CLIMATIC DATA FOR THE NORTHWEST ATLANTIC: A SEA ICE DATABASE FOR THE GULF OF ST. LAWRENCE AND THE SCOTIAN SHELF

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CLIMATIC DATA FOR THE NORTHWEST ATLANTIC: A SEA ICE DATABASE FOR THE GULF OF ST. LAWRENCE AND THE SCOTIAN SHELF

by

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ABSTRACT

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A sea-ice database for the Gulf of St. Lawrence and Scotian Shelf is described. The data are derived from digitization of approximately weekly composite ice charts between January 1963 and June 1997 produced by Canadian Ice Service of Environment Canada in Ottawa. They include the total ice concentration, the concentrations of various ice types (new, grey, grey-white and first year) plus the amount of open water within 130 grid cells, each with dimensions 0.5° latitude by 1° longitude. An analysis of the day of first and last presence of ice and the duration of ice is presented including the long-term (30-year) means, the annual values and their deviations from the long-term mean. Ice volumes are estimated from the ice area and assumed thicknesses of the different ice types. Correlation analysis suggests that the ice area is a good proxy for the estimated ice volumes during most of the ice season. The ice area accounts for 80% of the variance in ice volume in the Gulf in December and January as well as in April and May but only 55-60% in February and March. It accounts from 76-93% of the variance throughout the ice season on the Scotian Shelf. In addition to the sea-ice database, we have calculated an areal index of sea ice for the Scotian Shelf and Laurentian Channel. It is the area enclosed by the ice edge seaward of Cabot Strait. This index shows that the 1960s was a time of below normal ice area, in contrast to 1985-1994 when it was typically above normal.

RÉSUMÉ

Drinkwater, K.F., R.G. Pettipas, G.L. Bugden, and P. Langille. 1999. Climatic data for the Northwest Atlantic: a sea ice database for the Gulf of St. Lawrence and the Scotian Shelf. Can. Tech. Rep. Hydrogr. Ocean Sci. 199: iv + 134 p.

Le rapport décrit une base de données sur les glaces de mer du golfe du Saint-Laurent et du plateau néo-écossais. Les données sont issues de la numérisation de tableaux approximativement hebdomadaires de glaces composites, produits par le centre des glaces d'Environnement Canada à Ottawa entre janvier 1963 et juin 1997. Ils incluent la concentration totale des glaces, la concentration de divers types de glace (nouvelle, grise, blanchâtre et première année), plus la superficies des eaux libres de glace dans 130 cellules de quadrillage, mesurant chacune 0,5° de latitude par 1° de longitude. Le rapport offre une analyse des journées de la première et de la dernière présence de la glace et de la durée de la glace, y compris les moyennes à long terme (30 ans), les valeurs annuelles et leur variation par rapport à la moyenne à long terme. Les volumes de glace sont estimées à partir des superficies et de l'épaisseur estimée des divers types de glace. Une analyse de corrélation suggère que la superficie est un bon indicateur des volumes de glace estimés pendant la plupart de la saison des glaces. La superficie de la glace représente 80 pour 100 de la variation du volume de glace dans le golfe en décembre et janvier et en avril et mai, mais seulement 55 à 60 pour 100 en février et mars. Elle représente de 76 à 93 pour 100 de la variation du volume durant toute la saison des glaces sur le plateau néo-écossais. En plus de la base de donnée sur les glaces de mer, nous avons calculé un index de superficité des glaces de mer du plateau néo-écossais et du chenal laurentien. Il couvre le secteur fermé par le front de glace au large du détroit de Cabot. Cet index montre que durant les années 60, la superficie des glaces était sous la normale, alors que de 1985 à 1994, elle était en général au-dessus de la normale.

INTRODUCTION

Cold air and strong northwest winds in winter cause sea ice to form over the Gulf of St. Lawrence (see Fig. 1 for location). Ice usually begins to form in December within the western regions and along the north shore of Quebec (Coté, 1989). By the end of February most of the Gulf is covered. At its maximum seasonal coverage, typically in March, ice extends out onto the northeastern Scotian Shelf. Ice is important, not only because it is a hazard to transportation, but also because of its effect on fisheries. The presence of heavy sea ice will restrict the geographical location of fishing and has in some areas delayed the opening of the lobster fishing season. The migration of cod into the Gulf of St. Lawrence in spring has been shown to be dependent upon sea ice. The timing of the cod's return on the Magdalen Shallows is directly related to when the sea ice disappears (Sinclair and Currie, 1994). In years when the ice retreat is delayed, the majority of the cod entering the Gulf appear later-than-normal.

Information on the location and concentration of sea ice is available in the form of ice charts produced by the Canadian Ice Service (Environment Canada) in Ottawa. Comparison of these charts, which have been available since the early 1960s, reveal year-to-year variability in the timing of the advance and retreat of the sea ice, as well as its concentration and areal extent. In this technical report we describe a sea ice database for the Gulf of St. Lawrence and the Scotian Shelf developed at the Bedford Institute of Oceanography. We also produce climatological means of the seasonal progression and retreat of the ice and interannual fluctuations in the area covered by ice. A similar sea-ice database exists for the Labrador and northern Newfoundland Shelves (Peterson and Prinsenberg, 1990).

This is the third in a series of reports describing climate data for the Northwest Atlantic. Earlier reports focused upon surface wind stresses (Drinkwater and Pettipas, 1993), and the position of the Gulf Stream and shelf/slope fronts (Drinkwater et al., 1994) A fourth report on air temperature records is in preparation. Our prime motivation has been to explore relationships between climate changes and fisheries. To expedite such studies we have assembled a large number of representative oceanographic,

meteorological, sea ice and hydrological indices. The reports are published to inform the general research community of the various indices that are available and to provide some graphical presentations of the data.

DATA AND METHODS

Sea-Ice Database

Various ice parameters were digitized on a 0.5° of latitude by 1° of longitude grid covering the Gulf of St. Lawrence, the Laurentian Channel and the Scotian Shelf. This resulted in 130 grid cells to cover our region of interest (Fig. 2). The data were digitized from composite charts published approximately weekly by the Canadian Ice Service (CIS) beginning in January 1963. The database, originally restricted to the Gulf of St. Lawrence, was a subset of one maintained until 1972 by W.E. Markham of the Ice Service. Within each grid cell we recorded the total concentration of the sea ice present (in tenths), the concentration of new, grey, grey-white, first-year and old (that survived more than one melt season) ice, the presence of any ice edges and the area of open water (in tenths). Further details on the database appear in Appendix I.

In this report we present data from 1963 up to and including 1997. Our plans are to continue to update this database on an annual basis.

Data Analyses

From the available ice data, we calculated the area and volume of ice for each cell, as well as for the Gulf and Scotian Shelf as a whole. For cell j of area A_j, the area of ice (A_{ij}) is estimated from

$$A_{ij} = C_{ij} * (1-A_{wj}) * A_j$$

where C_{ij} represents the concentration of sea ice and A_{wj} is the area of open water in cell j. The total area covered by ice is the summation over all the jth cells, i.e.

$$A_i = \sum_j A_{ij}$$

For the Gulf of St. Lawrence the summation was for cells 1 through 79 inclusive and for the Scotian Shelf it was 80 through 130 (Fig. 2).

The thickness of the ice types were listed by CIS as 0-10 cm for new ice, 10-15 cm for grey ice, 15-30 cm for grey-white ice and > 30 cm for first year ice. Ice volume calculations for the Gulf of St. Lawrence and the Scotian Shelf were undertaken by combining the concentrations of different ice types and assumed mean thicknesses of 5 cm for new ice, 12.5 cm for grey ice, 22.5 cm for grey-white ice, and 75 cm for first year ice. The first year ice thickness we have used is based upon mean thickness estimates of Forward (1954). Since 1982, the ice charts have shown more thickness categories, but these have not been included in the present database.

An analysis of the dates of first and last presence and duration of sea ice was also carried out. For these, an ice year was defined as the period extending from day 300 of one year to 299 of the next. All chart dates were converted to day number for this purpose. For example the period 1 November 1996 to 31 May 1997 would be considered the 1997 ice year. Appearance and duration values presented herein were based on the presence of any ice within a grid cell, regardless of amount. Unless a grid cell was 10 tenths open water, it was considered to have ice.

In addition to the database we have developed an areal ice index for the Scotian Shelf. This index is the area of ice seaward of Cabot Strait and is calculated by estimating the area within the digitized ice edge seaward of a line joining Cape Ray, Newfoundland, and Cape North on Cape Breton Island.

RESULTS AND GRAPHICAL PRESENTATIONS

First and Last Appearance of Ice

For each ice year, the minimum and maximum date of ice presence was determined for each grid cell. If ice appeared in a given cell, disappeared for several charts and returned, the earliest and latest date were used for the first and last appearance of ice, respectively. Once values of the first and last appearance were determined for each cell, these were optimally estimated (using the center of the cell) onto a finer 0.2° by 0.2° grid for contouring purposes. This produced a more continuous, smoother field.

Values were plotted with respect to December 31, i.e. day 0 is December 31, day –15 is December 16, day 15 is January 15, etc. For convenience, we have plotted the data in contours at 15 d intervals which roughly correspond to the beginning and middle of a month. Estimates where the errors were large were not included in the contour plots. These large errors only tended to occur beyond approximately a half a grid spacing (based on the original 0.5° of latitude by 1° of longitude) from the edge of the grid where the estimates were based upon extrapolation of gradients.

Thirty-year means of the first and last appearance of sea ice (1964-1993) were computed for each grid cell. The 30-year period follows the meteorological standard. The 1963 ice year was not considered complete because of a lack of data for December 1962 and hence was not included in the determination of the long-term mean. The mean values were optimally estimated onto the 0.2° by 0.2° grid, excluding grid cells where ice appeared in fewer than 5 years. Anomalies were calculated by subtracting the optimally estimated 30-y means from the individual values. A positive anomaly indicates ice was later-than-usual for both first and last appearance and a negative anomaly that they were earlier-than-usual. Thus, colder-than-normal conditions generally produce a negative anomaly for first appearance and a positive anomaly for last appearance.

The long-term mean of the first appearance confirms that ice begins to form in late December within the St. Lawrence Estuary, along the western shore of the Magdalen Shallows and in the Strait of Belle Isle (Fig. 3). It gradually spreads southeastward such that by the end of January most of the Gulf is ice-covered, the exception being off the southwestern tip of Newfoundland. By mid-February the ice pushes out onto the northeastern Scotian Shelf and by the end of February in heavy ice years, it will occupy large sections of the Shelf. Ice begins to disappear by mid-March on the Scotian Shelf and later in the month in the St. Lawrence estuary (Fig. 4). Ice lasts longest in the southwestern Magdalen Shallows (after mid-April) and in the Strait of Belle Isle (after mid-May). The year-to-year variability about these means is evident from the plots of the date of first and last appearance of ice for each year from 1963 to 1997 and their deviations from the 30-y means found in Appendix II.

Ice Duration

Data records were ordered by grid cell, ice year and day number. A simple routine was then run to determine the ice duration for each year. A value of 7 days was assigned for the initial chart appearance, subsequent appearances added the day number of the current chart minus the day number of the previous chart. Counting the number of chart appearances of ice for a given cell in a given year and multiplying by 7 would yield very similar results, however, there were occurrences of the chart days not being 7 days apart.

The resulting values were optimally estimated from the 0.5° latitude by 1.0° longitude grid onto the 0.2° by 0.2° grid for all years. Values with large estimation errors were again discarded, being judged as unreliable. Note that the ice duration is not necessarily the difference between the first and last presence of ice since the ice can disappear for a time and then reappear.

As with ice appearance, mean duration values were computed for each cell for the 1964-1993 period. These means were determined by dividing the total number of days of duration over the period by the number of years of appearance (instead of 30). These long-term mean values were also optimally estimated onto the 0.2° by 0.2° grid, as were the number of years of appearance at each grid cell. Although all cells were plotted for the number of days of duration (with the exception of high estimation errors), only those with a minimum of 10 years appearance are represented in the anomalies.

The mean number of days of ice typically ranges from less than 20 on parts of the Scotian Shelf and off southern Newfoundland to over 120 in the Strait of Belle Isle (Fig. 5). The duration displays a minimum in the Laurentian Channel with longer durations over the Magdalen Shallows and the Strait of Belle Isle. The duration in the former ranges from 80 to over 110 days during a normal year. The ice duration for each year from 1963 to 1997 is displayed in Appendix III.

Ice Seaward of Cabot Strait

In addition to the sea-ice database containing the amount of ice in tenths within designated grid cells, we also digitized the position of the ice edge seaward of Cabot Strait. The area encompassed by the ice edge and surrounding land (if applicable) was

calculated. Those times when there were isolated ice sheets or floes, their areas were added to the area of the main ice field to produce an overall sea-ice area. Daily ice areas were then estimated using linear interpolation and a monthly mean calculated based upon the average of the daily values. The long-term seasonal mean of this index reveals that ice normally appears in January, reaches a peak of over 25000 km^2 in March and declines thereafter, usually disappearing by the end of May (Fig. 6). The time series of the monthly means and their anomalies reveal large interannual variability (Fig. 6). The 1960s was generally a decade of below normal ice area whereas from 1985 to 1994, the ice-area was typically above normal. From 1995 to 1997, the ice areas have been lower-than-average.

Comparisons were made between this sea-ice areal index and that calculated from the sea-ice database using cells 80-130 (Fig. 7). Initially ignoring the ice concentrations in the latter, the correlation between the two ice area time series was 0.99 with the slope of the regression not significantly different from one (Fig. 8). Thus both methods give identical results. When the ice concentration was accounted for in the area based on the database (discrete cell digitization), the correlation still remained high (r=0.96) but the slope of the regression declined to 0.72 (Fig. 9). Given that the intercept was not statistically different from zero, this suggests that the concentration of the ice within the area seaward of Cabot Strait is, on average, 72%.

Ice Volumes

Ice volumes were estimated from the weekly charts separately for the Gulf of St. Lawrence and the Scotian Shelf. As mentioned in the methods section, they are based upon mean thickness of each of the ice types, with 75 cm being chosen for first year ice. The data were further grouped by month since the thickness generally increases through the ice season. Correlations were then calculated between the estimated weekly volumes and the areal extent within each month. In particular, we wished to know how well the areal extent is as a proxy for ice volume. The correlations varied by month being highest at the beginning and end of the ice season. The variance in estimated sea-ice volume accounted for by the areal extent (r^2) varied between 55% to 97% for the Gulf and 76% to

93% for the Scotian Shelf (Table 1; Figs. 10, 11). The slope of the regression line represents an approximate monthly mean thickness. The ice thickness progresses from thinnest (new ice) in December and January through to the thickest (mostly first year ice) late in the season. Note that the monthly mean thickness is slightly smaller on the Scotian Shelf compared to the Gulf of St. Lawrence. For February and March, when the ice extent is greatest, the range of volumes for a given ice area increases as the area increases, especially in the Gulf of St. Lawrence but also to a lesser extent on the Scotian Shelf (Fig. 10, 11). These are the months when the ice is progressing from young ice (grey and grey-white; <30 cm) to first year ice (>30 cm). It must be remembered, however, that the ice volumes are based upon assumed ice thicknesses and not measured values and do not take into account year-to-year differences in the actual thickness of the different ice types nor the amount of ridges or rafting that occurs.

Table 1. Results of the regression of the estimated ice volume for the Gulf of St. Lawrence and the Scotian Shelf on the sea-ice areal extent, including the r^2 value, the number of weekly charts used in the regression, the slope (a) expressed in cm and the intercept (b).

	Gulf of St. Lawrence				**Scotian Shelf**			
Month	**r^2**	**# weekly**	**a (cm)**	**b (10^{-9} m^3)**	**r^2**	**# weekly**	**a (cm)**	**b (10^{-9} m^3)**
Dec	0.89	73	7.7	-0.22				
Jan	0.80	164	18.7	-4.47	0.78	63	14.1	-0.05
Feb	0.55	142	34.7	-1.49	0.76	177	23.9	-0.13
Mar	0.58	153	35.4	1.69	0.79	191	34.2	0.24
Apr	0.91	157	50.4	0.13	0.91	169	45.3	0.03
May	0.97	100	55.9	-0.28	0.93	30	52.0	-0.07

The monthly time series of the ice area and volume anomalies for the Gulf of St. Lawrence and the Scotian Shelf appear in Figs. 12 and 13, respectively. Years when there was no ice present are not plotted. The data are derived from the database. In the Gulf, the 1960s were light ice years (Fig. 12). Ice area expanded during the 1970s,

dropped to a minimum in the early 1980s before rising again through to a peak in the early to mid-1990s. Since the mid-1990s, the ice area has declined. There is more year-to-year (high frequency) variability in the ice area on the Scotian Shelf (Fig. 13) than in the Gulf with no long-term trends. Ice during May has been observed seaward of Cabot Strait only in 17 out of 35 years of observations (Fig. 13). No ice was detected in Cabot Strait or on the Scotian Shelf in any month during 1969.

CONCLUDING REMARKS

We have described a sea-ice database for the Gulf of St. Lawrence and the Scotian Shelf. The seasonal and interannual variability in the first and last presence of sea ice as well as the duration of ice have been provided. The database is presently being used to describe ice conditions as part of the annual overviews of environmental conditions in the Northwest Atlantic presented to fisheries assessment biologists and managers (e.g. Drinkwater et al., 1998). The data indicate extensive interannual variability in the sea-ice coverage which is presently under investigation, including studies of the dependence of the areal extent of the sea ice in the Gulf of St. Lawrence on local air temperatures, winds and the freshwater runoff from the St. Lawrence River system (Li et al., 1998).

The database will be made available for scientific research purposes upon request to the authors.

Acknowledgments – We would like to thank those who have encouraged and helped us in the assembly and analysis of this database, in particular, the Canadian Ice Service in Ottawa. We also acknowledge and greatly appreciate the help of I. Peterson and S. Prinsenberg at the Bedford Institute of Oceanography including comments on an earlier draft of this report.

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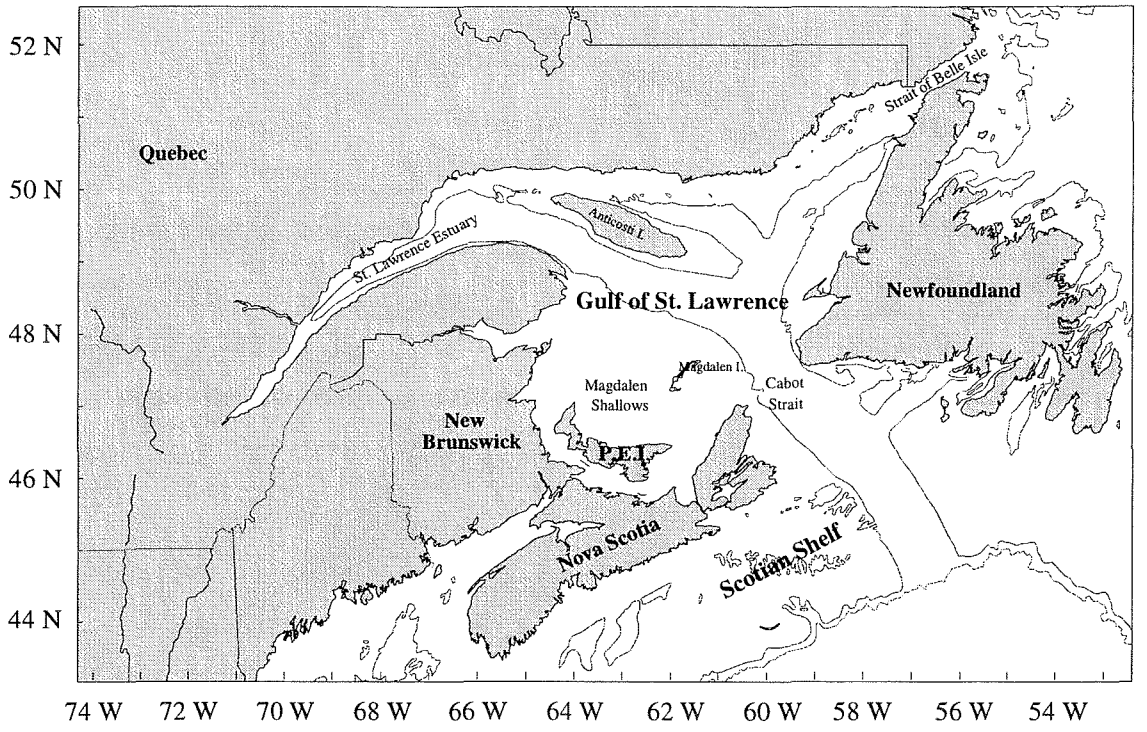


Fig. 1 Map of the Gulf of St. Lawrence and the Scotian Shelf

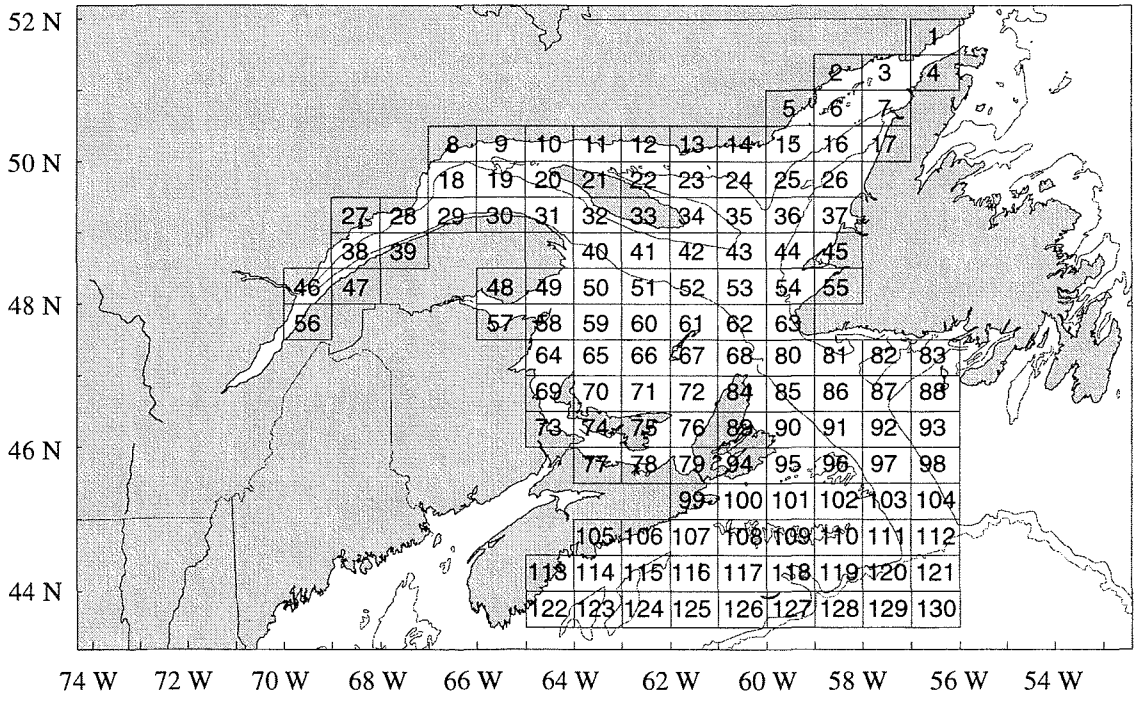


Fig. 2 The numbered grid cells used in the Gulf of St. Lawrence and Scotian Shelf sea ice database.

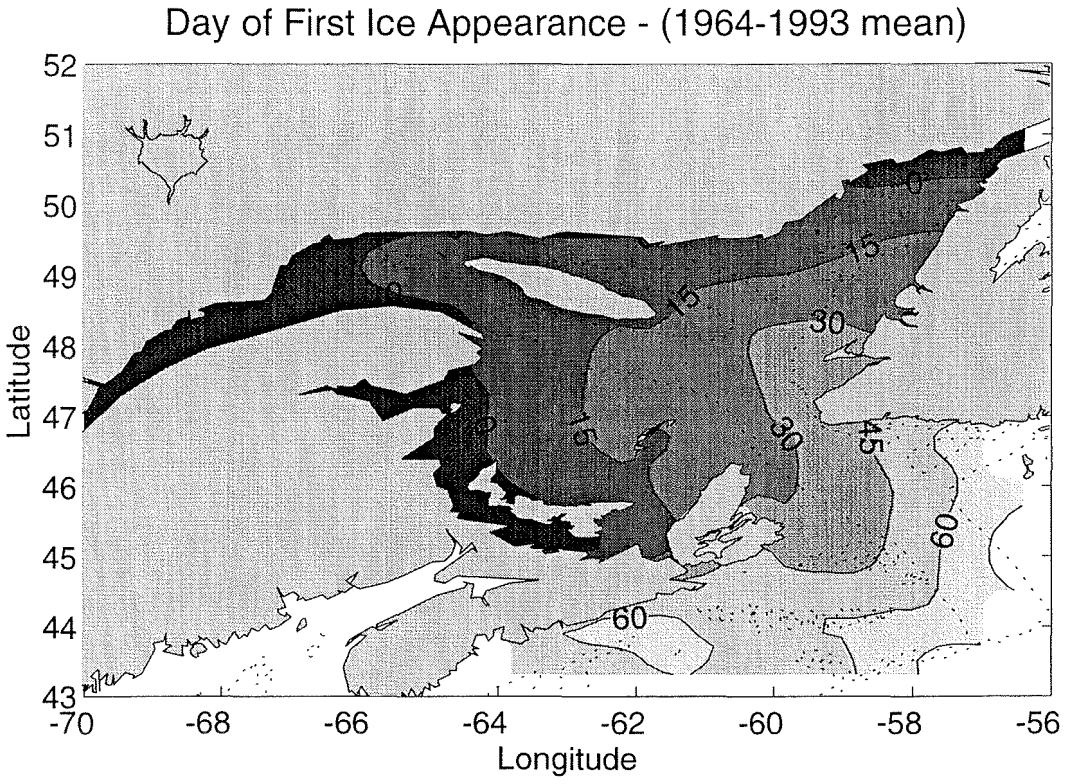


Fig. 3. The mean day of first appearance of ice based on the years 1964 to 1993. The numbers refer to days from December 31,thus day 15 is January 15th.

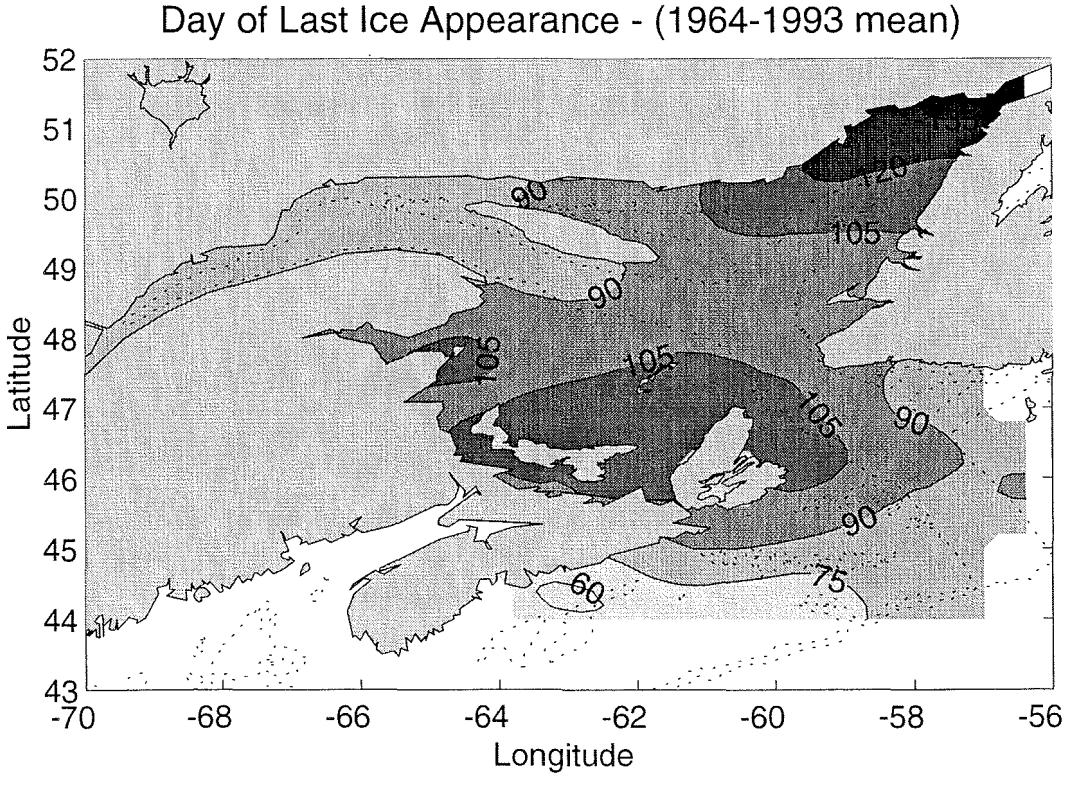


Fig. 4. The mean day of last appearance of ice based on the years 1964 to 1993. The numbers refer to days from December 31.

