTS(file_list_array)

for file_conversion_index=0,file_count-1 do begin
  numlines=0
  infile = file_list_array[file_conversion_index]
  openr,2,infile
  datestrng=strmid(infile,0,11); start w char 0, 11 chars long filename (2007)
  outfile=dirstrng + datestrng + '.ll'
  openw,1,outfile
  readf,2,header
  readf,2,conc
  iceconc = rotate(conc,7);flip the ice grid
  close,2
```

```
  close,1
  print,max(iceconc)
  print,min(iceconc)

  openw,1,outfile
  print,outfile
  printf,1,'        i       j       lat        lon      iceconc'

  for j=0,1023 do begin
    for i=0,1023 do begin
    cwmap1024_auto,i,j,lat,lon,0
    printf,1,i,j,lat,-lon,iceconc(i,j)
    end
  end
  close,1
  endfor
end
```