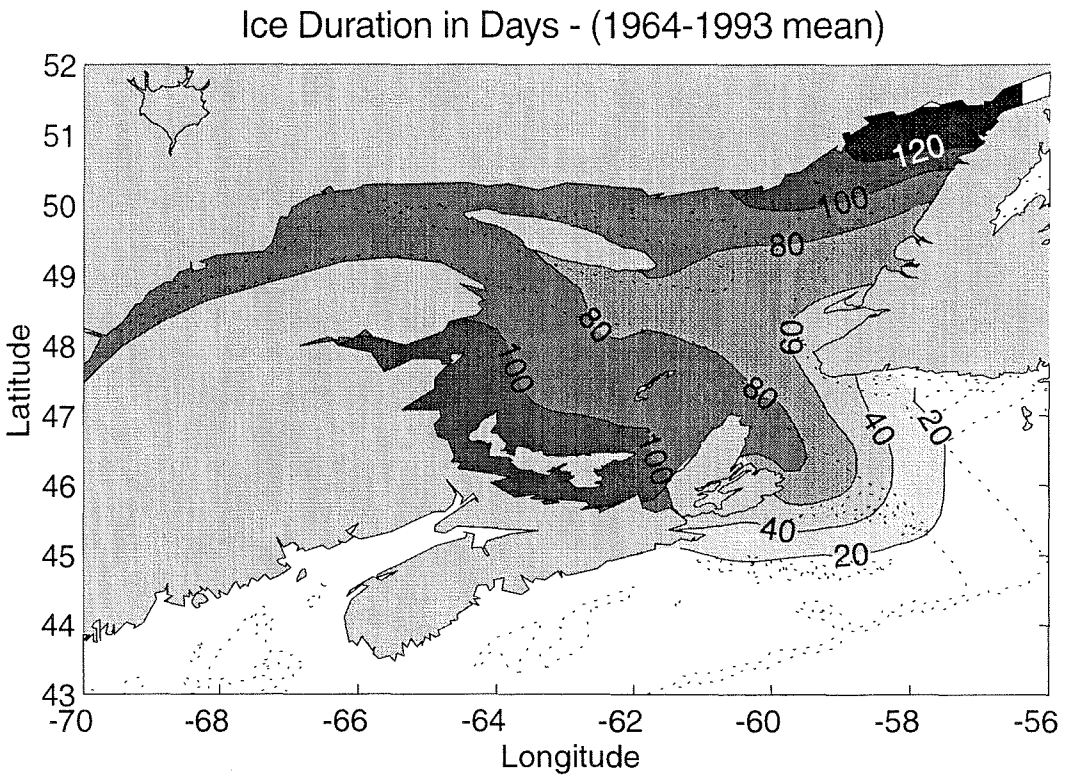


Fig. 5. The mean number of days of sea ice duration (1964-1993).

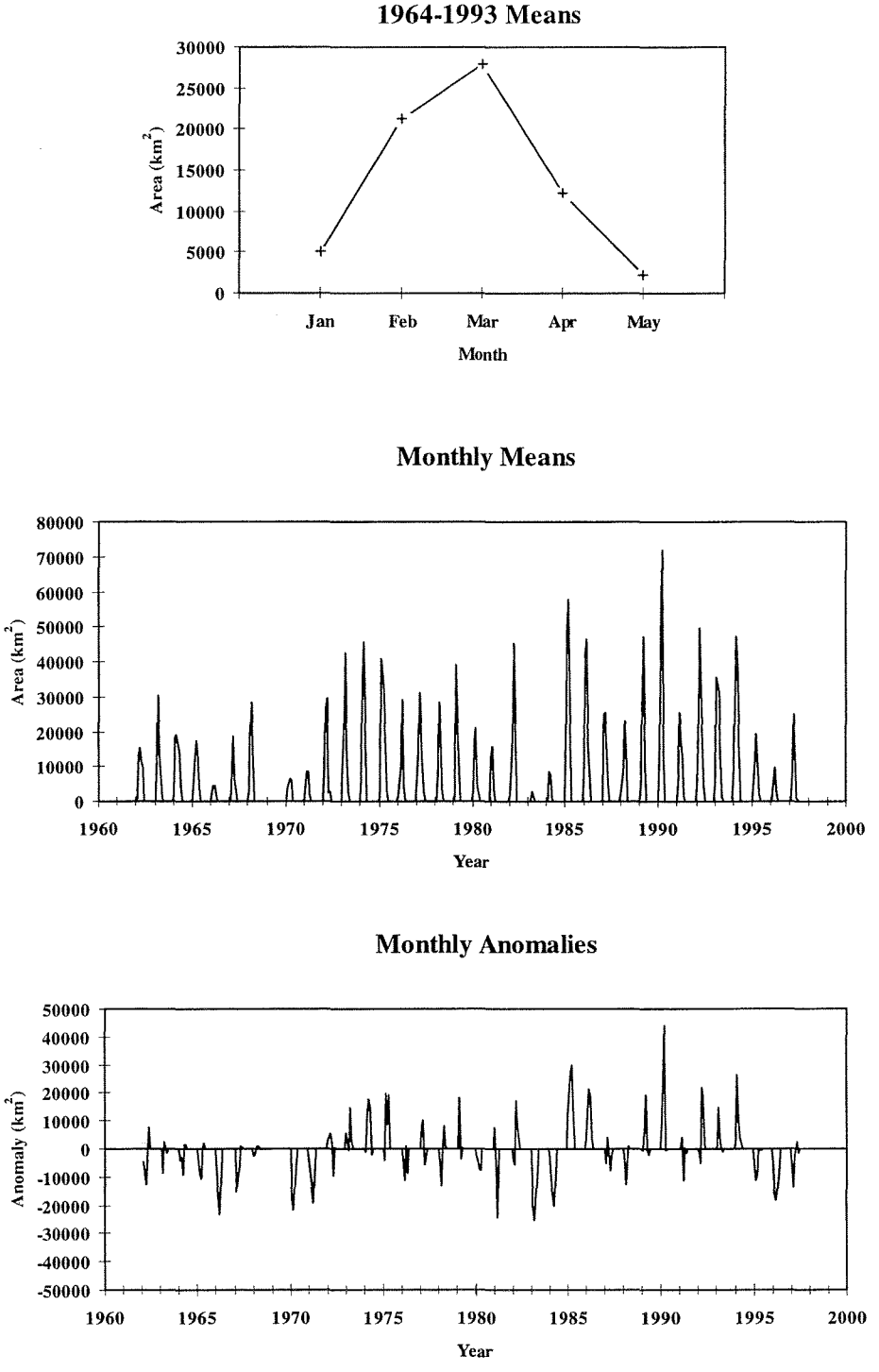


Fig. 6 The areal index of sea ice seaward of Cabot Strait determined from the digitized ice edge. The seasonal means are shown in the top panel, the time series of the monthly ice area in the middle panel and the anomalies of the monthly areas in the lower panel.

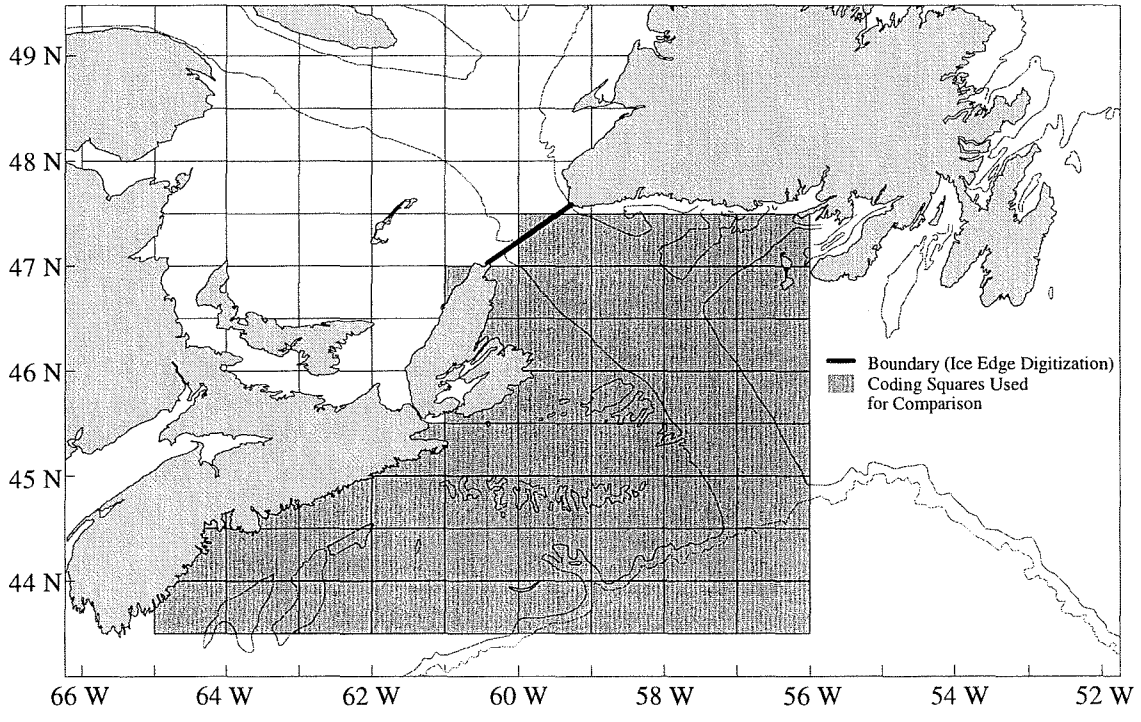


Fig. 7. The grid cells used in the comparison with the sea ice areal index seaward of Cabot Strait. The landward boundary used in the digitization of the sea ice edge for the areal index is also shown.

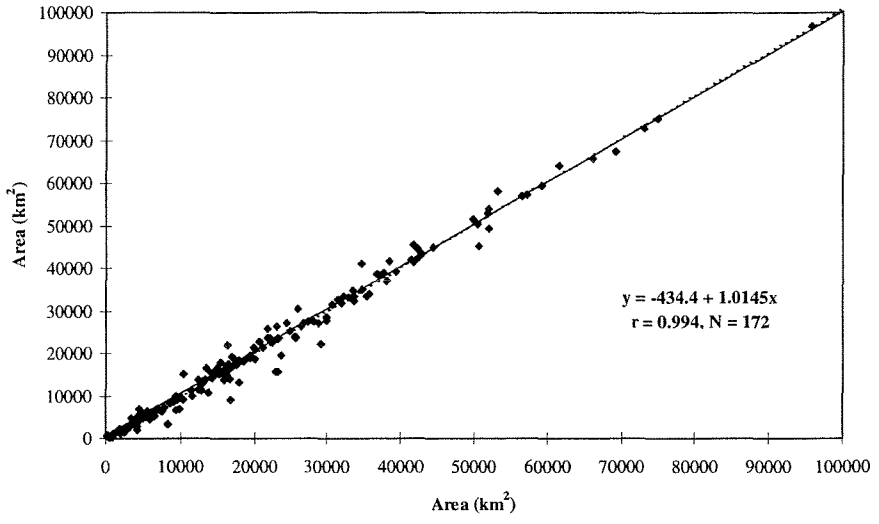


Fig. 8. Plot of the sea ice areas based upon digitization of the ice edge (y-axis) and the sea ice database (x-axis). The linear regression equation between the two areas as well as the plot (dashed line) are provided. Also given are the correlation coefficient (r) and the number of points (N). The solid line is the 1 to 1 relationship. No correction was made for the concentration of ice in this case.

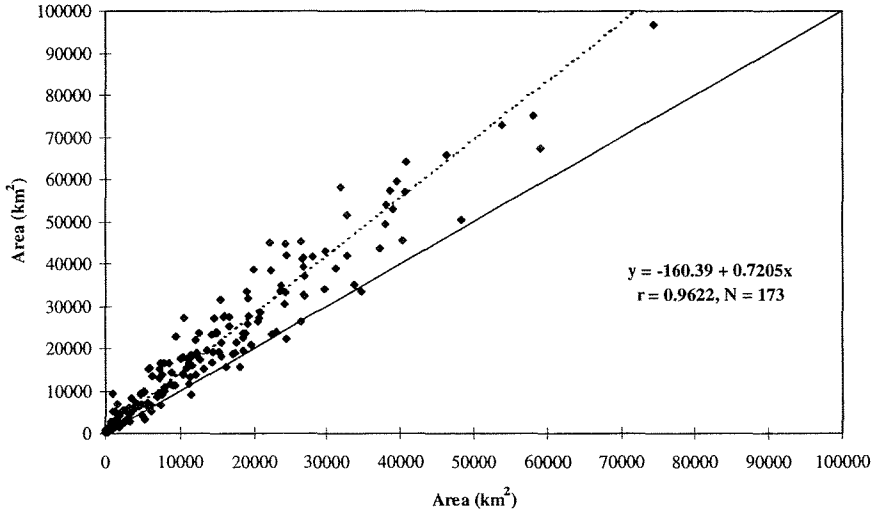


Fig. 9. Plot of the sea ice areas based upon digitization of the ice edge (y-axis) and the sea ice database (x-axis) after correction for the concentration of ice in the latter. The linear regression equation between the two areas as well as the plot (dashed line) are provided. Also given are the correlation coefficient (r) and the number of points (N). The solid line is the 1 to 1 relationship.

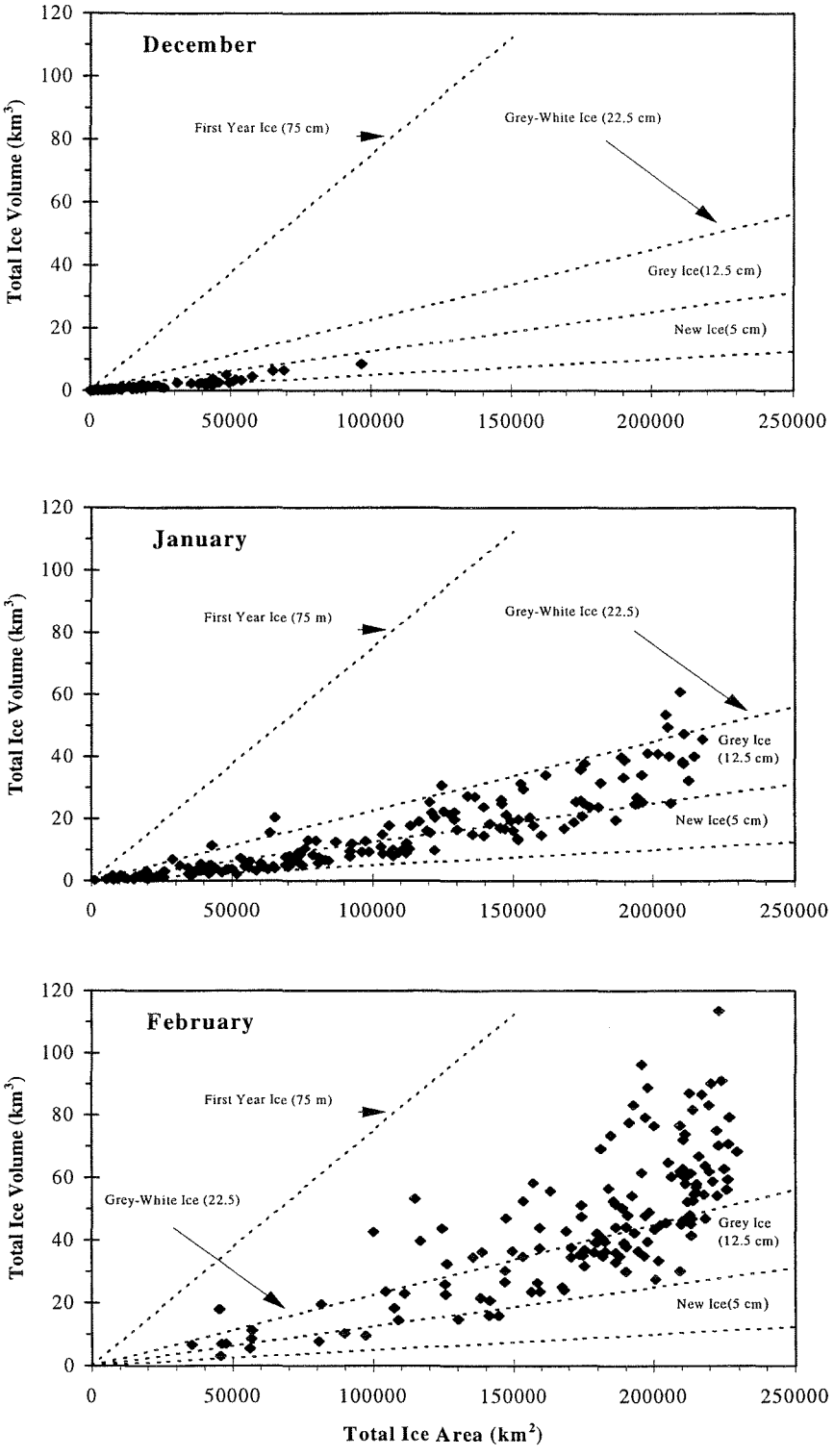


Fig.10. The sea-ice volume in km^3 versus area in km^2 by month (December, January and February) for the Gulf of St. Lawrence. The dashed lines represent the volume if the entire area were composed of new, grey, grey-white or first year ice. The assumed thickness for each type of ice are provided in parenthesis.

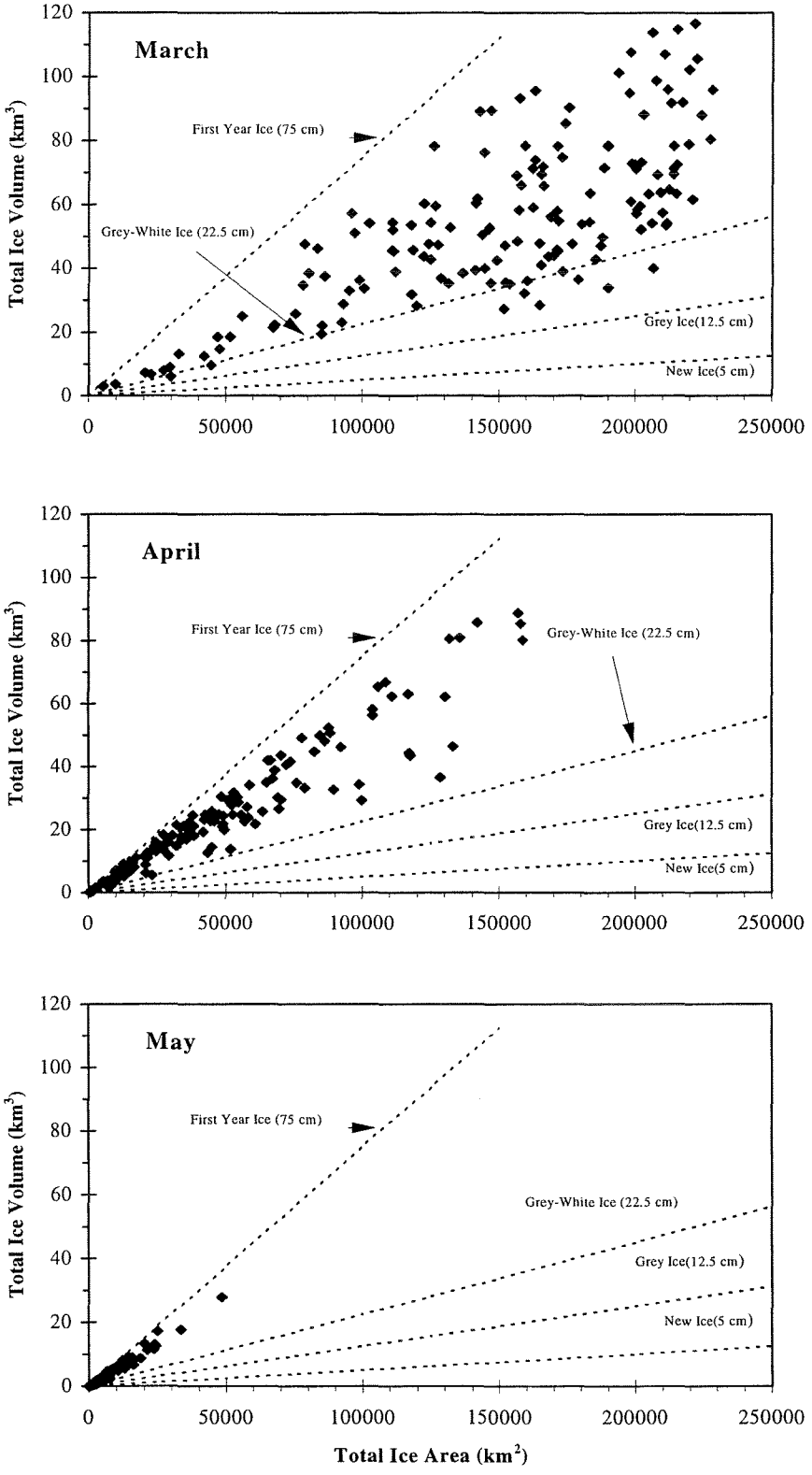


Fig.10. (cont'd.) The sea-ice volume in km^3 versus area in km^2 by month (March, April, and May) for the Gulf of St. Lawrence.

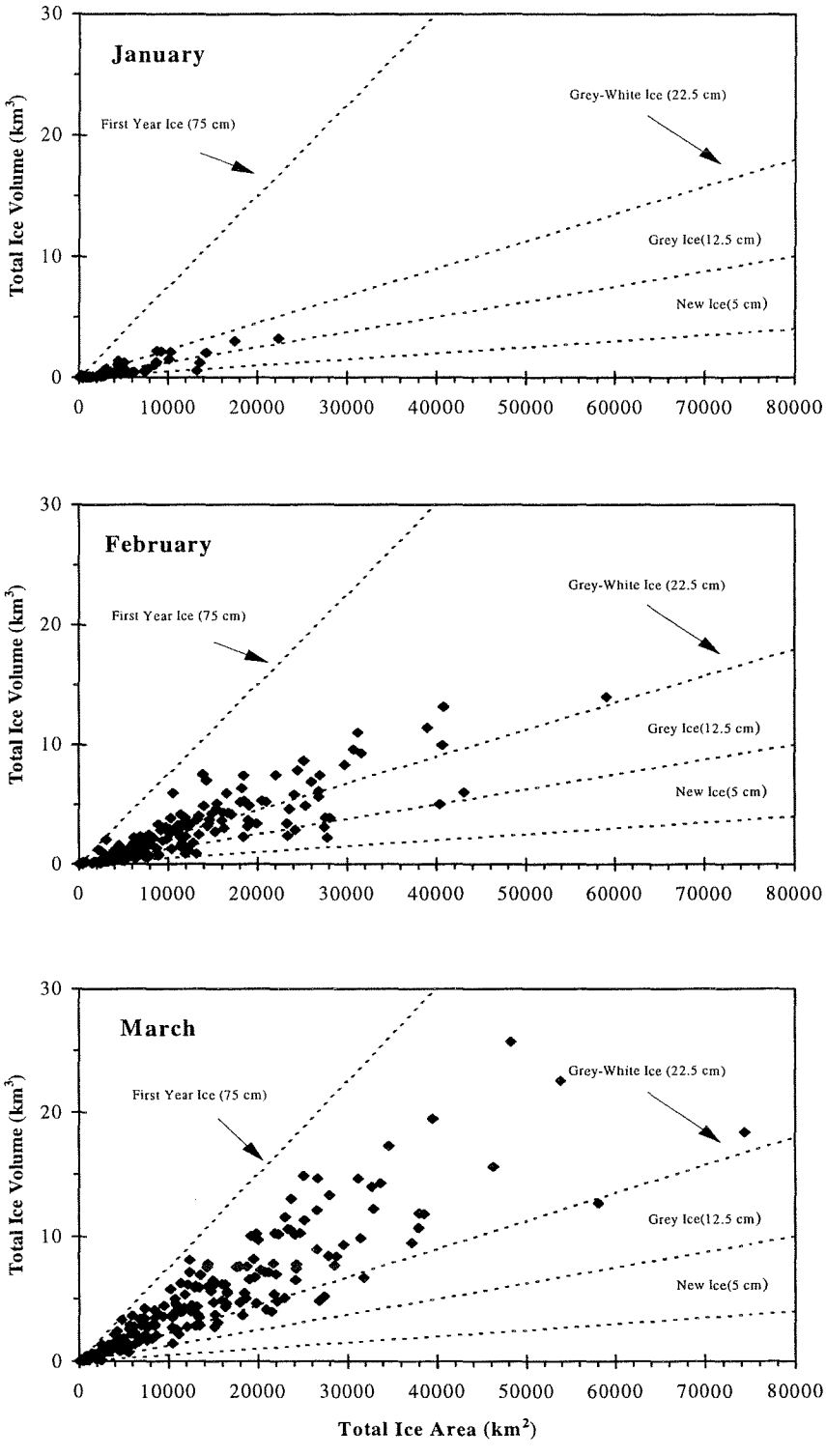


Fig.11. The sea-ice volume in km^3 versus area in km^2 by month (January, February and March) for the Scotian Shelf. The dashed lines represent the volume if the entire area were composed of new, grey, grey-white or first year ice. The assumed thickness for each type of ice are provided in parenthesis.

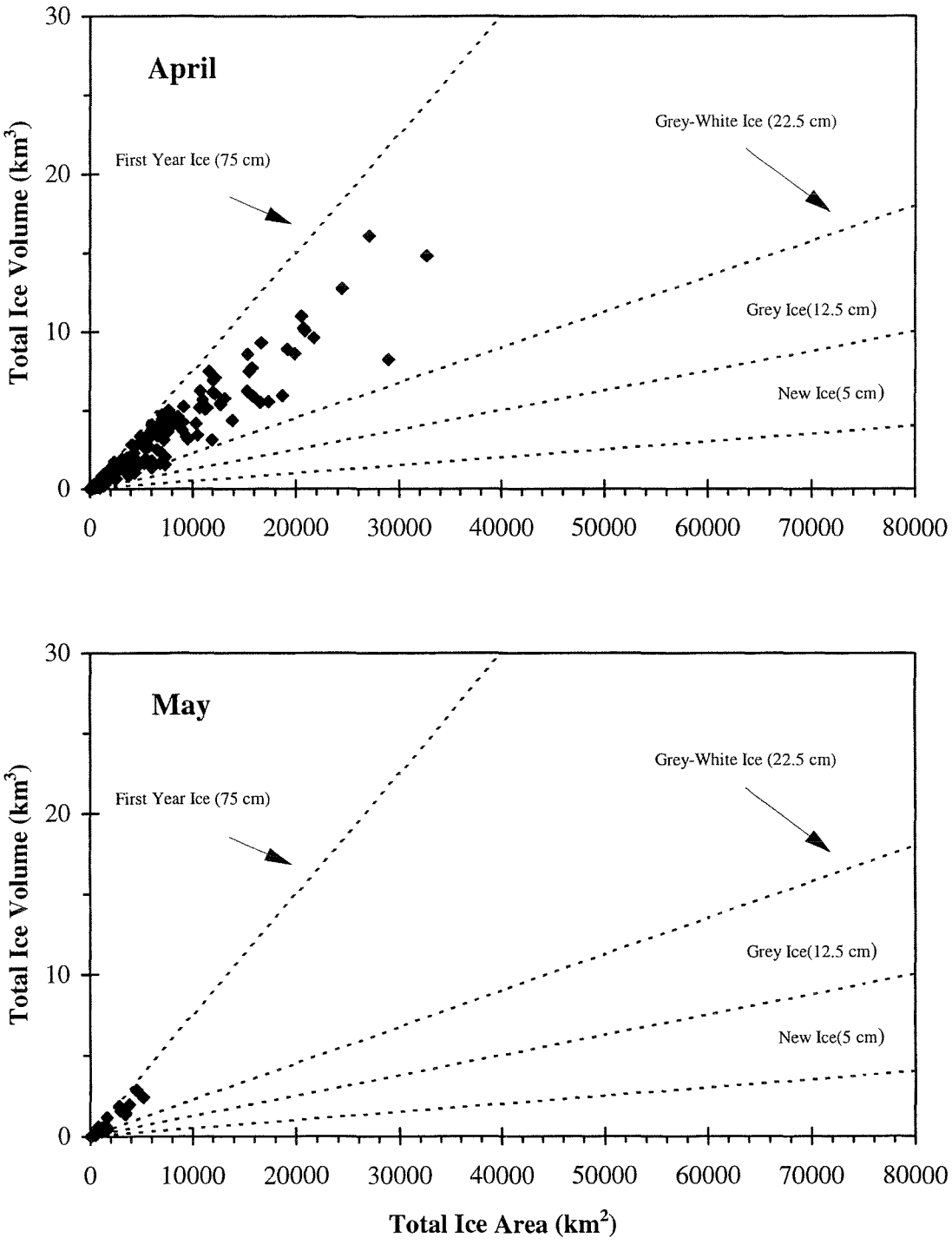


Fig.11. (cont'd.) The sea-ice volume in km^3 versus area in km^2 by month (April, and May) for the Scotian Shelf.

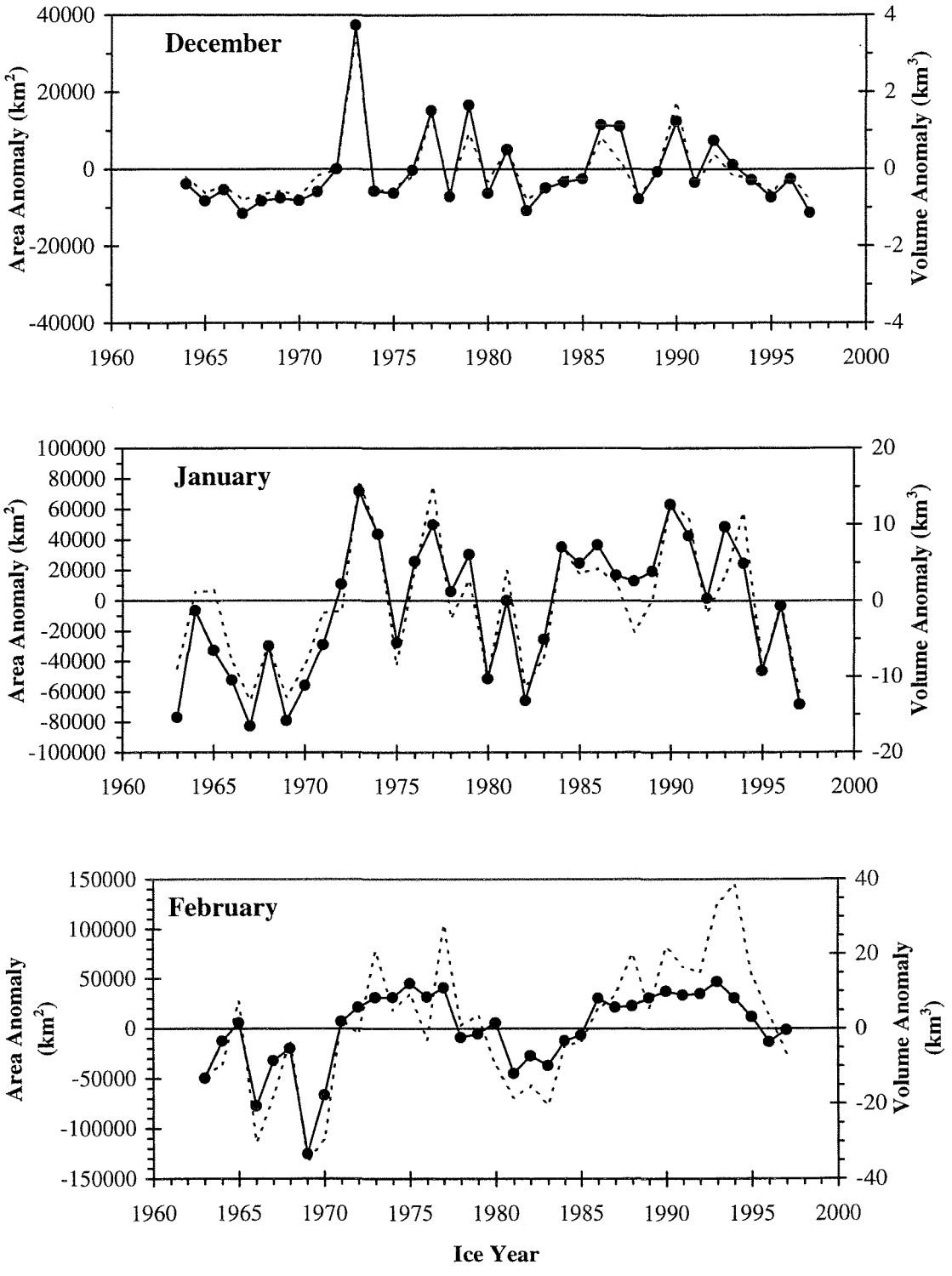


Fig.12. The monthly (December, January and February) time series of anomalies of sea-ice area in km^2 (solid line) and volume in km^3 (dashed line) for the Gulf of St. Lawrence. The dots indicate in what years ice was present.

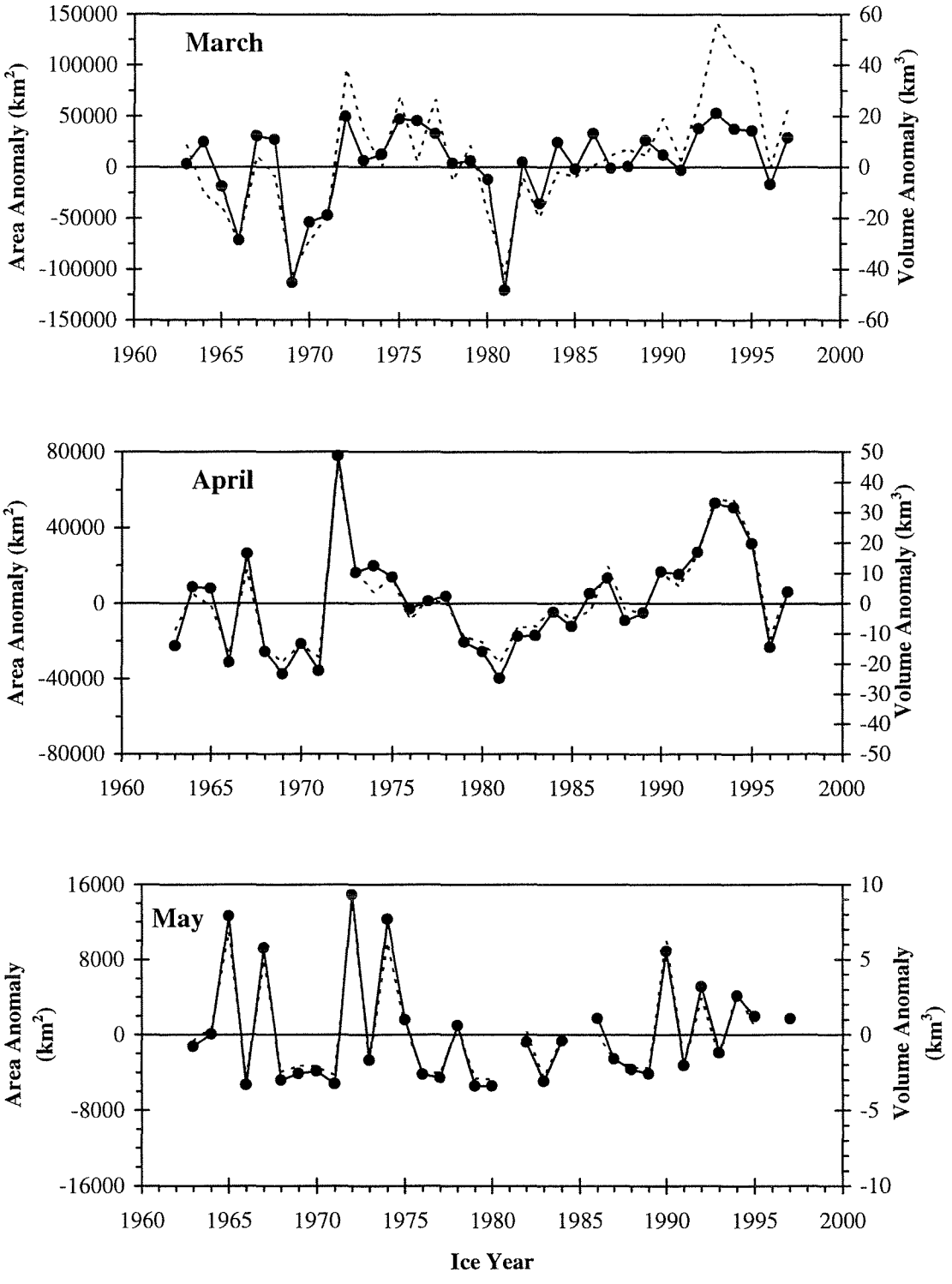


Fig.12. (cont'd.) The monthly (March, April, and May) time series of anomalies of sea-ice area in km^2 (solid line) and volume in km^3 (dashed line) for the Gulf of St. Lawrence. The dots indicate in what years ice was present.

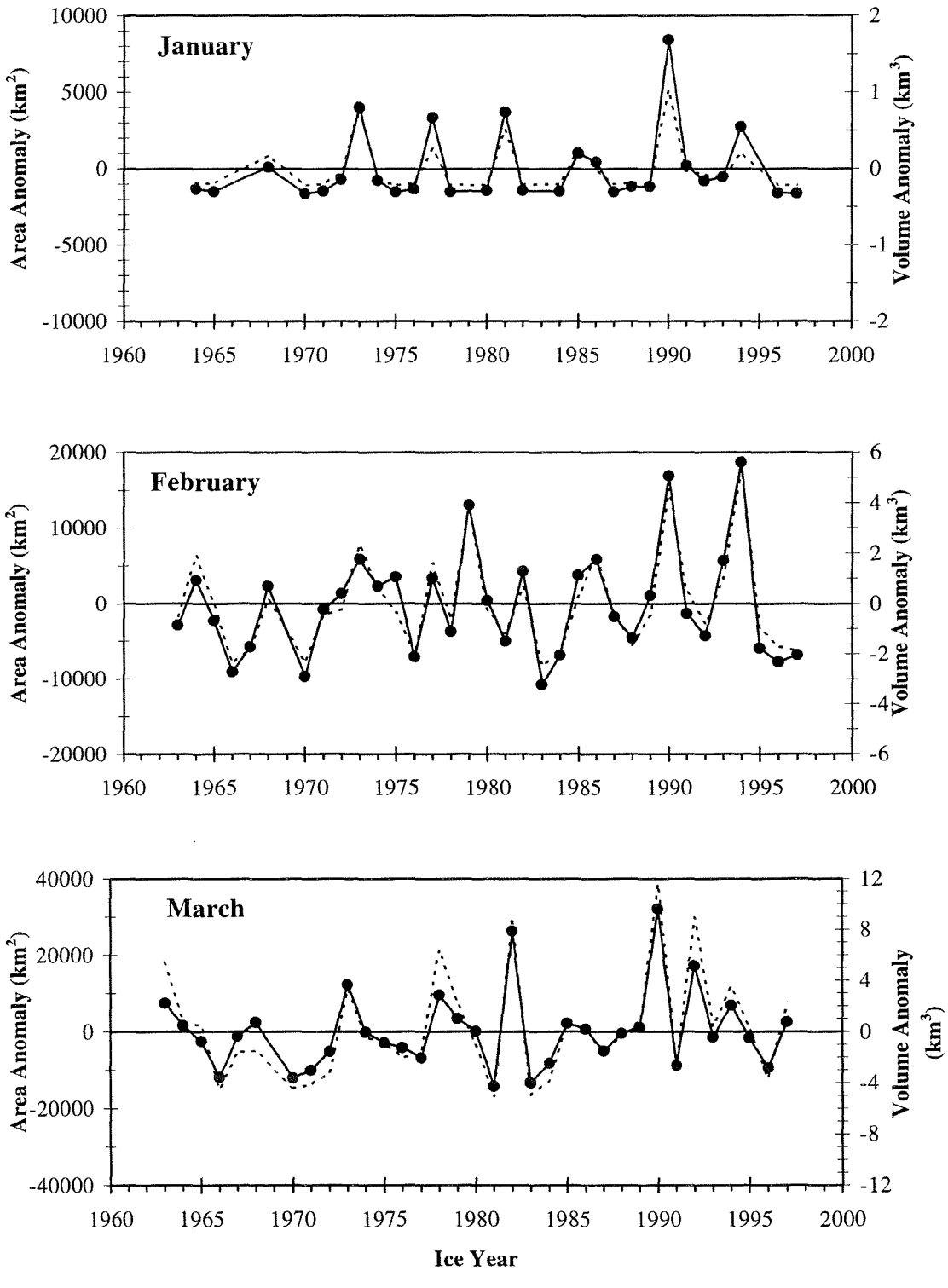


Fig.13. The monthly (January, February and March) time series of anomalies of sea-ice area in km^2 (solid line) and volume in km^3 (dashed line) for the Scotian Shelf. The dots indicate in what years ice was present.

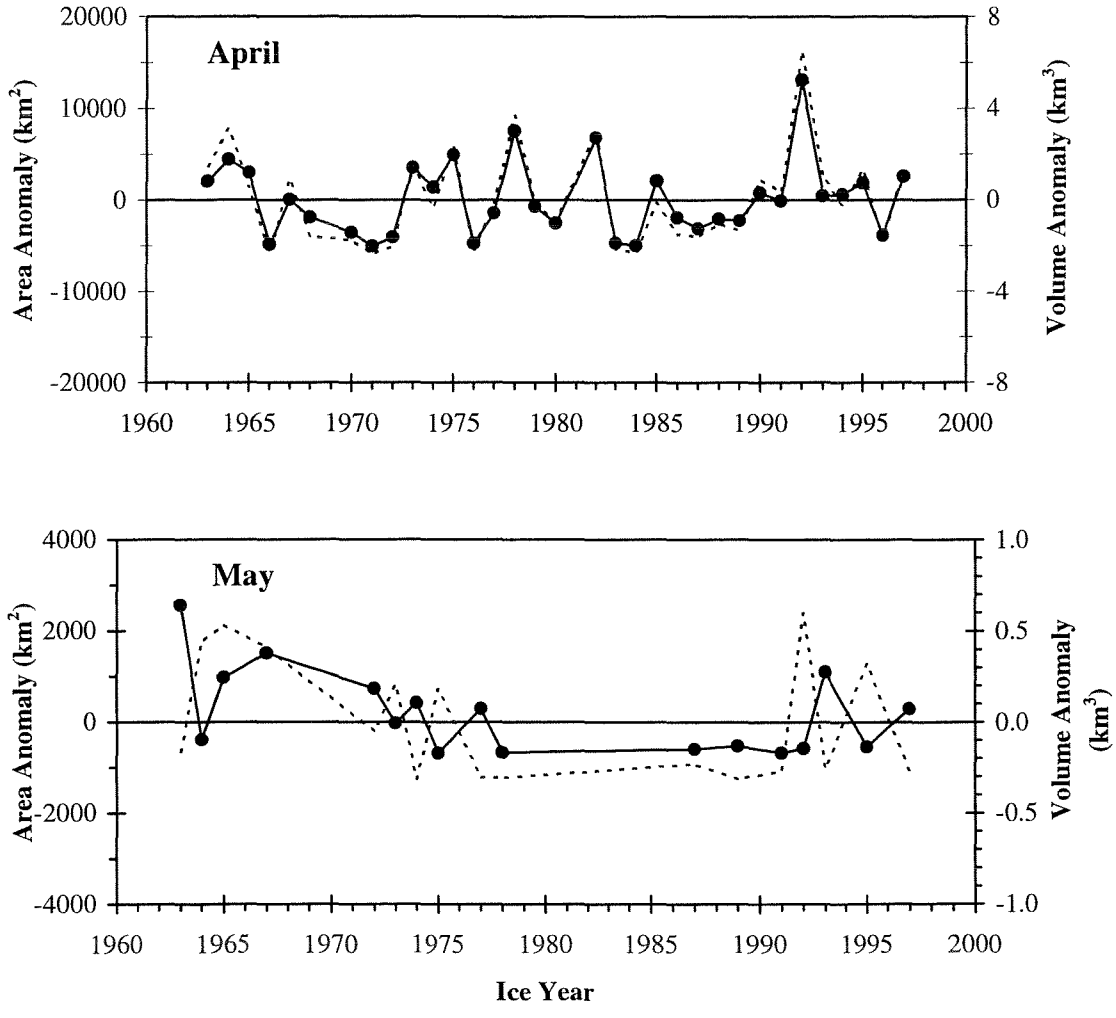


Fig.13. (cont'd.) The monthly (April and May) time series of anomalies of sea-ice area in km^2 (solid line) and volume in km^3 (dashed line) for the Scotian Shelf. The dots indicate in what years ice was present.

Appendix I. Sea-ice Database

As described in the text, the Gulf of St. Lawrence was divided into 79 cells and the Scotian Shelf into another 51 (cells 80 through 130; Fig. 2). Ice properties were digitized at approximately weekly intervals from the charts produced by Ice Central of Environment Canada. The cells are labeled by their southwestern corner in whole degrees of latitude and longitude with a subcell number of 1 for the northern cell and 2 for the southern cell.

The weekly ice data for each cell is described by a 18-character record.

Character #	Item	Code
1-2	Year	-
3-4	Month	-
5-6	Day	-
7-8	Latitude (SW corner of cell)	-
9-10	Longitude (SW corner of cell)	-
11	Subcell	1
12	Total Concentration	2
13	Amount of First-Year Ice	3
14	Amount of Grey-White Ice	3
15	Amount of Grey Ice	3
16	Amount of New Ice	3
17	Ice Edge	4
18	Open Water	3

The Code number refers to the Code Tables given below. The definitions of the types of ice are taken from the publication by the U.S. Naval Oceanographic Office (1968). *New ice* is the general term for recently formed ice which includes frazil ice, grease ice, slush and shuga. These types of ice are composed mainly of ice crystals which are only weakly frozen together (if at all). Young ice is in the transition stage between new ice and first year ice. It includes grey ice and grey-white ice. *Grey ice* is typically 10-15 cm thick, will break in the presence of swell and usually rafts under horizontal pressure. Rafting is when one piece of ice overrides another. *Grey-white ice* is 15-30 cm thick and is more likely to form ridges than to raft. Ridges are lines or walls of ice forced up by pressure.

First-year ice is not more than one winter's growth, developing from young ice and has a thickness of typically 30 cm to 2 m. Ice does not survive to the next year so there is no old (multi-year) ice in the Gulf of St. Lawrence or on the Scotian Shelf.

Code Table 1. Subcells

Code	Definition
1	Northern Subcell
2	Southern Subcell

Code Table 2. Total Ice Concentrations

Code	Definition
0	No Ice
/	< 1/10
1	1 tenth
2	2 tenths
3	3 tenths
4	4 tenths
5	5 tenths
6	6 tenths
7	7 tenths
8	8 tenths
9	9 tenths
+	Over 9 tenths
F	10 tenths, fast ice
A	1-3 tenths
B	4-6 tenths
C	7-9 tenths
D	9-10 tenths
X	Ice present but concentration unknown
M	Missing data

Code Table 3. Concentration of Ice by Age or Type

Code	Definition
0	No Ice
/	< 1/10
1	1 tenth
2	2 tenths
3	3 tenths
4	4 tenths
5	5 tenths
6	6 tenths
7	7 tenths
8	8 tenths
9	9 tenths
+	Over 9 tenths
-	10 tenths
M	Missing data

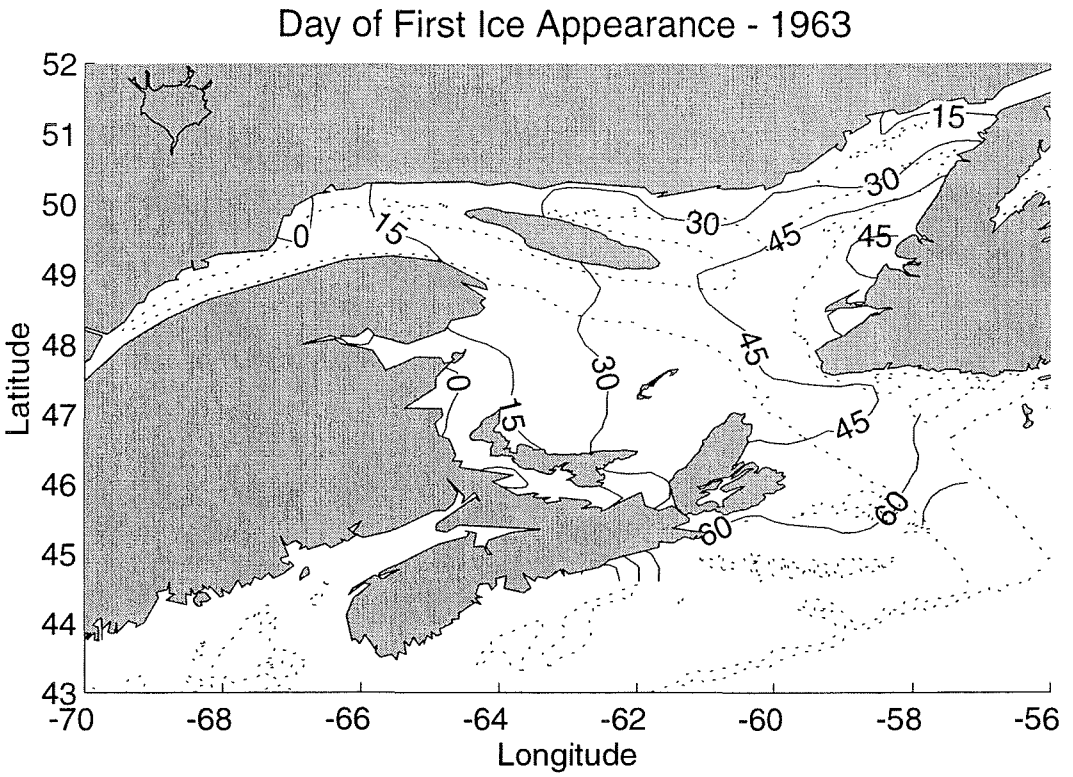
Code Table 4. Ice Edge

Code	Definition
0	No ice edges
1	Main ice edge present
2	Two main ice edges present
3	Edge of large polynya present
4	Both sides of small polynya present
5	Polynya within cell
6	Shore lead present
7	Flaw lead present
8	Patches present but not main edge
9	Patches present and main edge
M	Missing data

Ice edge is the demarcation between the sea ice of any type and the open sea. *The main edge* separates the main ice field from the open water. *Polynya* is any nonlinear-shaped opening enclosed by ice. *Leads* are open passageways through the sea ice which are generally navigable by ships. *Shore leads* are limited on one side by the coast while called *flaw leads* are limited on one side by fast ice. *Patches* are pieces of ice detached from the main ice field.

Appendix II. First and last presence of sea ice.

For 1963 to 1997, plots are provided on the time of first presence and last presence of sea ice and their anomalies in days relative to their long-term (1964-1993) means. The time of first and last presence is in days after December 31. Shaded anomalies are generally associated with colder conditions, i.e. earlier-than-normal first presence (negative anomalies) and longer-than-normal last presence (positive anomalies).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Latitude
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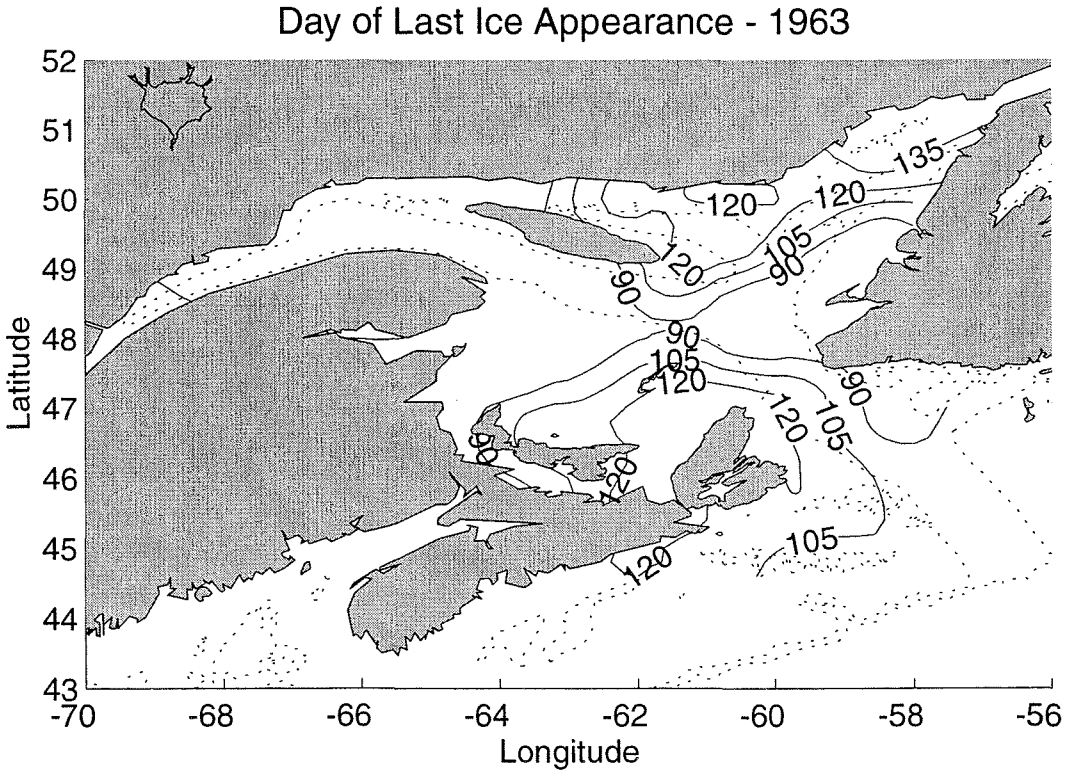
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-60
-58
-56
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105
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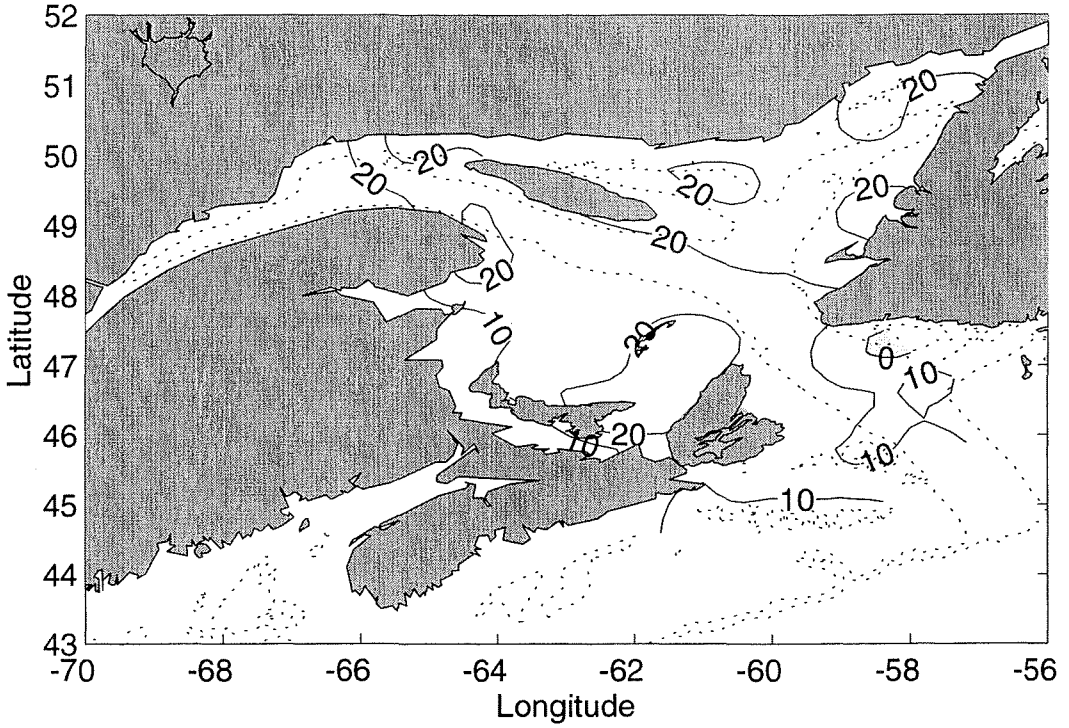
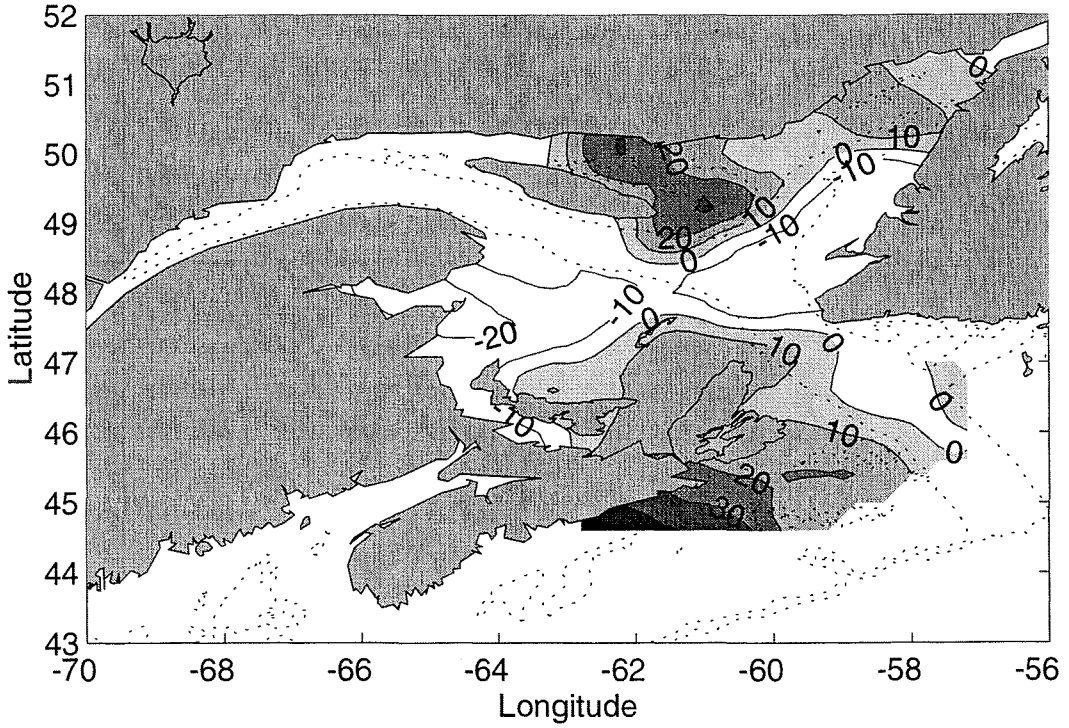
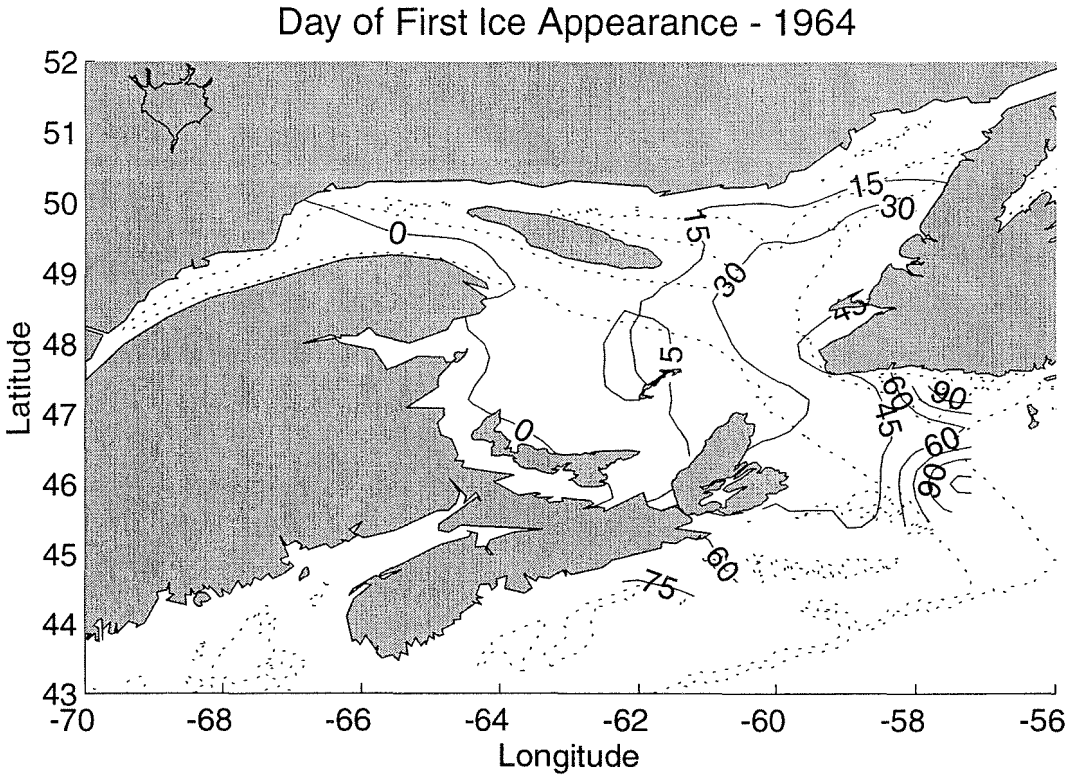
First Ice Appearance (Anomaly in Days) - 1963



Last Ice Appearance (Anomaly in Days) - 1963

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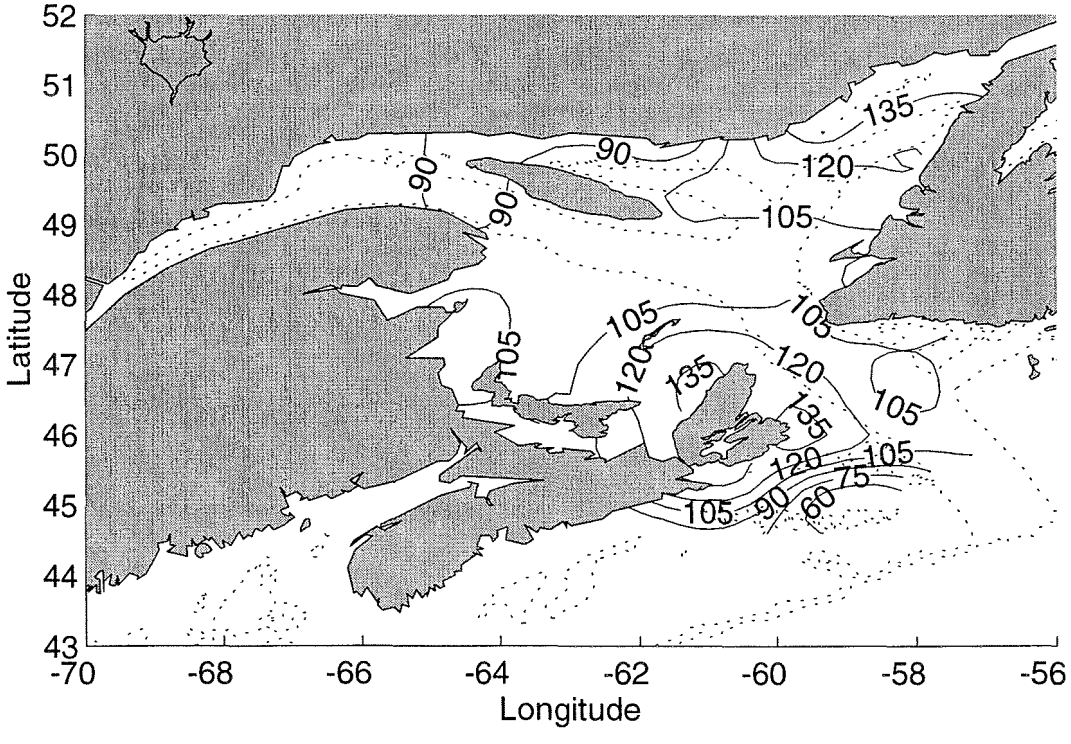
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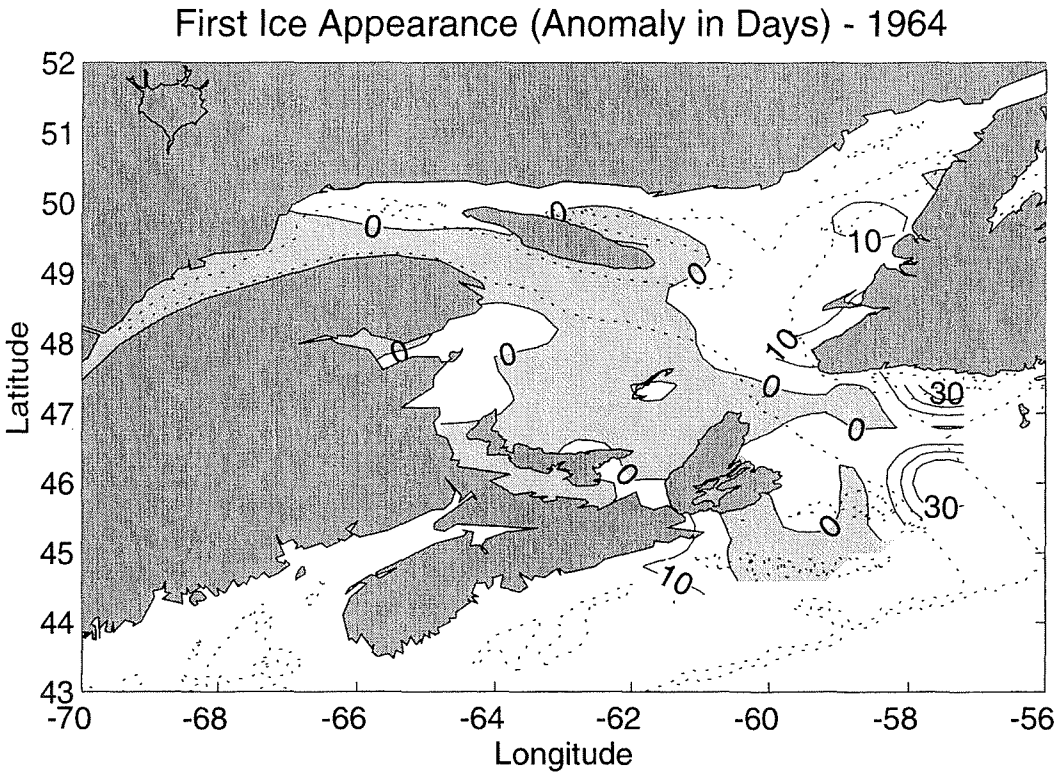
First Ice Appearance (Anomaly in Days) - 1964
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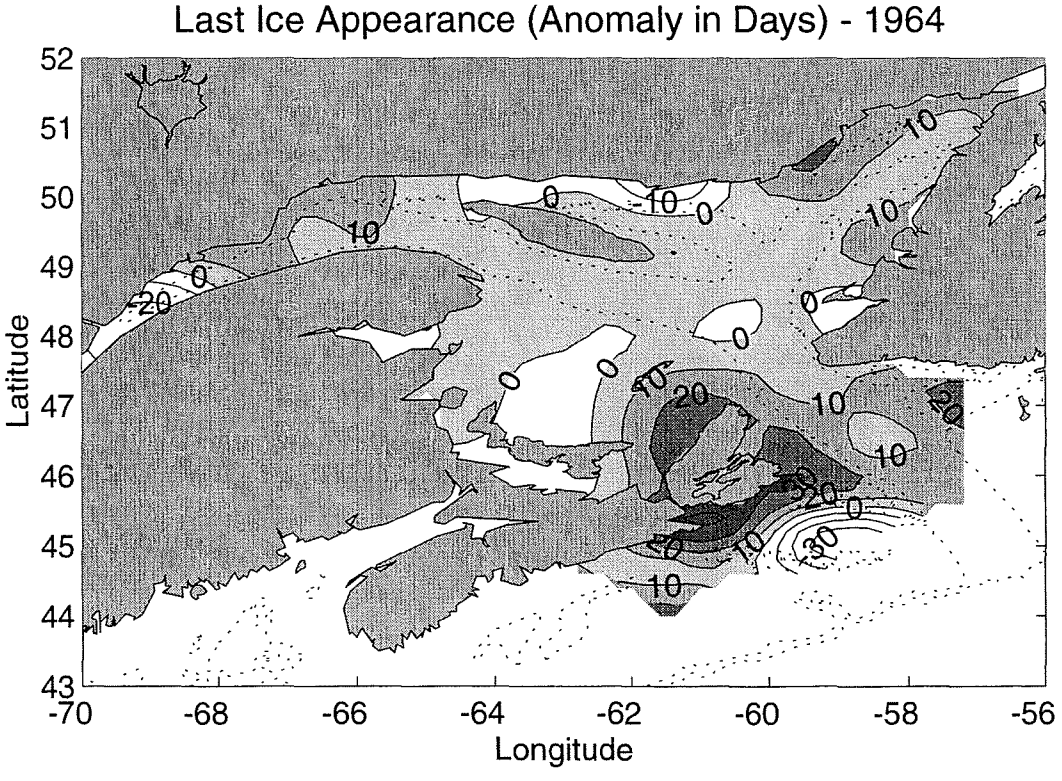
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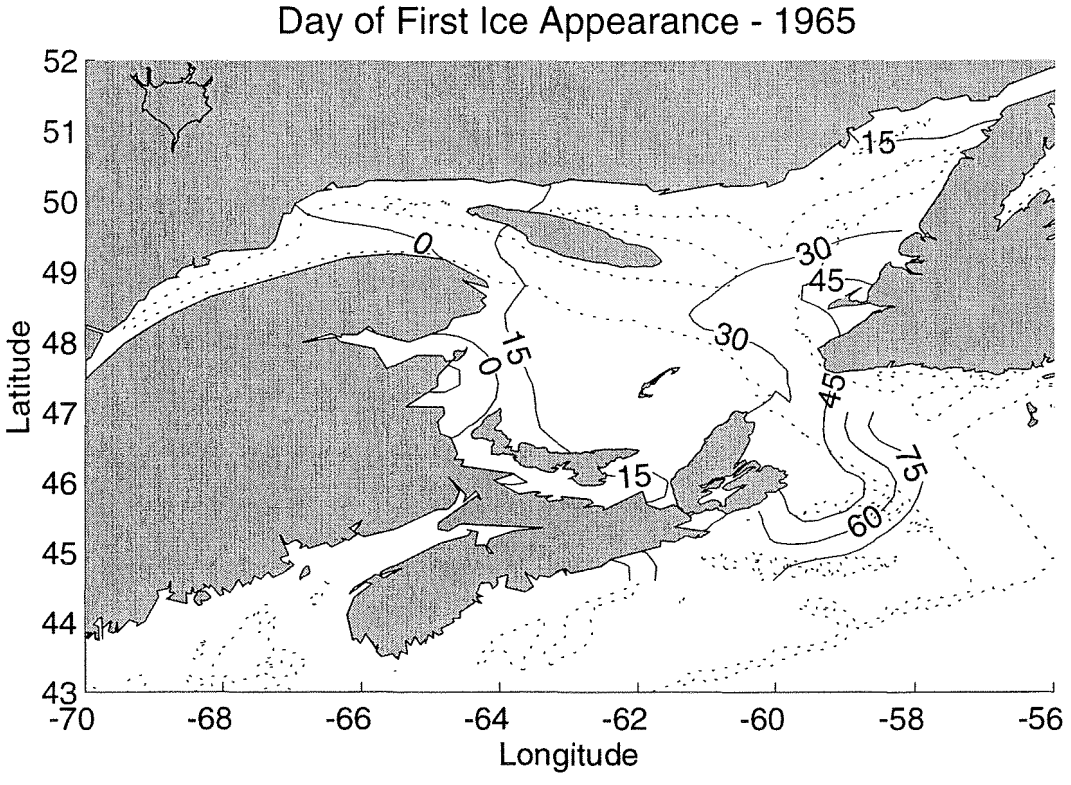
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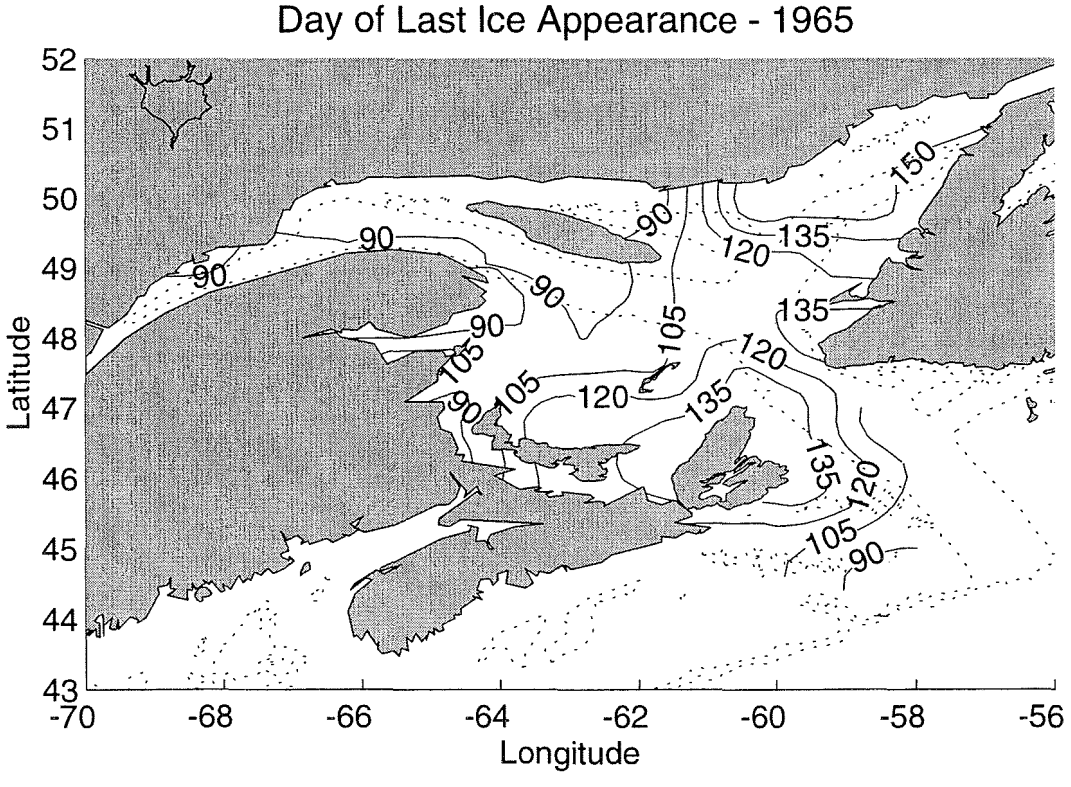
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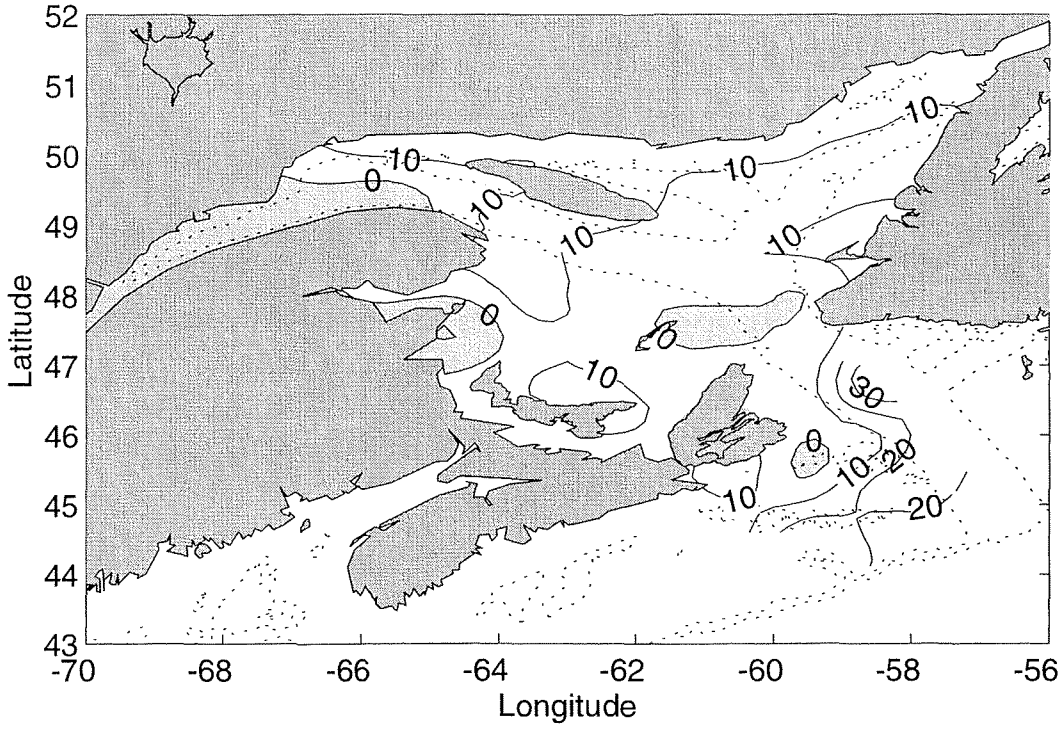
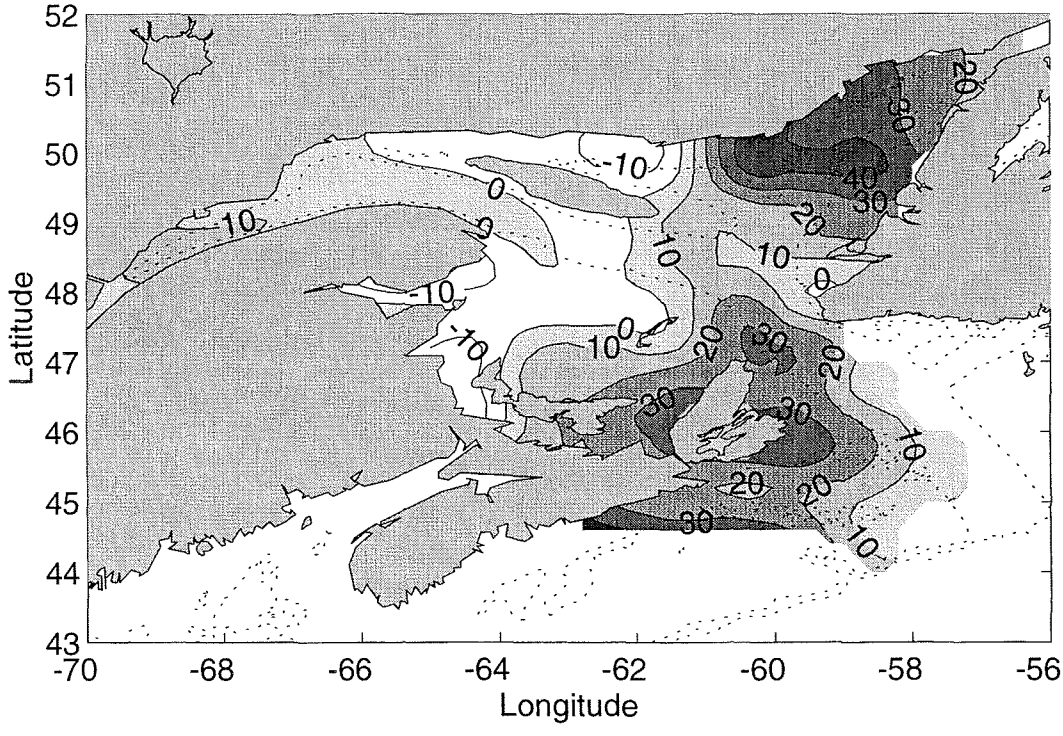
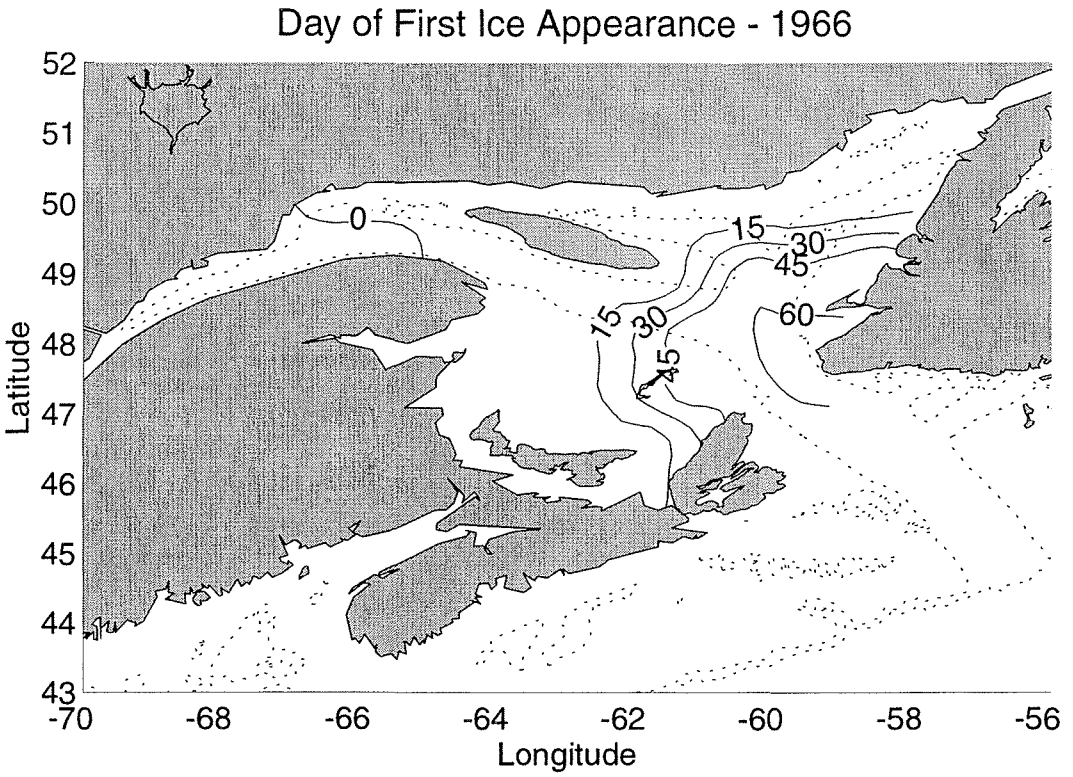
First Ice Appearance (Anomaly in Days) - 1965



Last Ice Appearance (Anomaly in Days) - 1965

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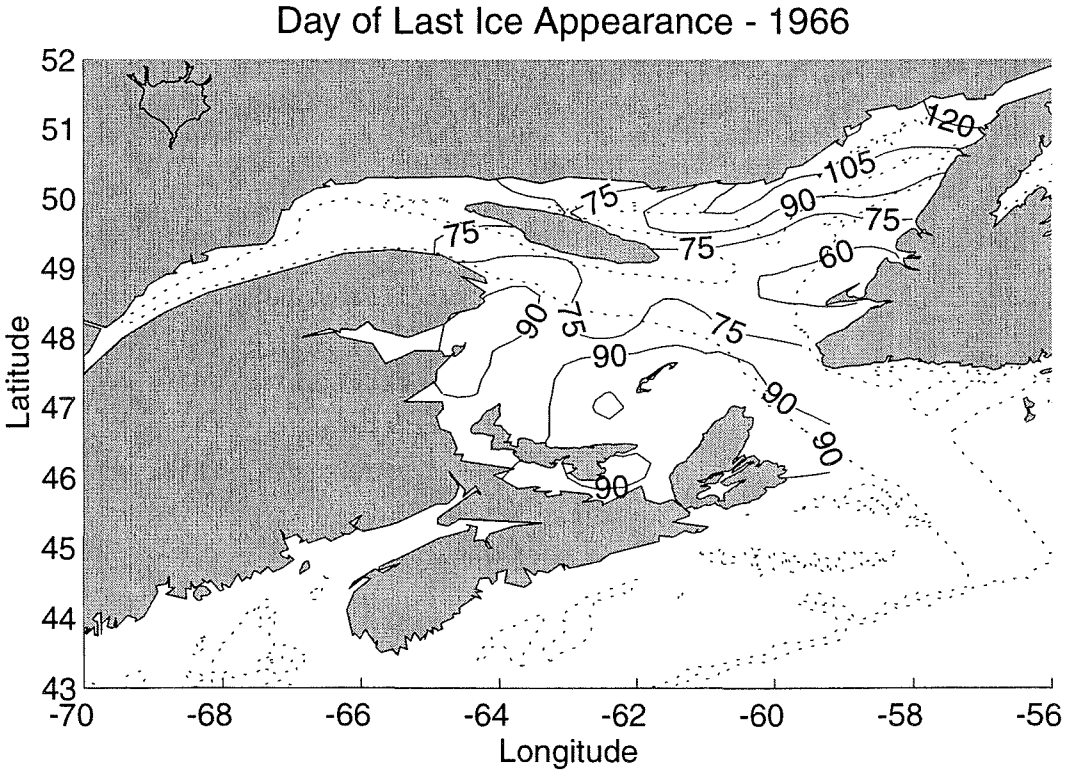
Day of Last Ice Appearance - 1966
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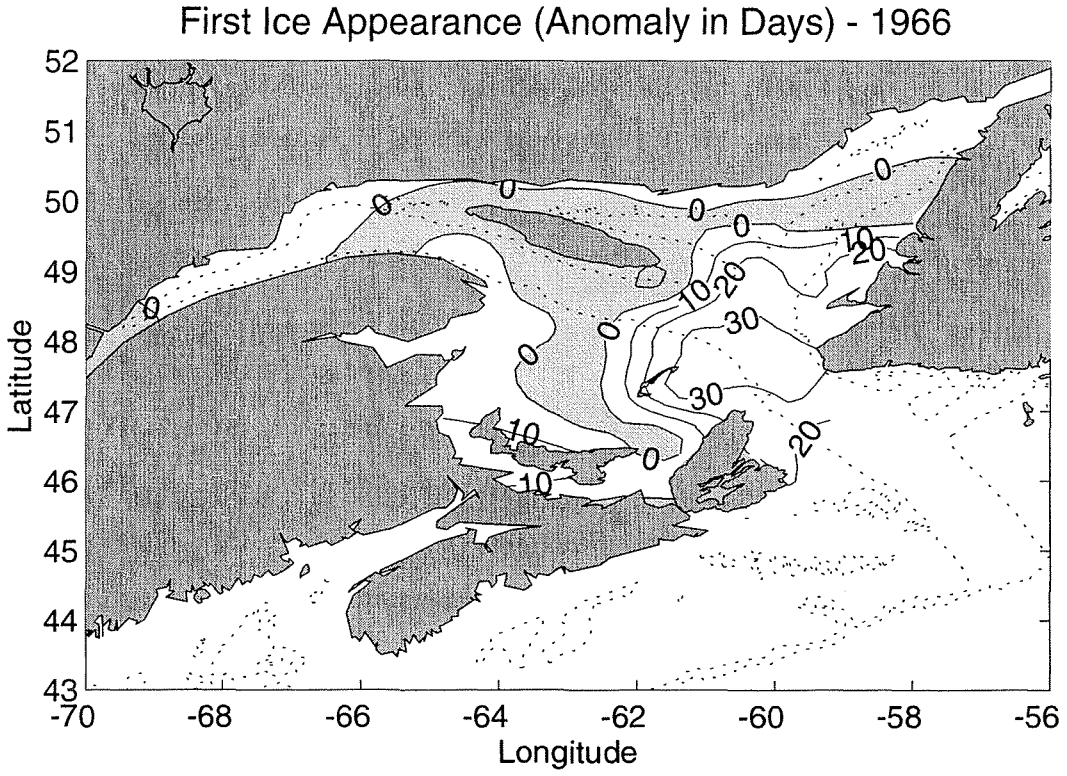
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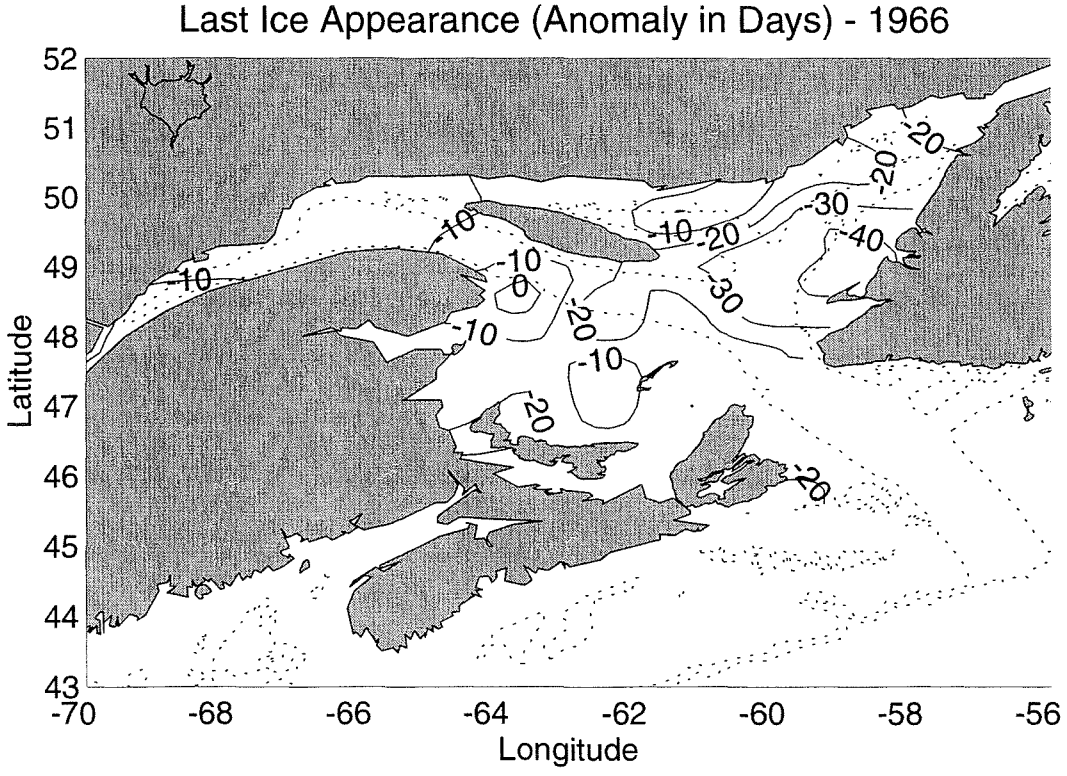
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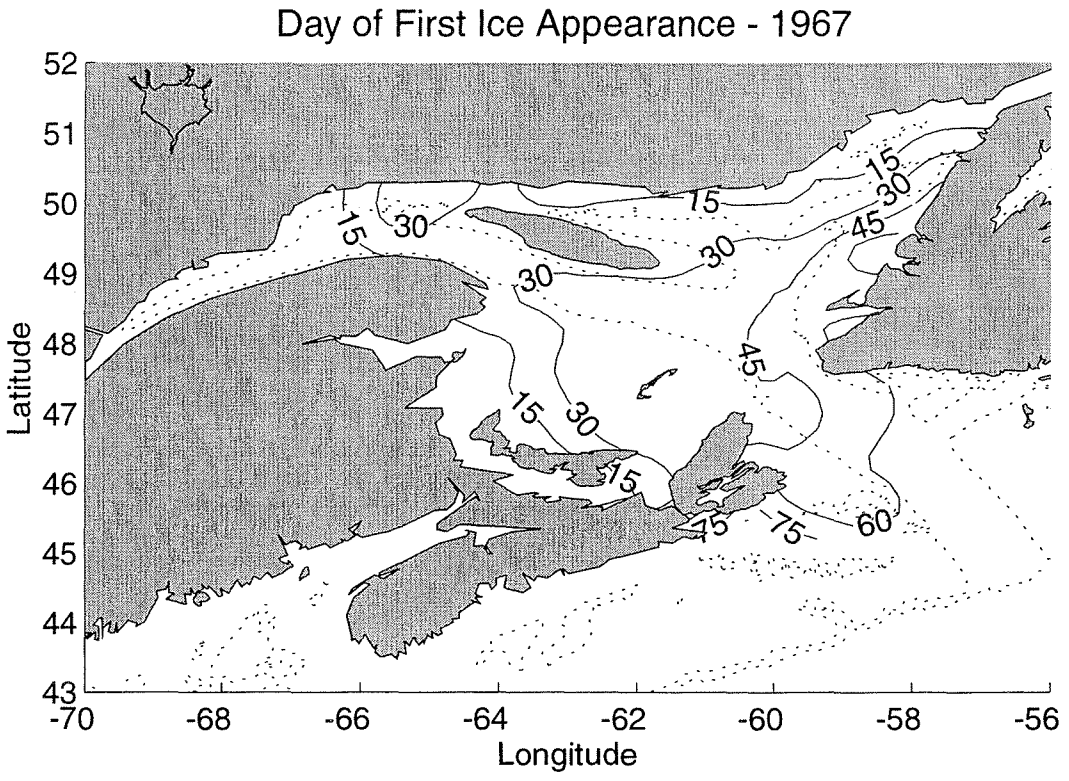
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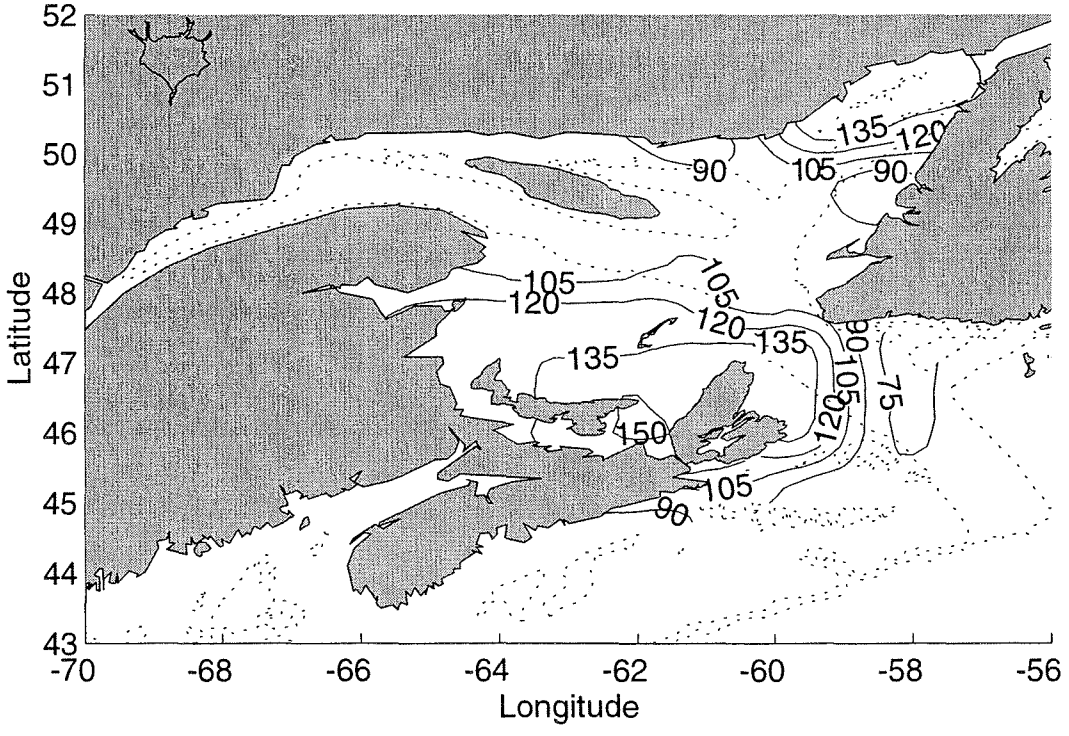
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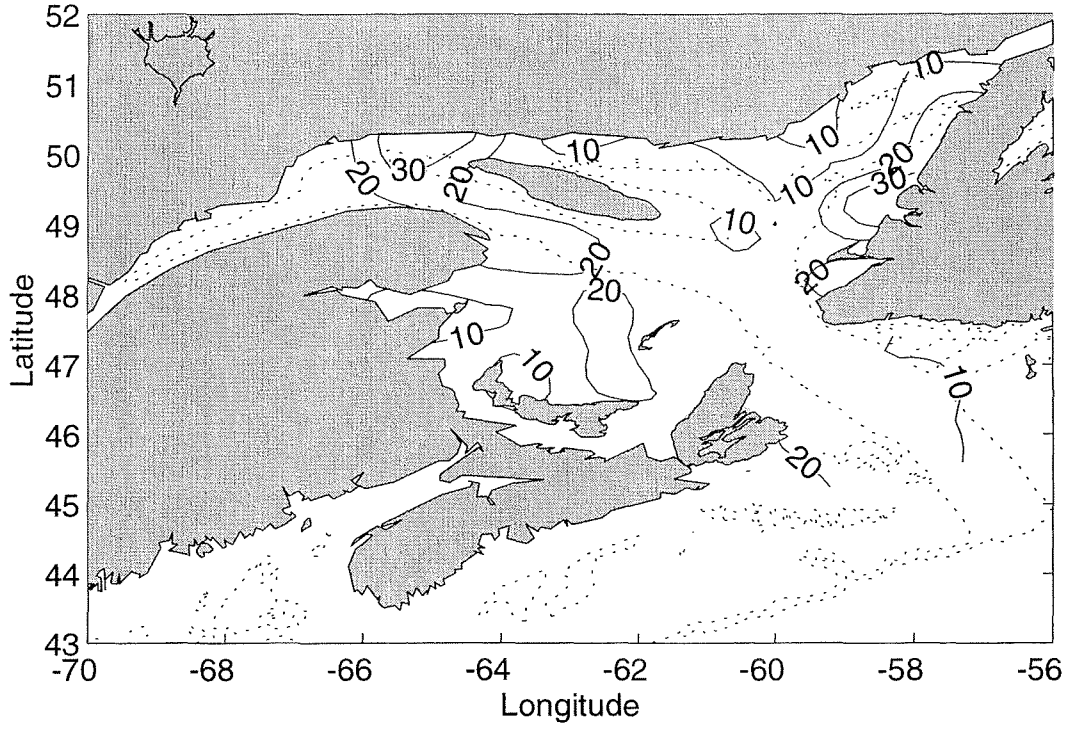
First Ice Appearance (Anomaly in Days) - 1967



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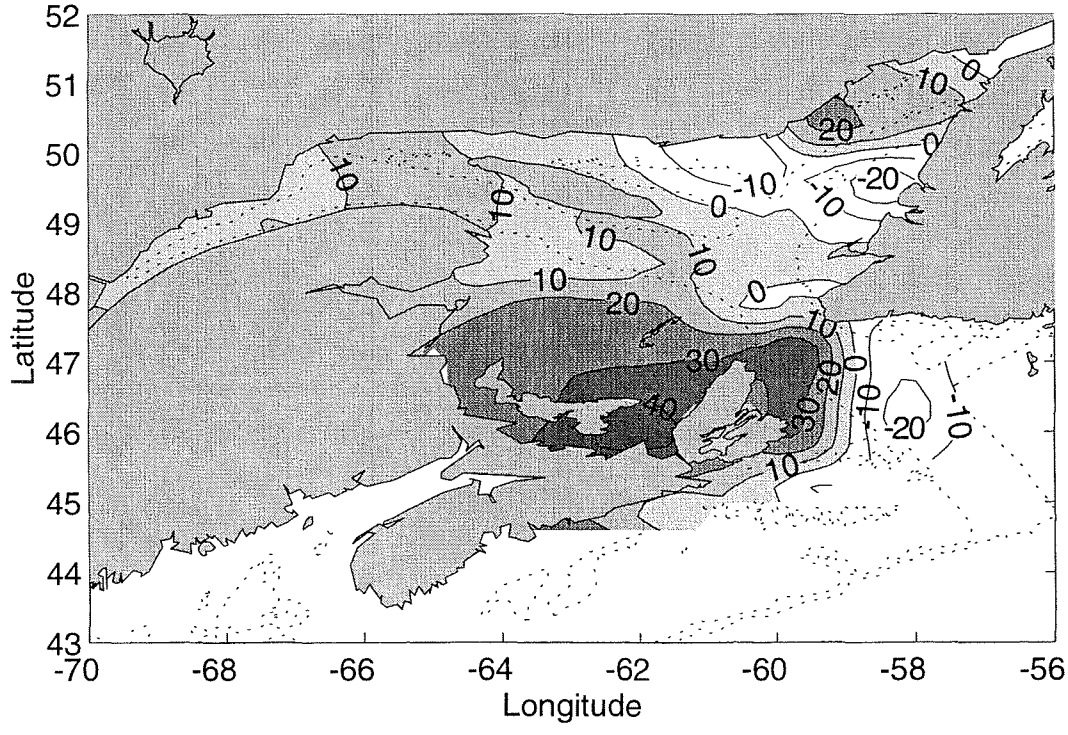

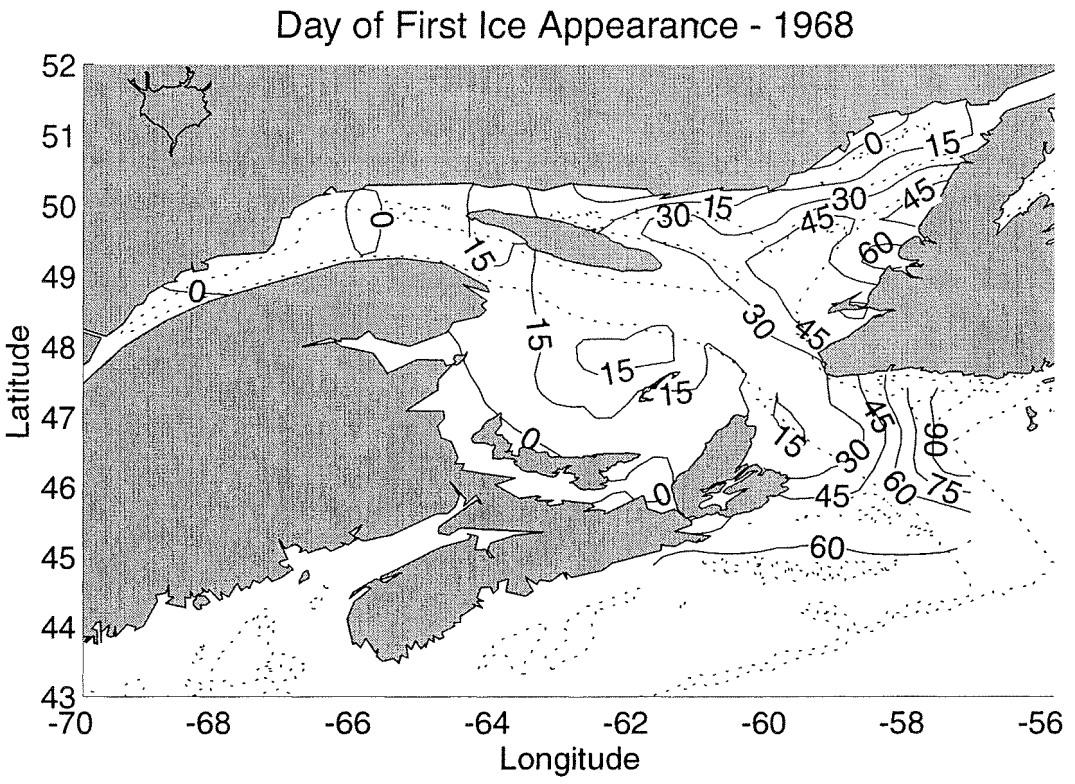
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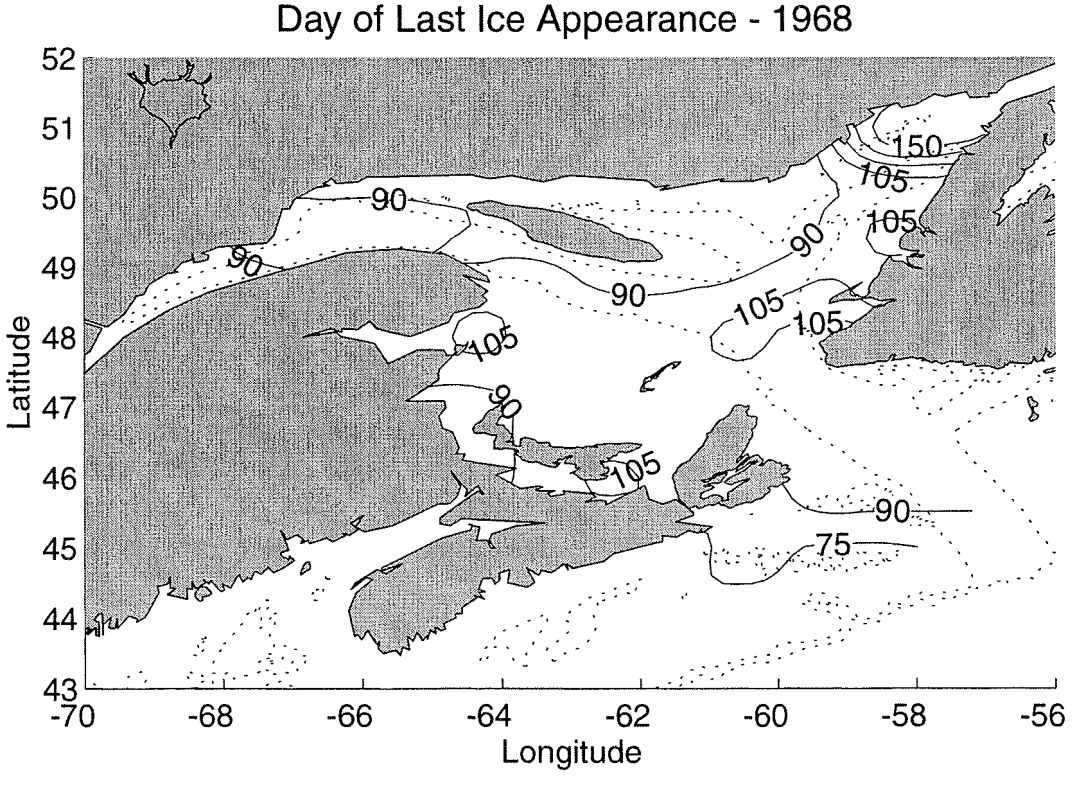
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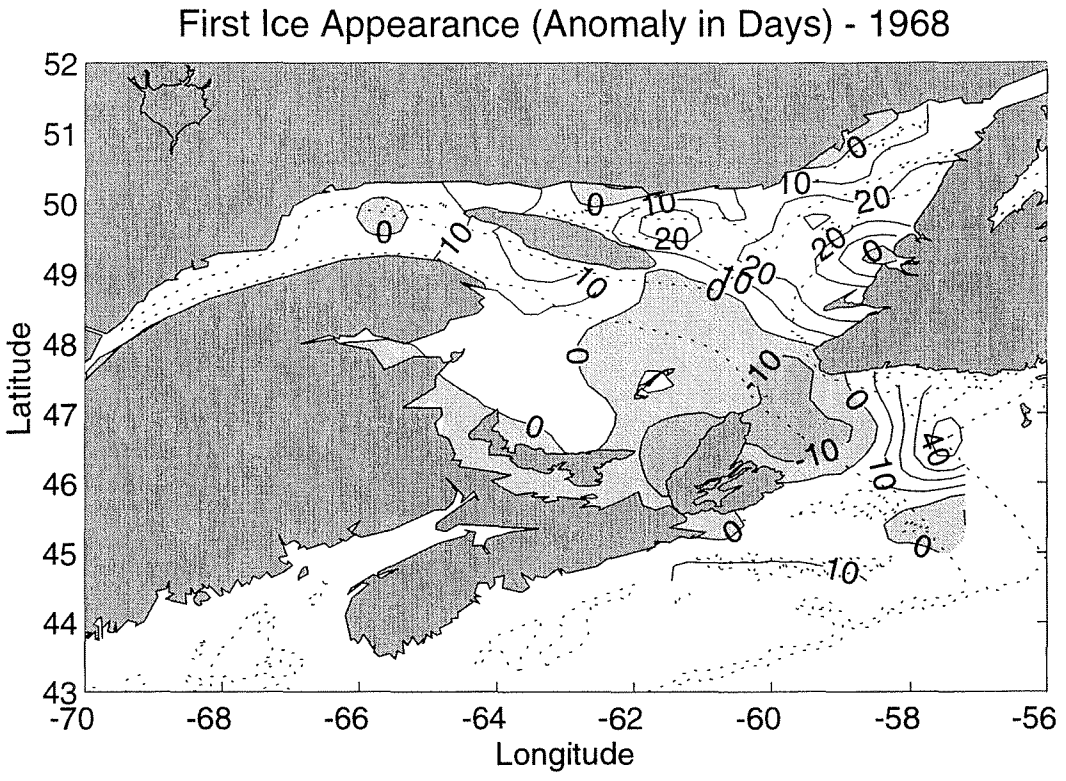
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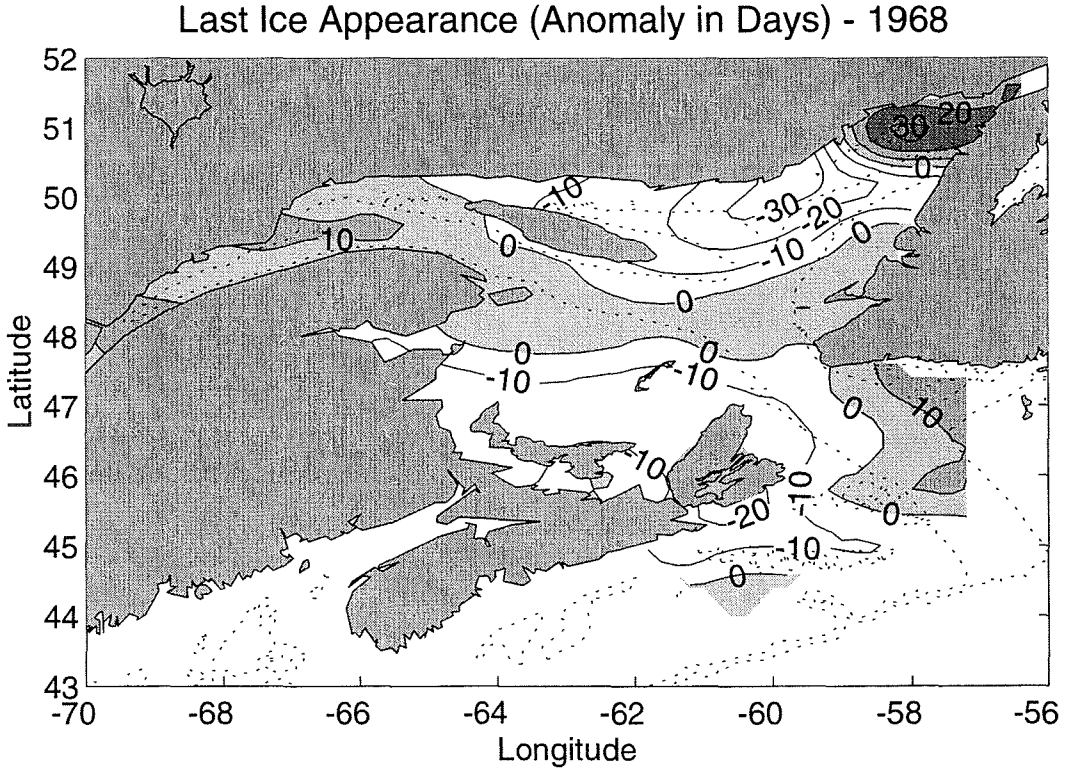
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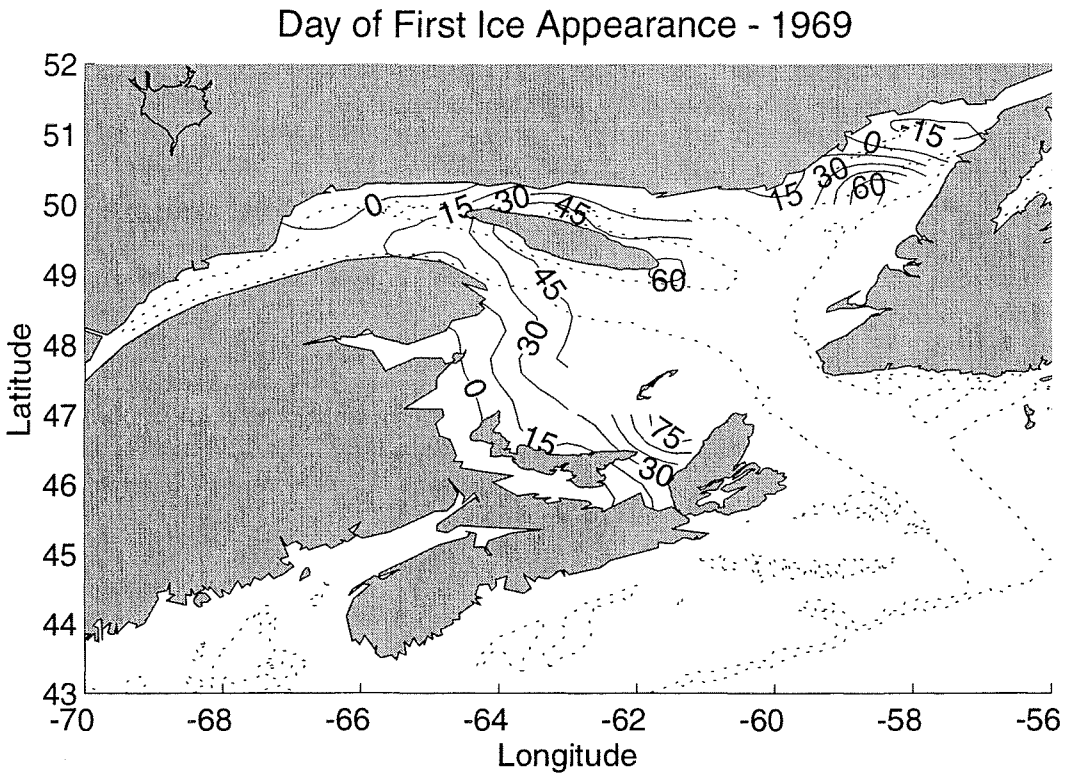
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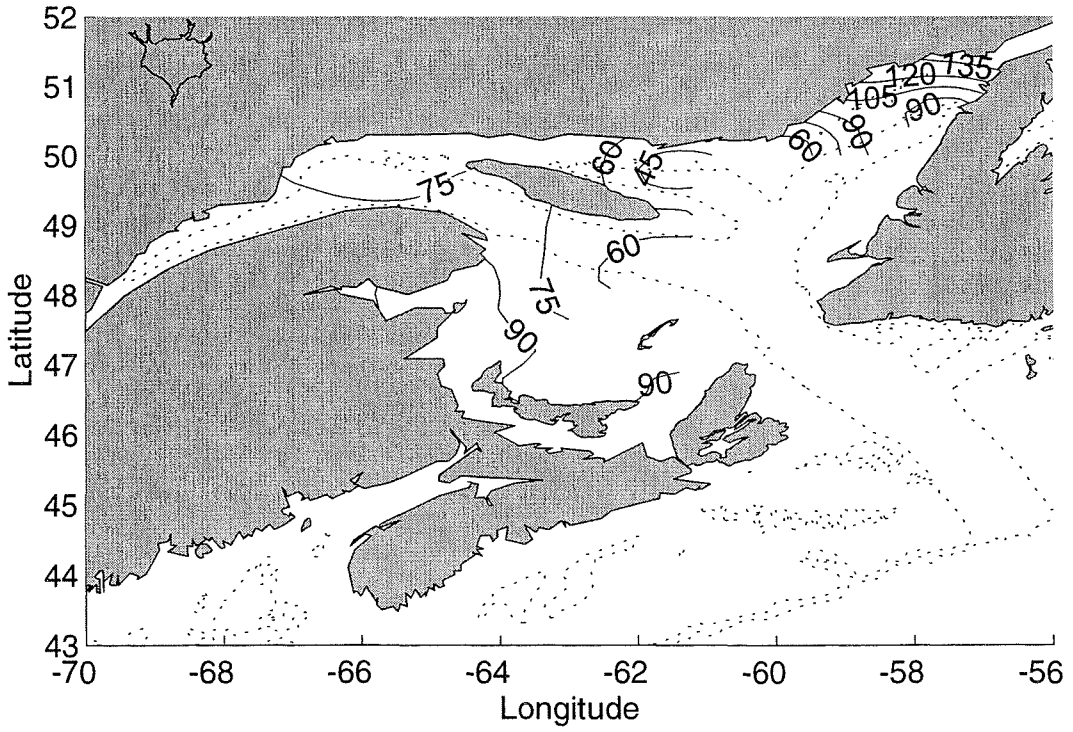
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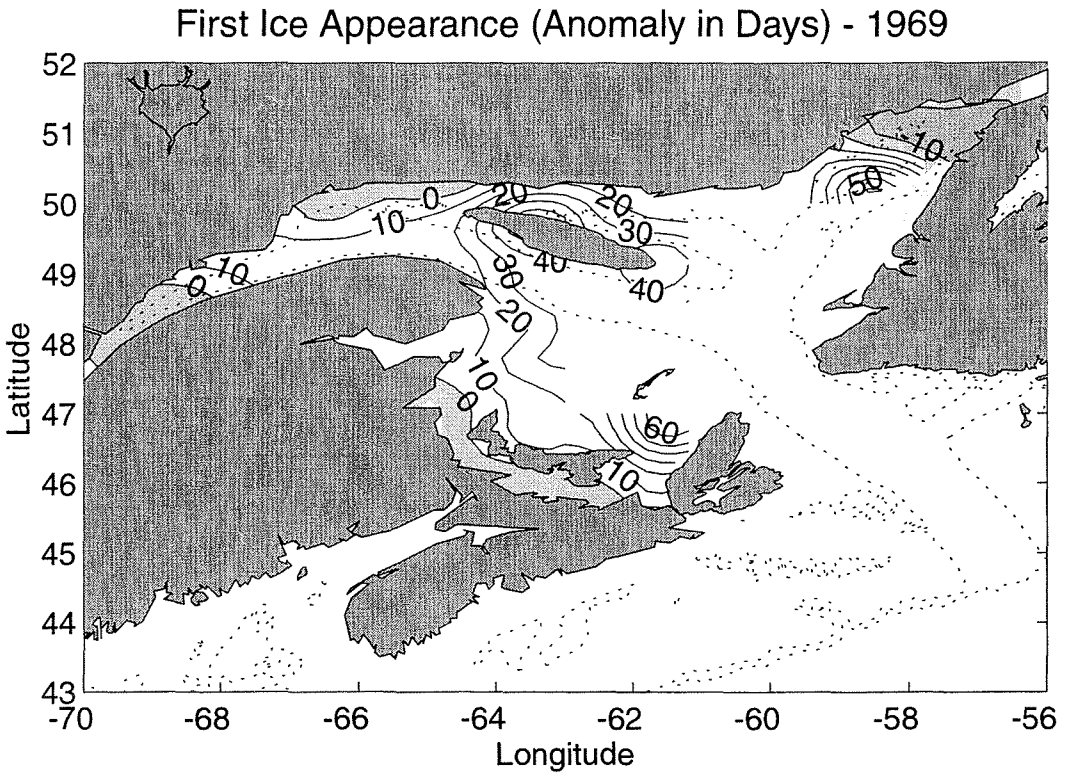
First Ice Appearance (Anomaly in Days) - 1969
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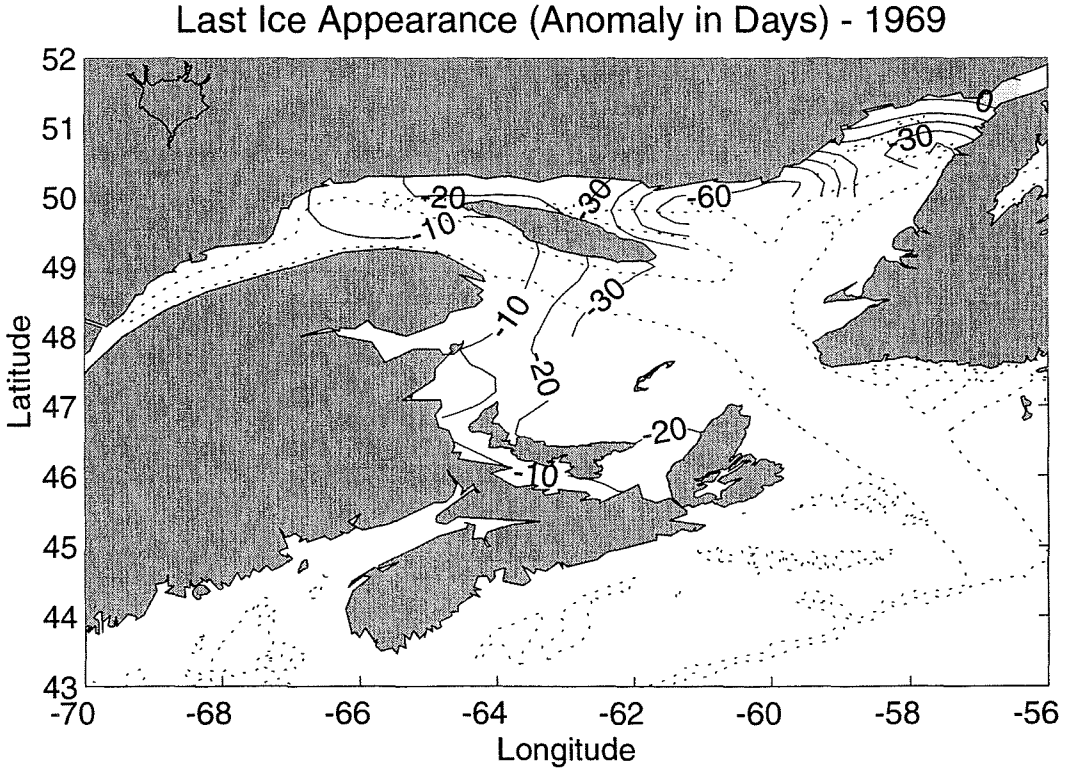
Last Ice Appearance (Anomaly in Days) - 1969
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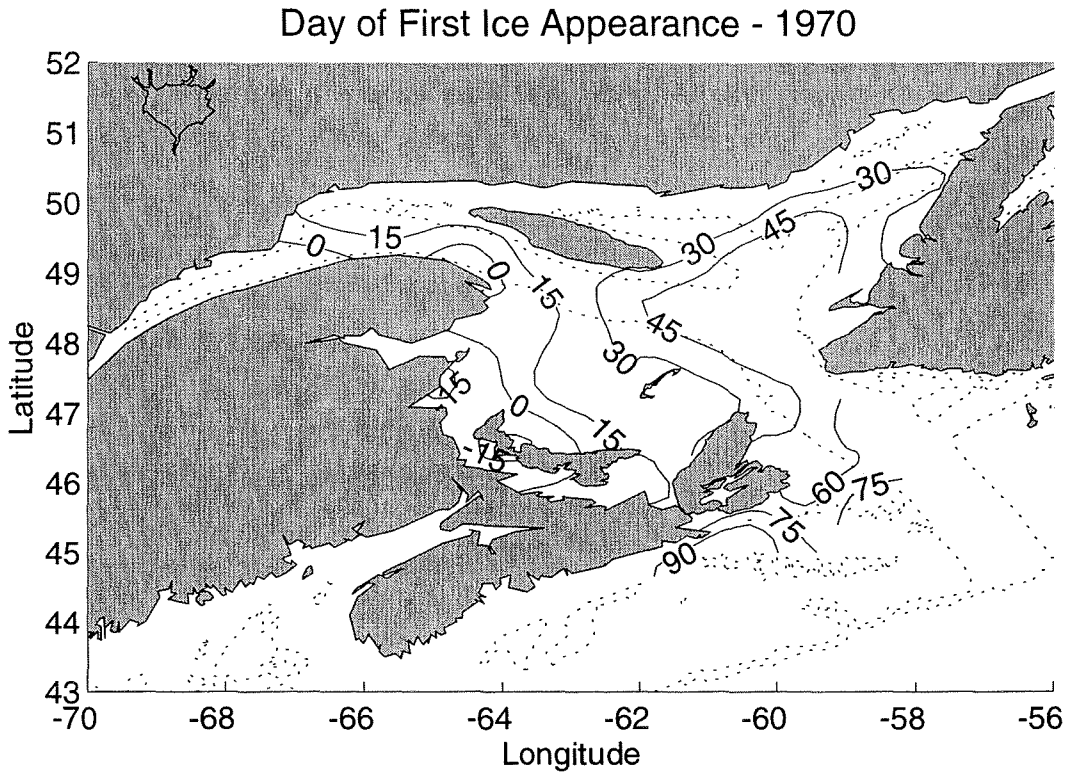
Day of First Ice Appearance - 1970
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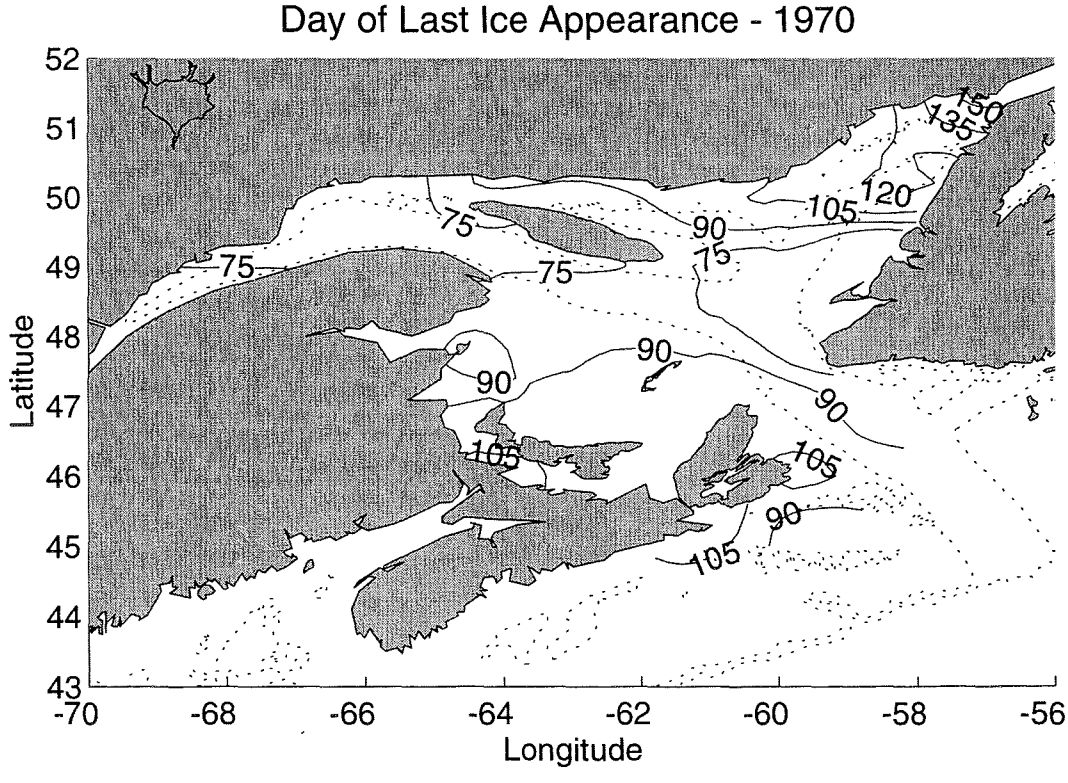
Day of Last Ice Appearance - 1970
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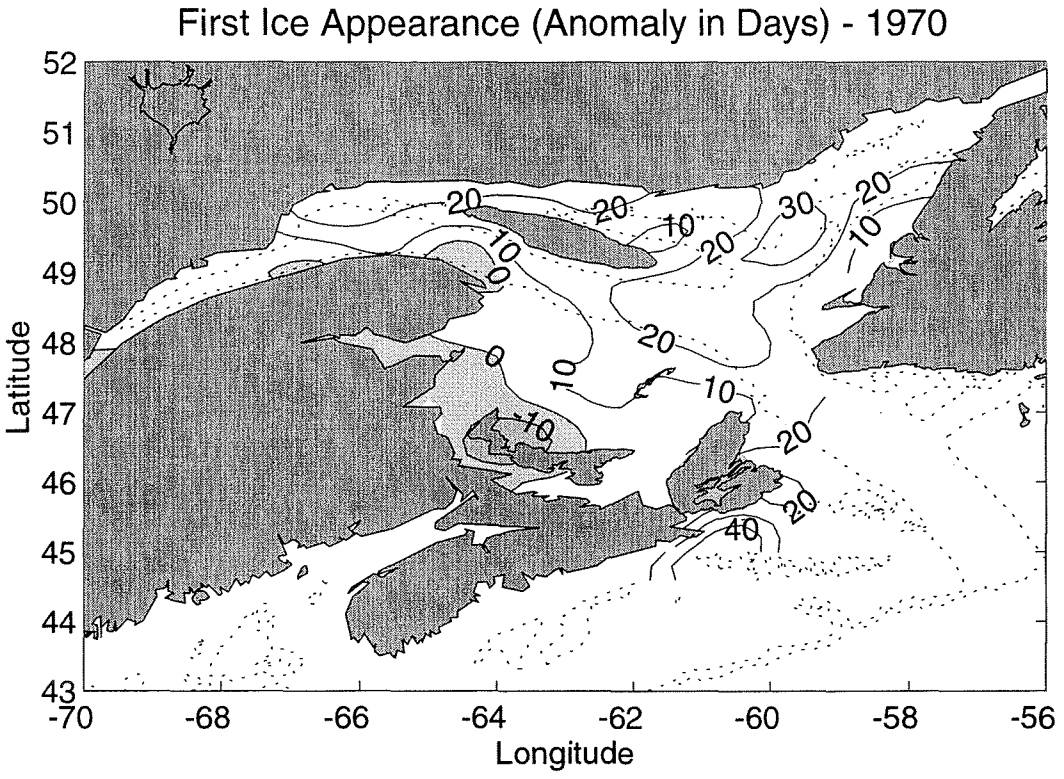
First Ice Appearance (Anomaly in Days) - 1970
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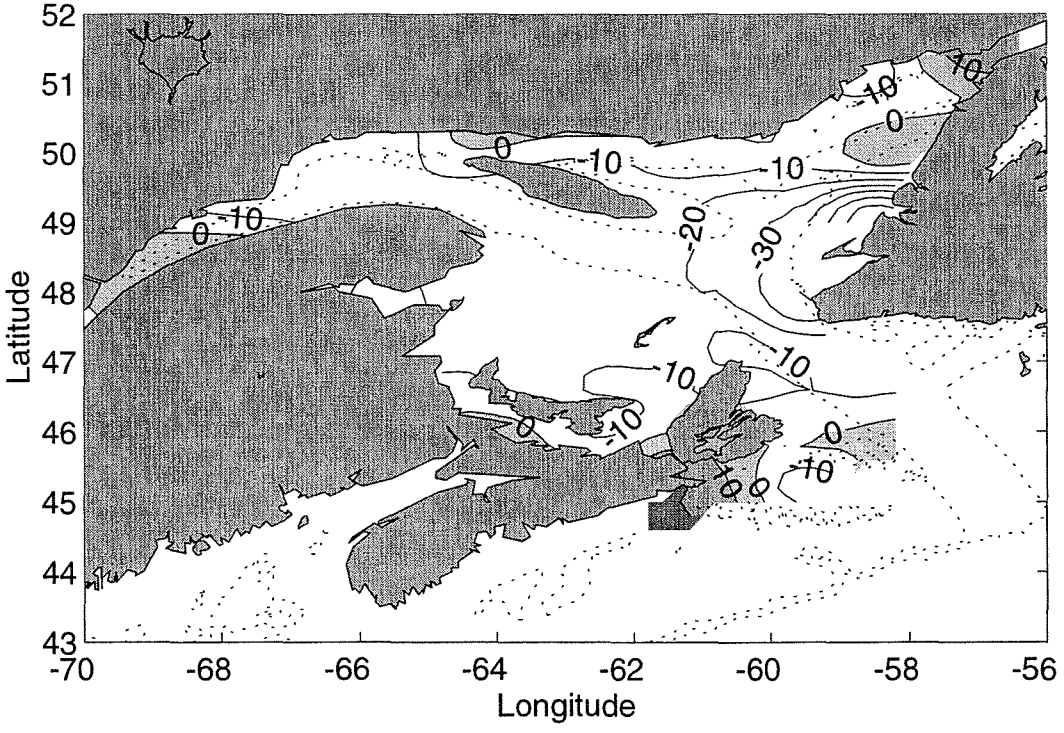
Last Ice Appearance (Anomaly in Days) - 1970
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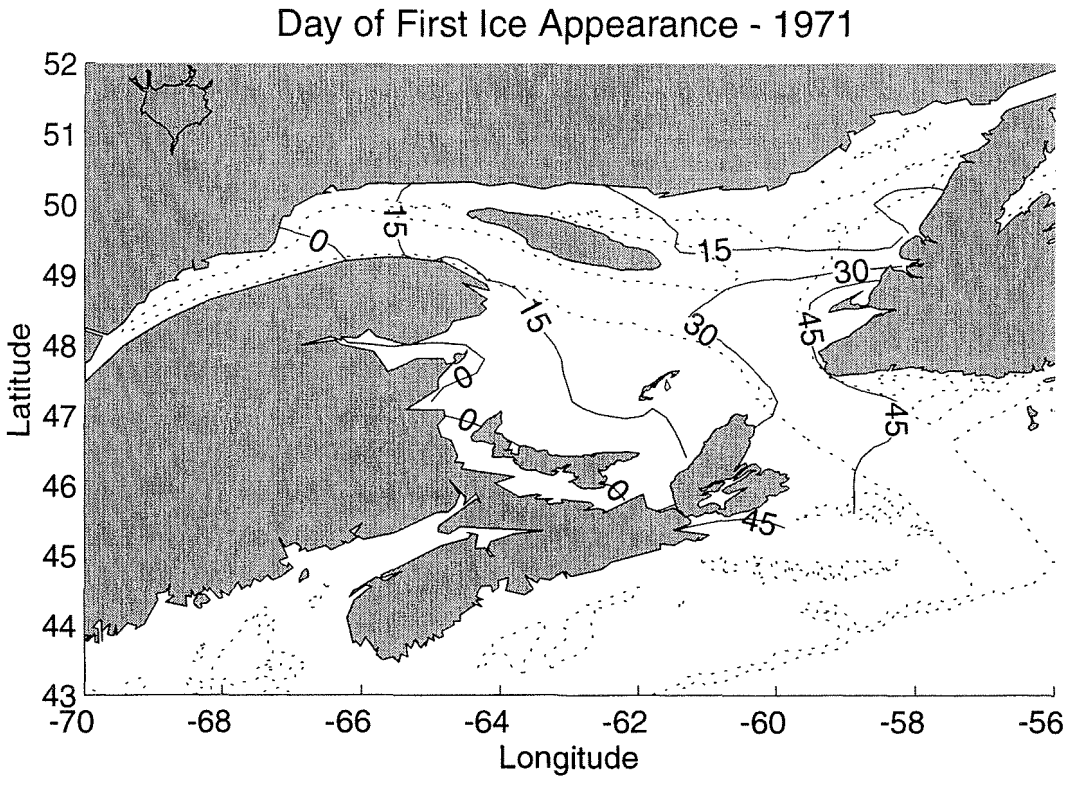
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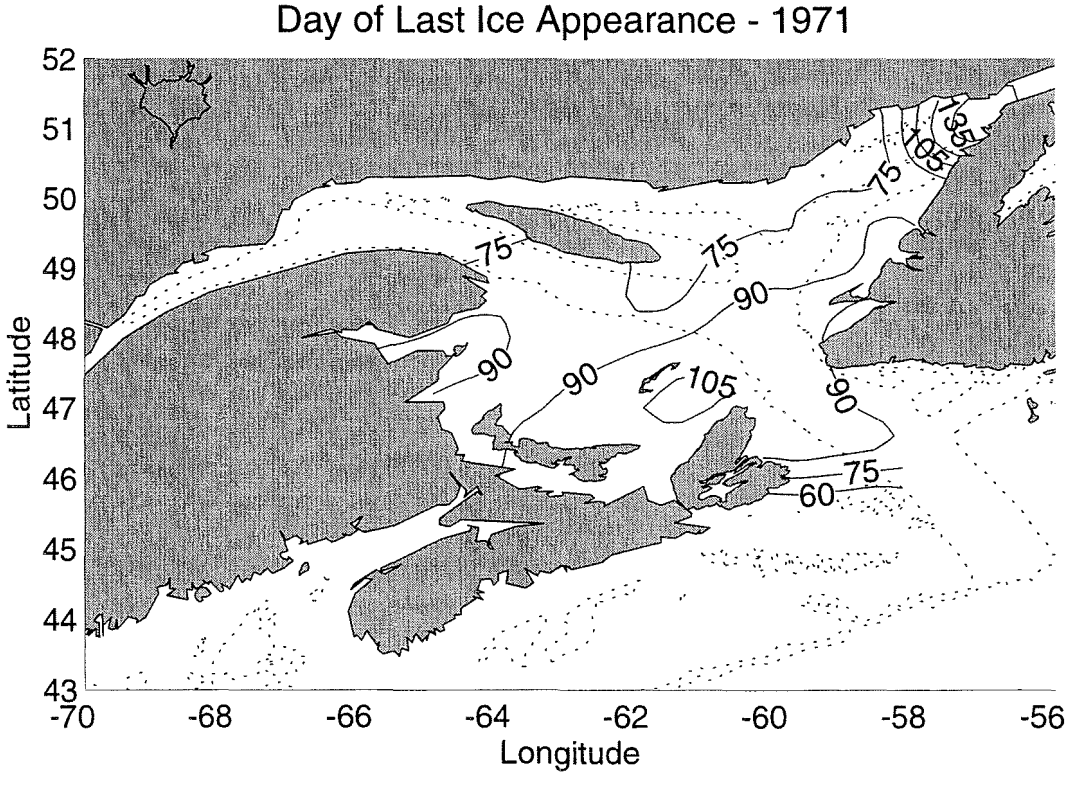
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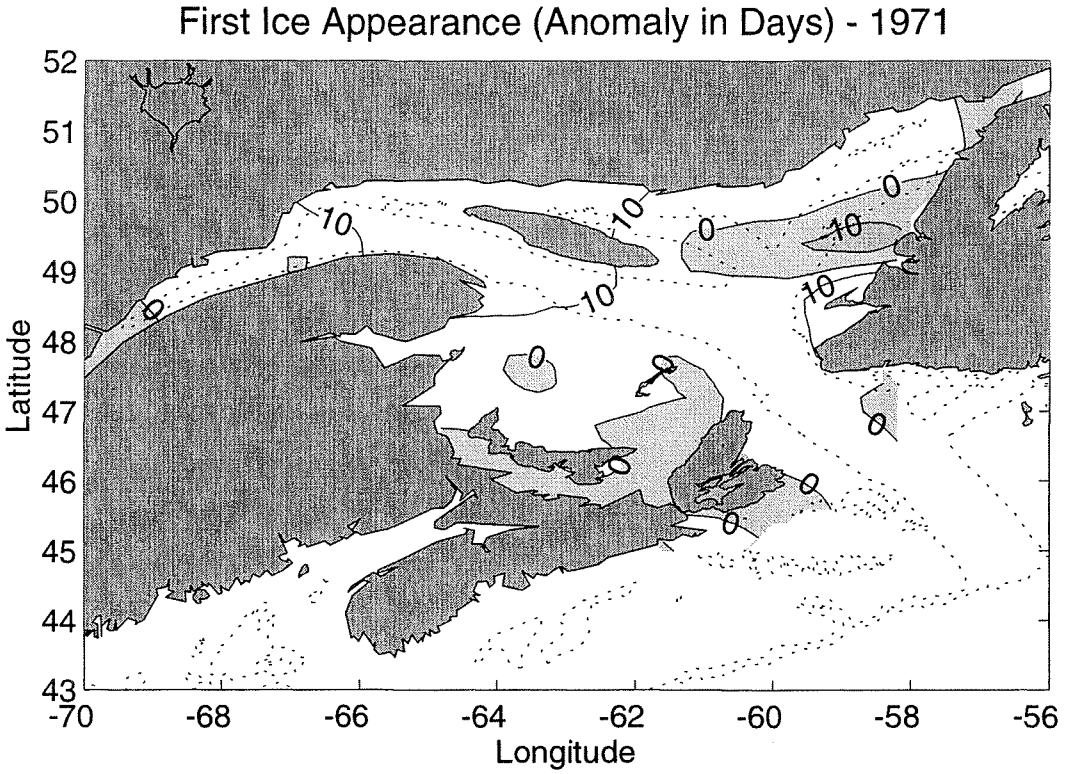
First Ice Appearance (Anomaly in Days) - 1971
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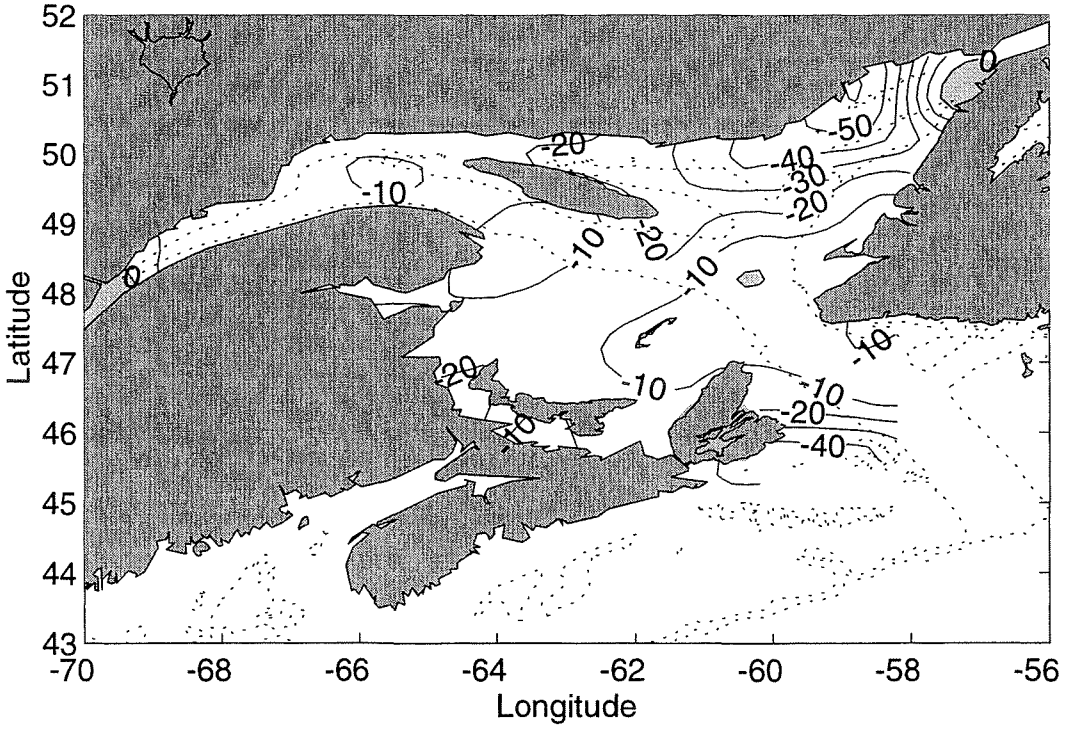
Last Ice Appearance (Anomaly in Days) - 1971
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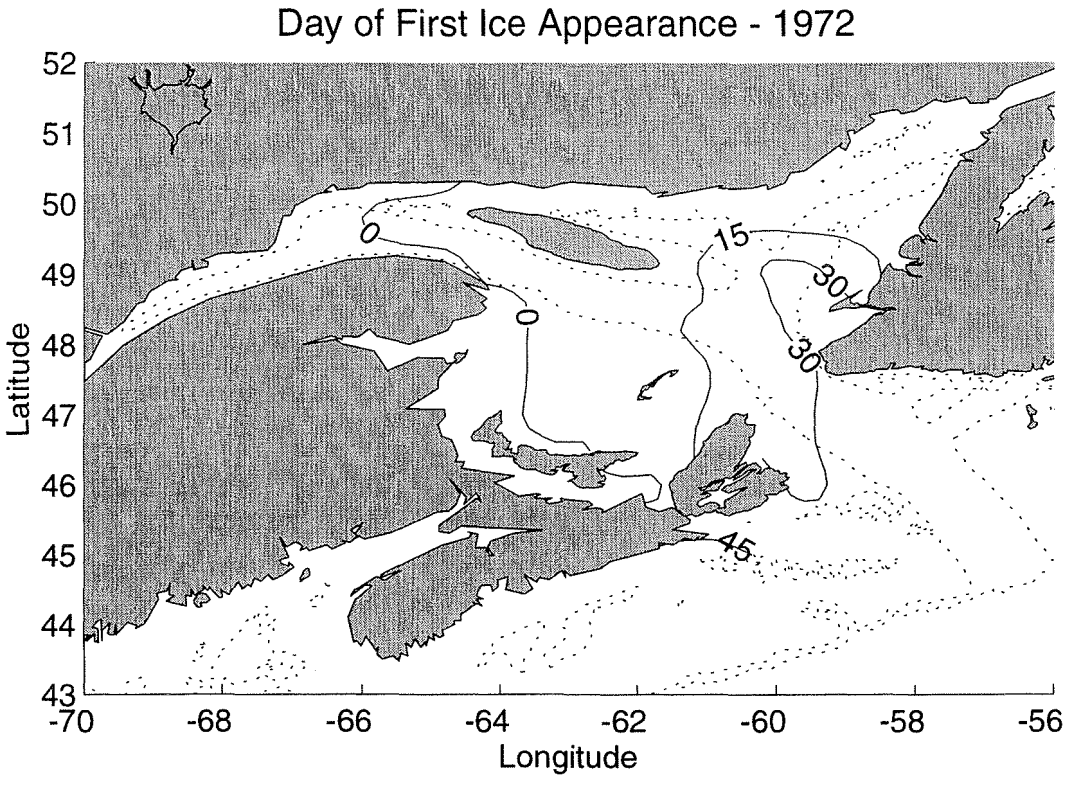
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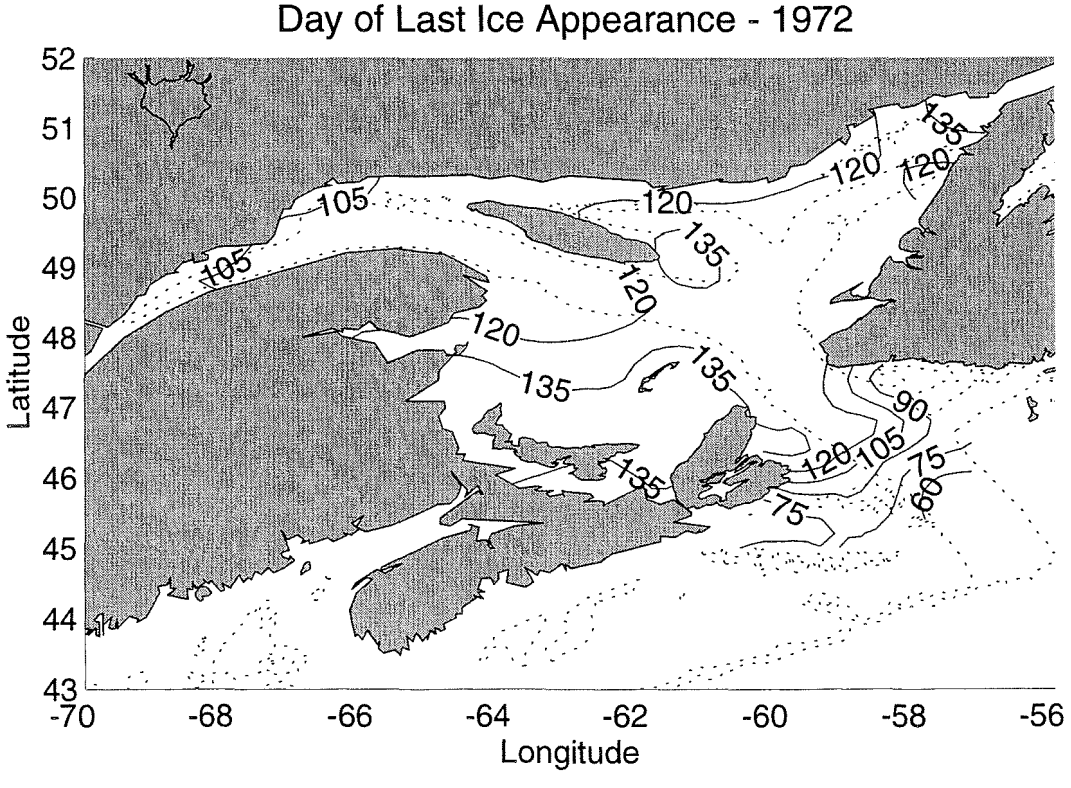
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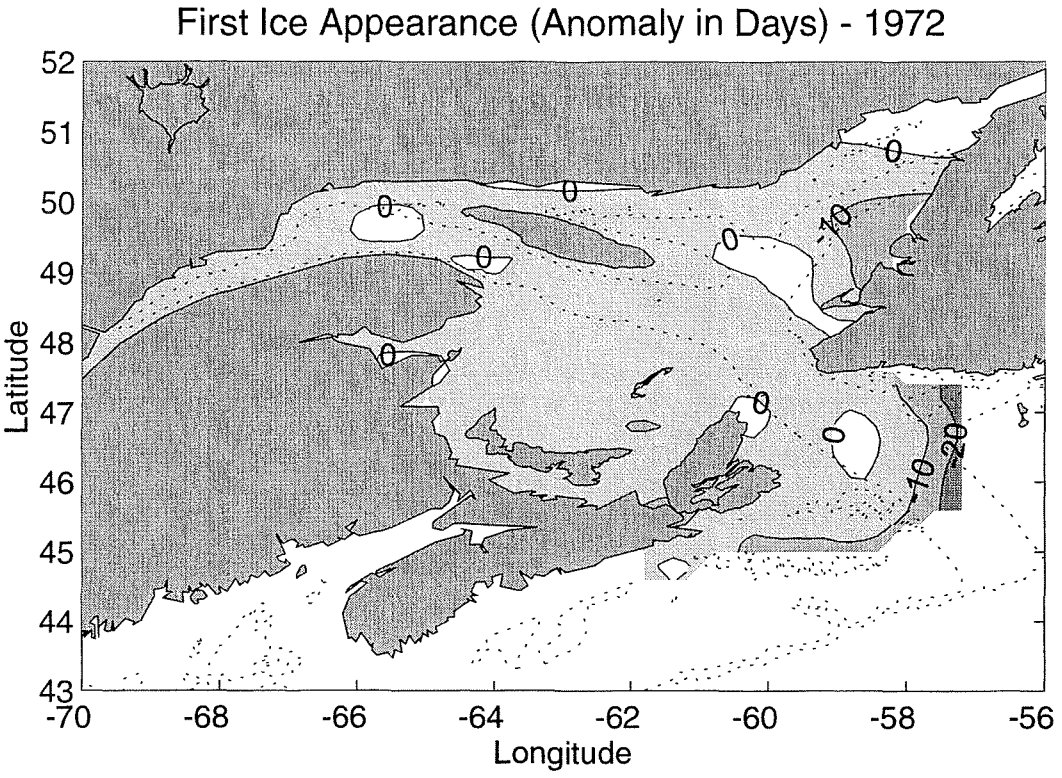
First Ice Appearance (Anomaly in Days) - 1972
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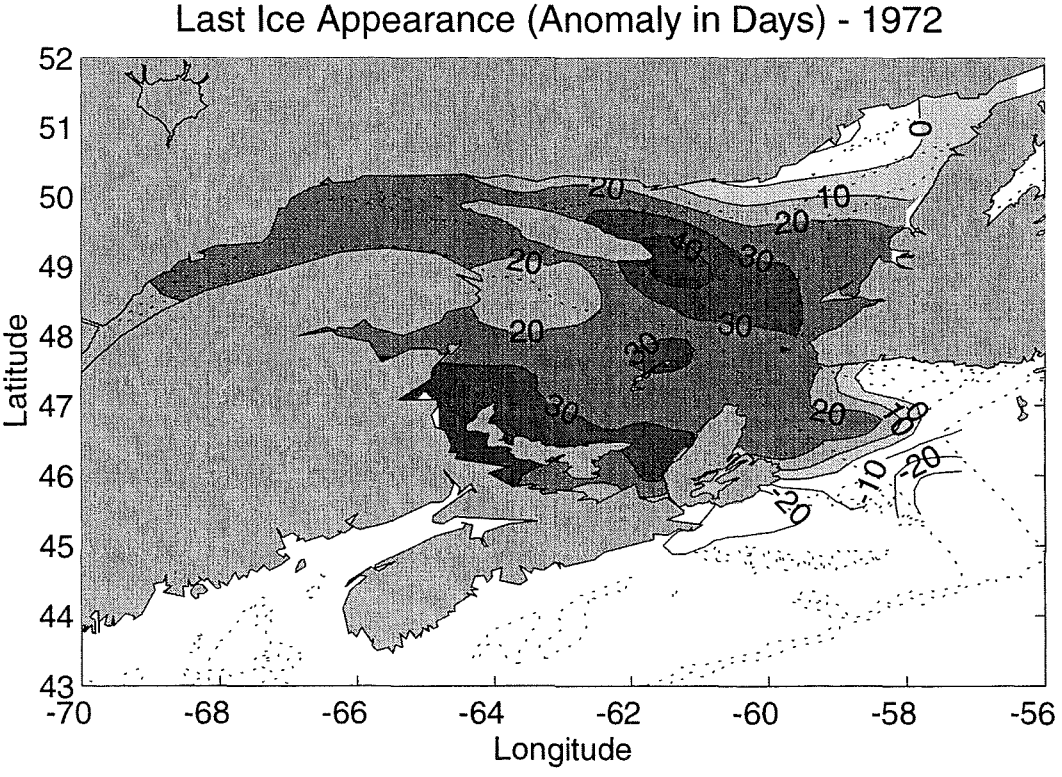
Last Ice Appearance (Anomaly in Days) - 1972
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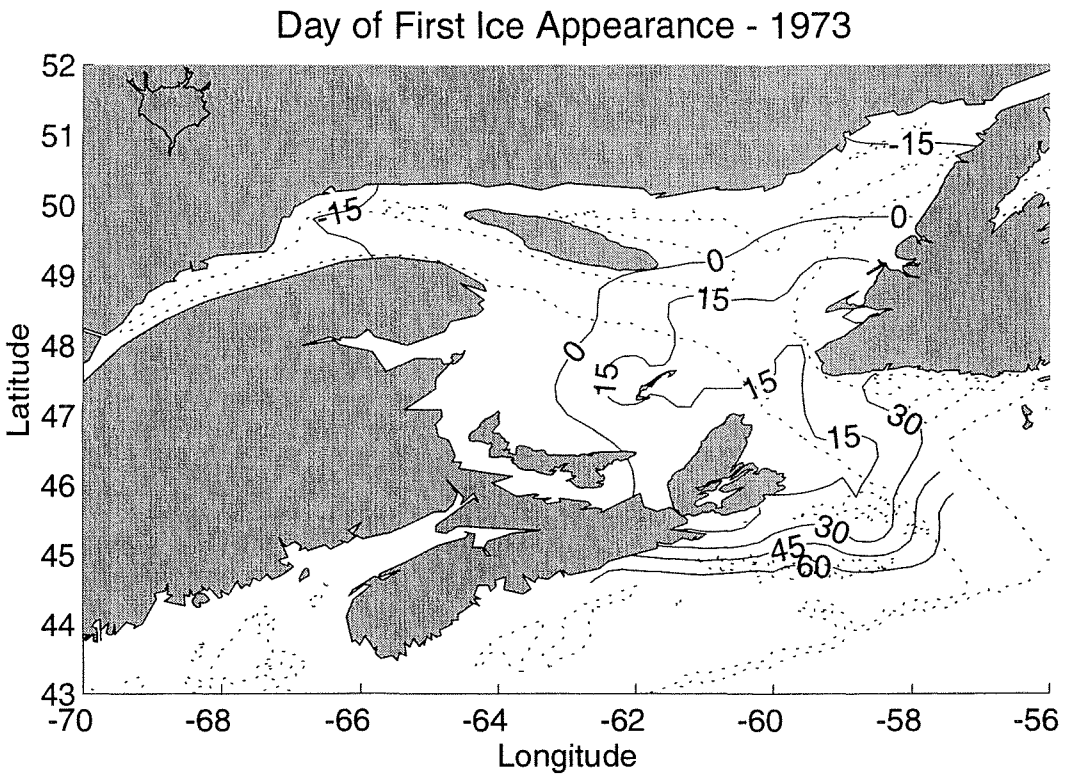
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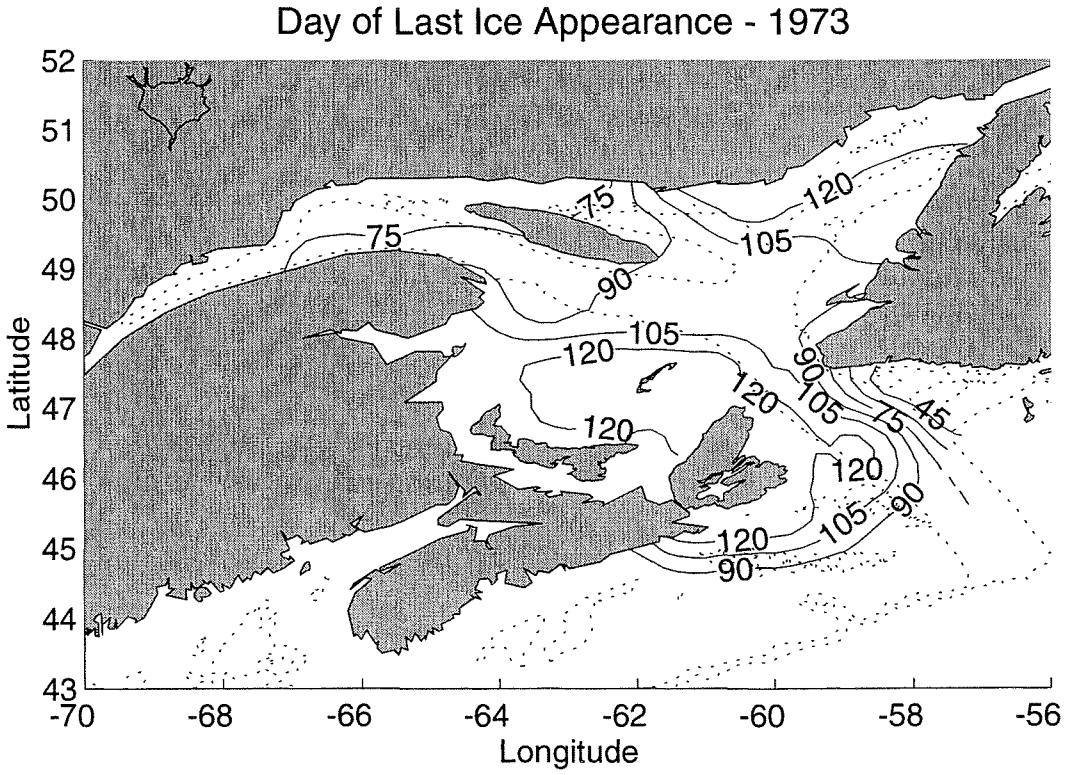
Day of Last Ice Appearance - 1973
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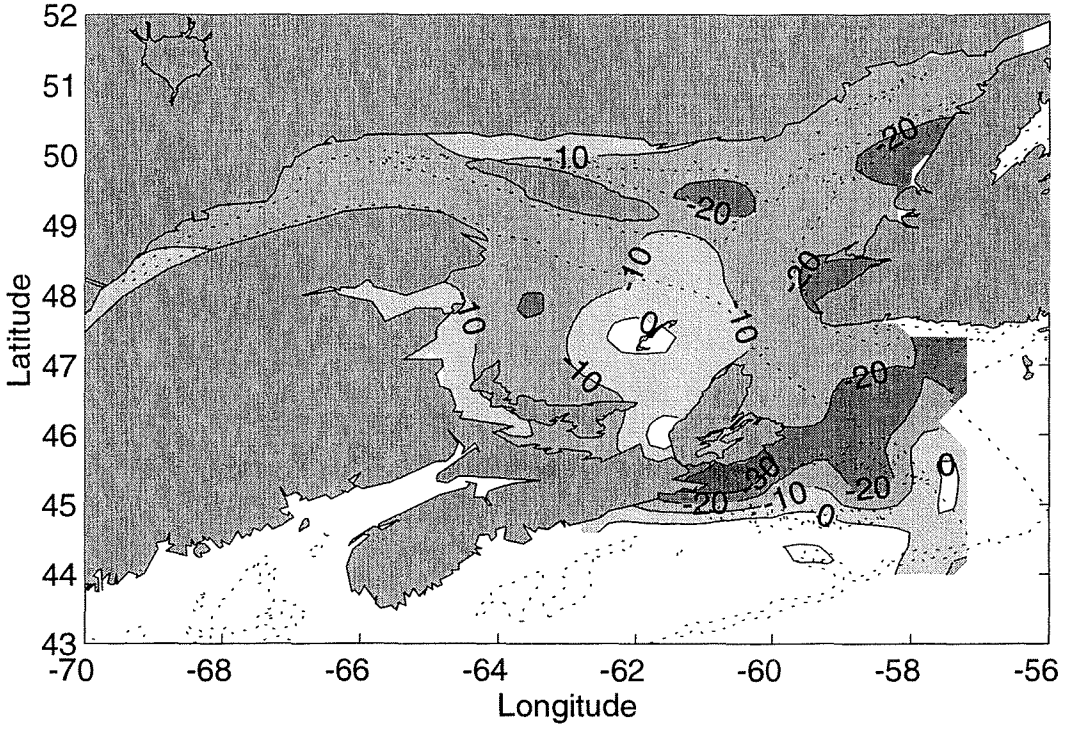
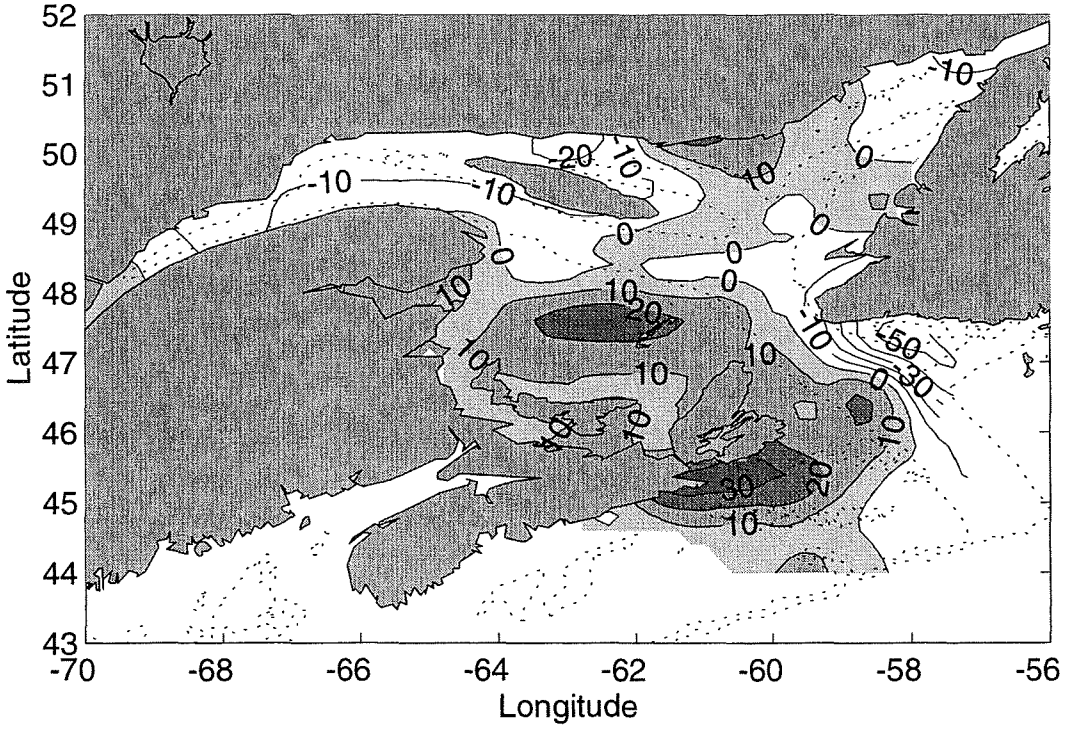
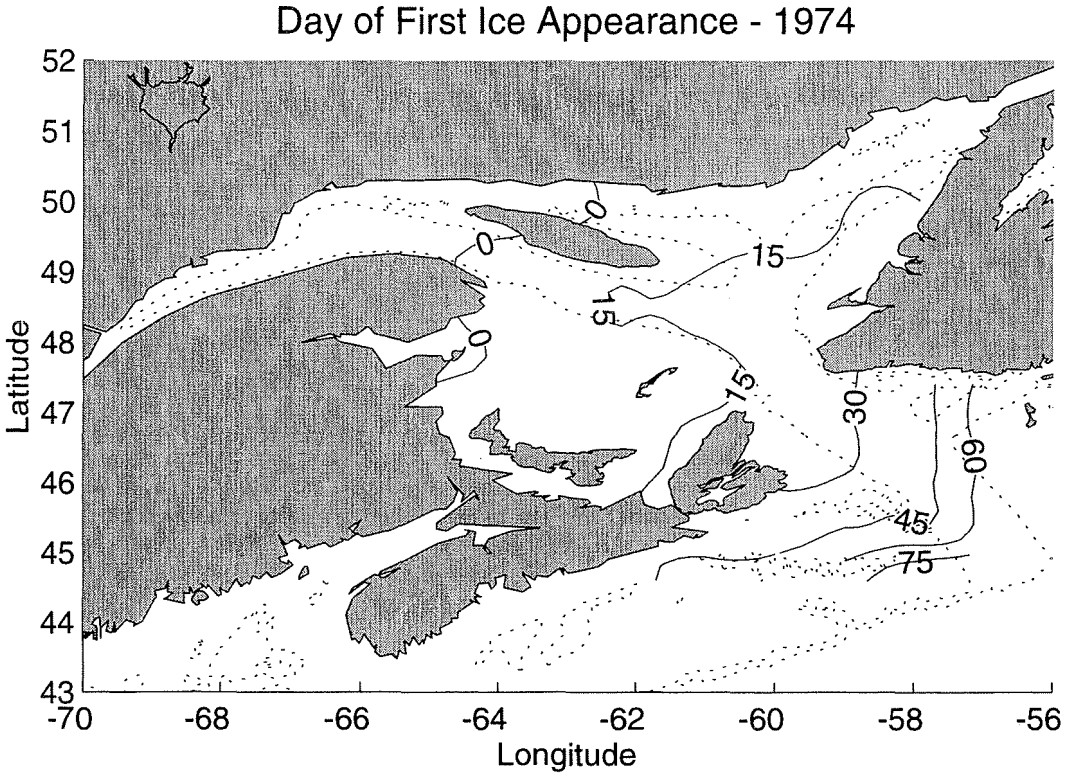
First Ice Appearance (Anomaly in Days) - 1973



Last Ice Appearance (Anomaly in Days) - 1973




Day of First Ice Appearance - 1974
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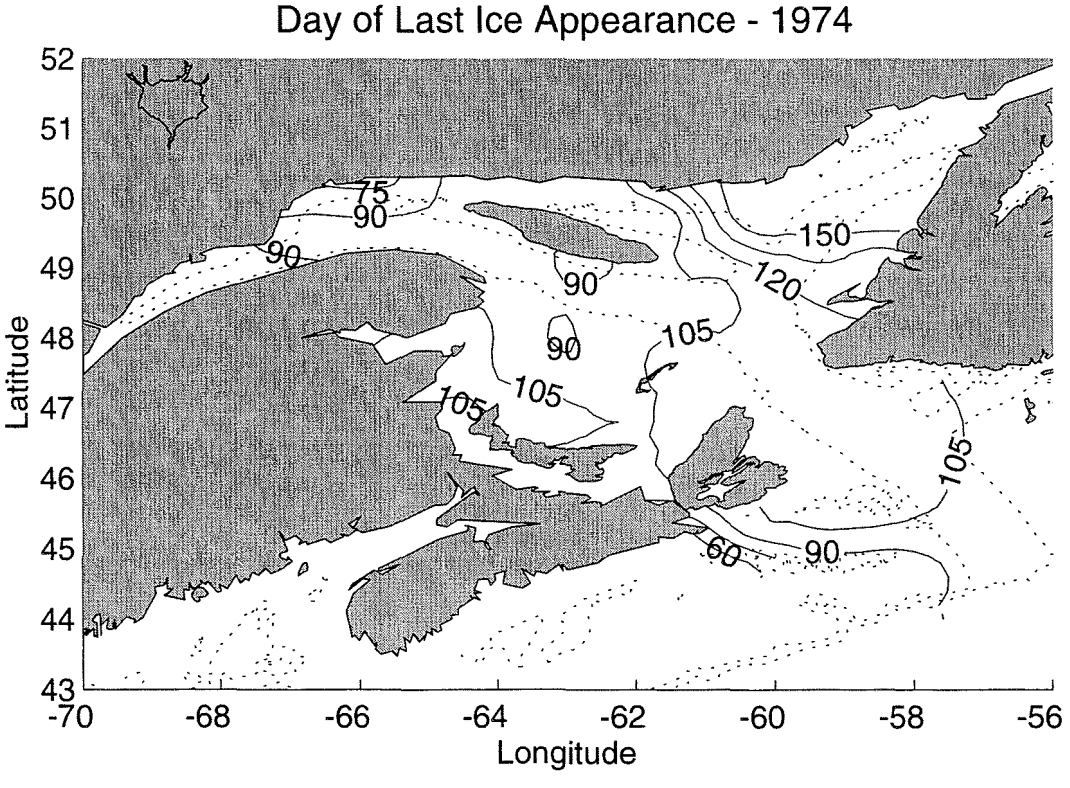
Day of Last Ice Appearance - 1974
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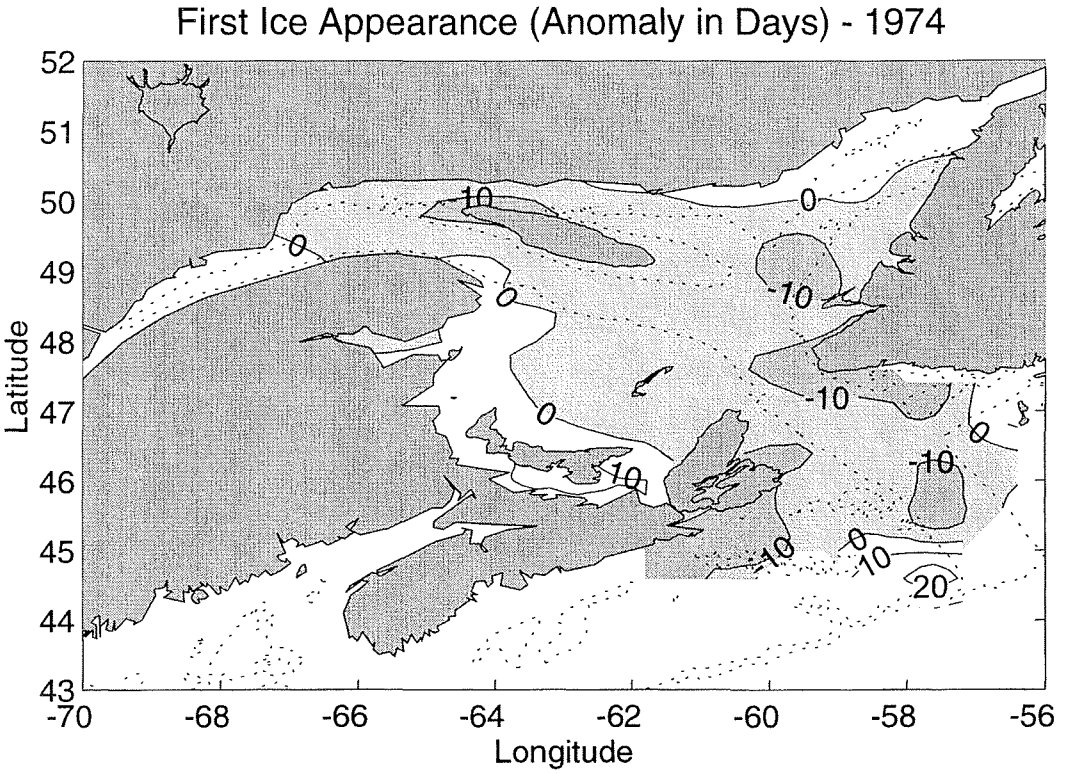
First Ice Appearance (Anomaly in Days) - 1974
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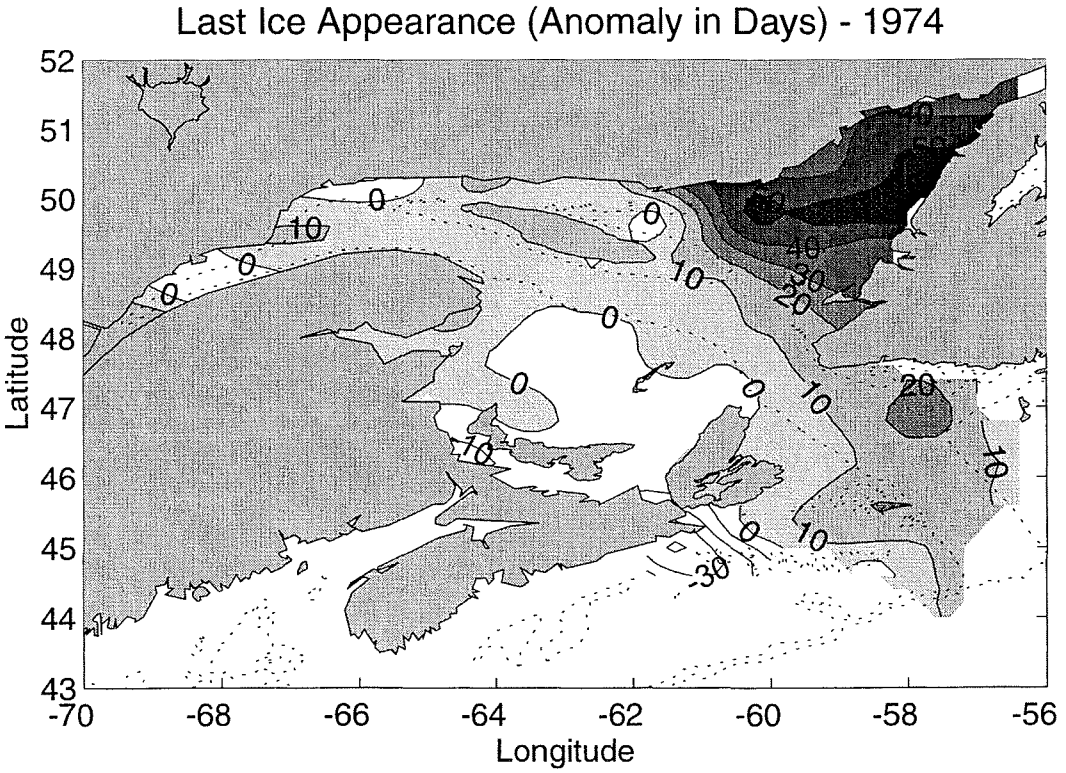
Last Ice Appearance (Anomaly in Days) - 1974
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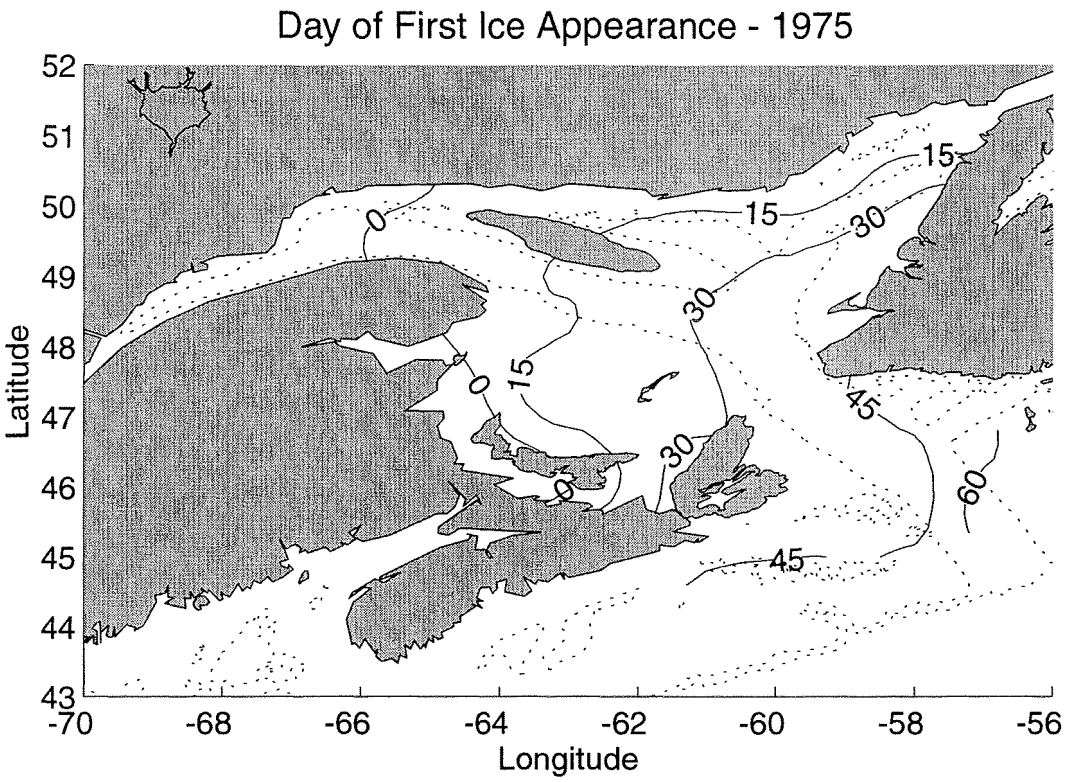
Day of First Ice Appearance - 1975
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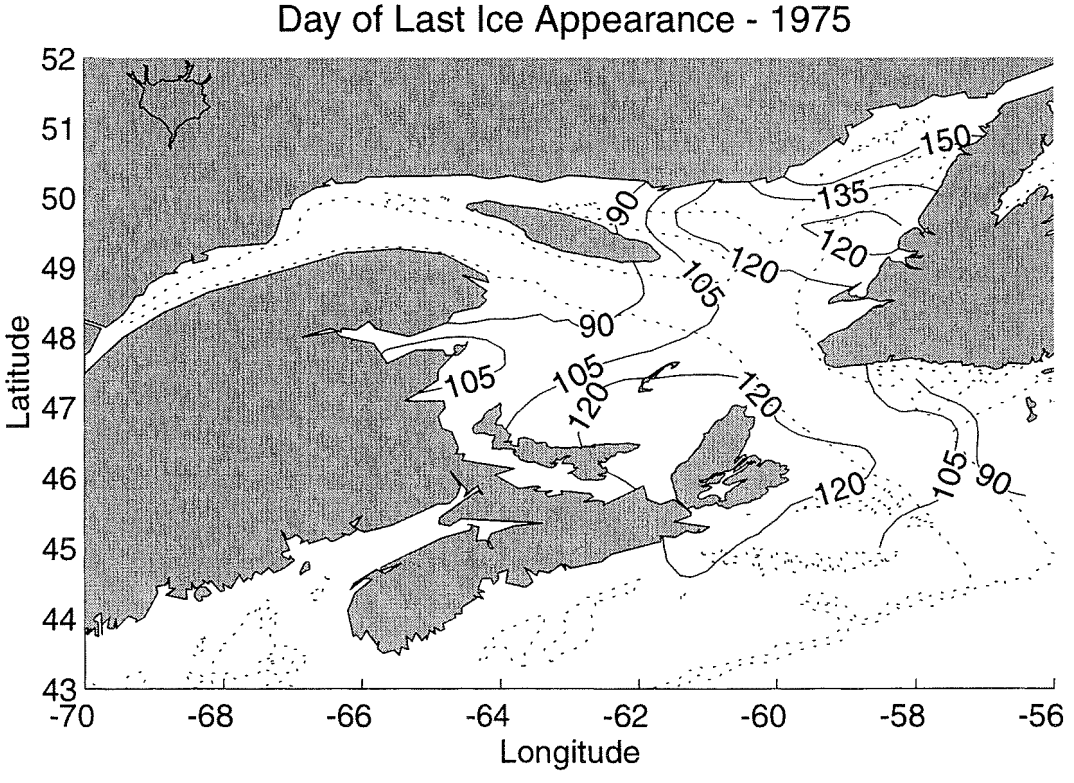
Day of Last Ice Appearance - 1975
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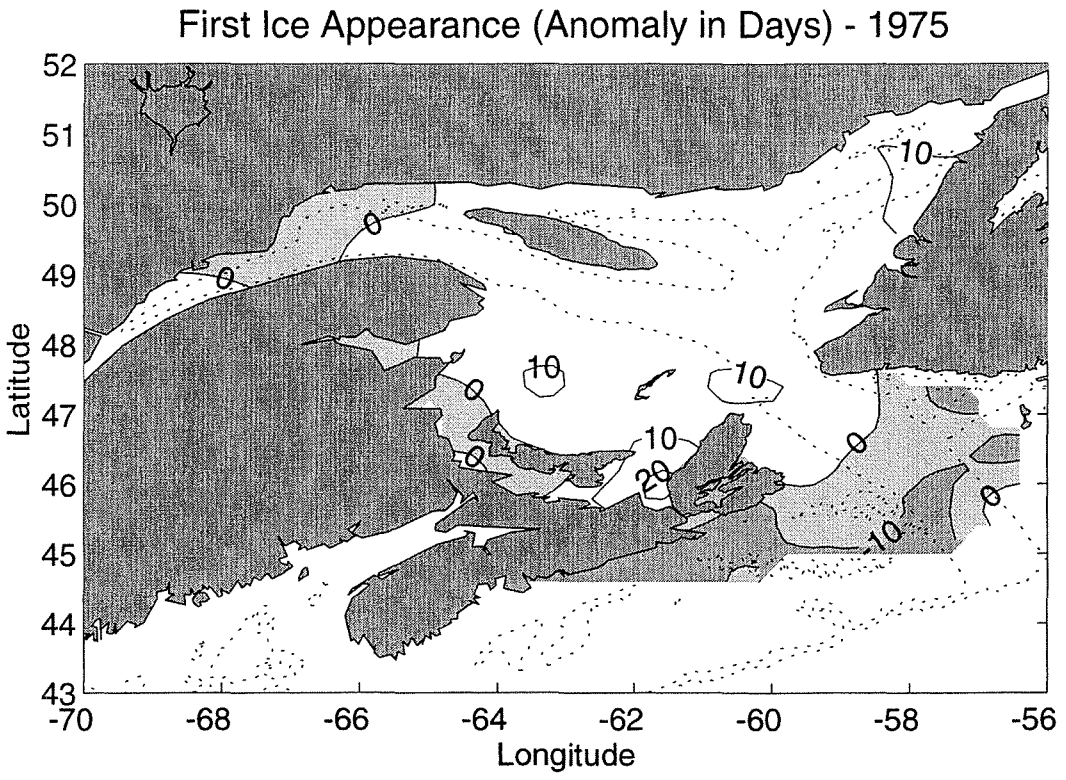
First Ice Appearance (Anomaly in Days) - 1975
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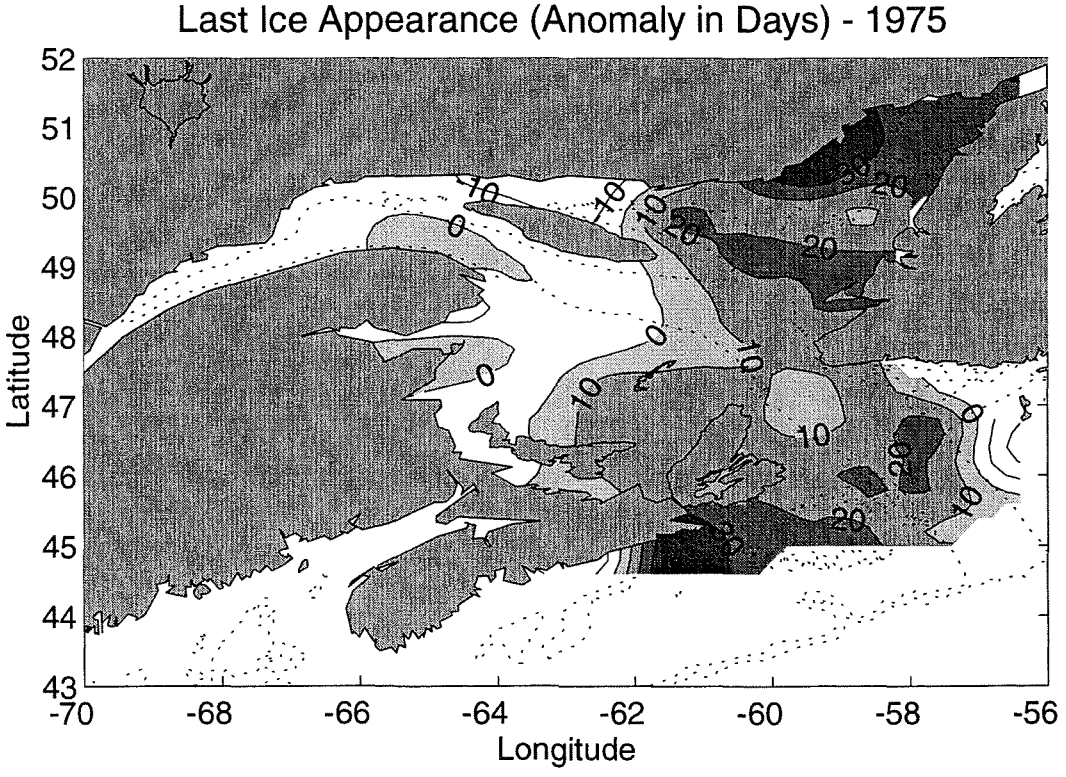
Last Ice Appearance (Anomaly in Days) - 1975
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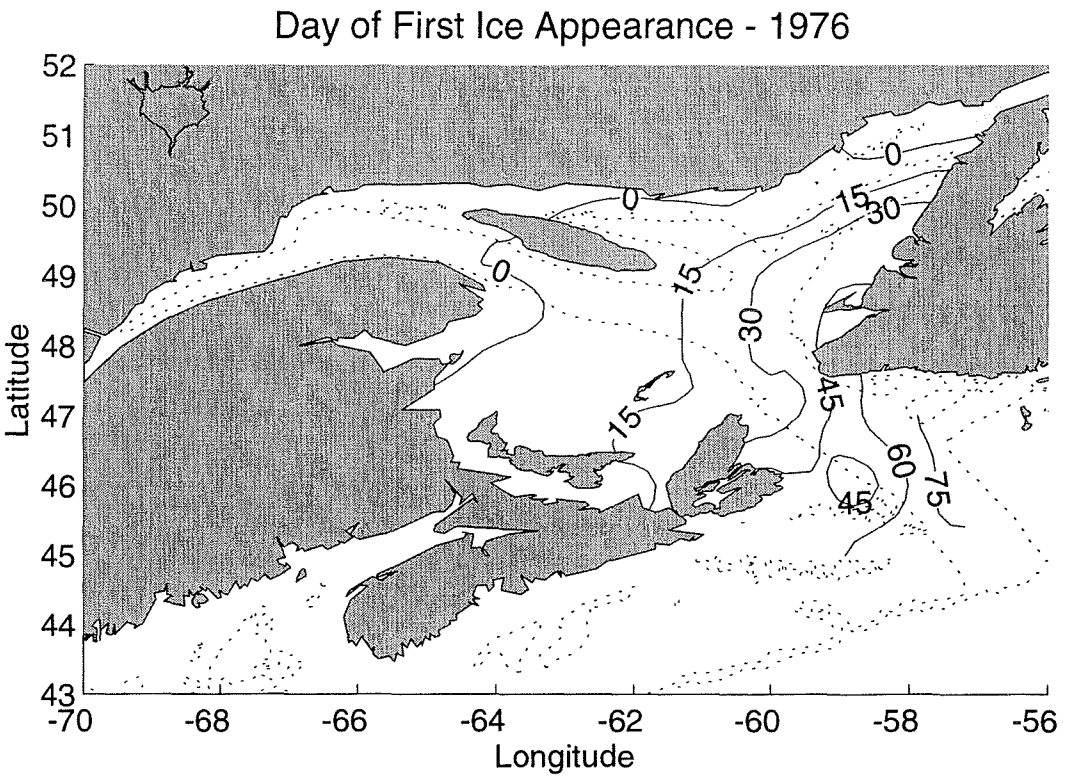
Day of First Ice Appearance - 1976
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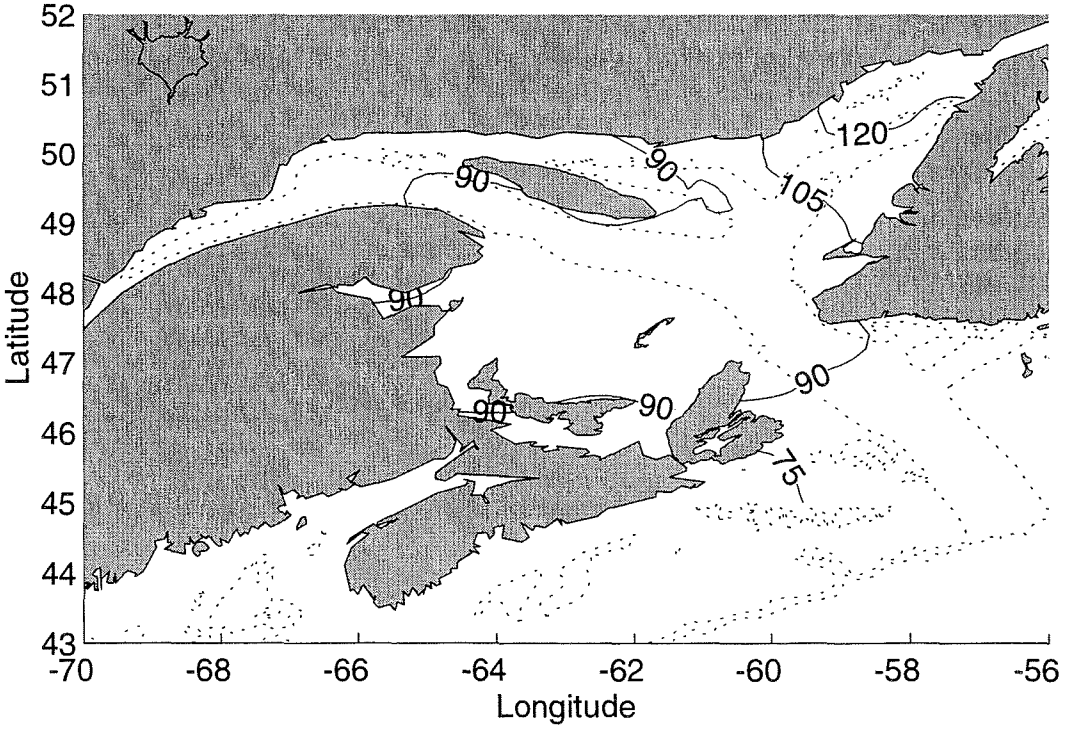
Day of Last Ice Appearance - 1976
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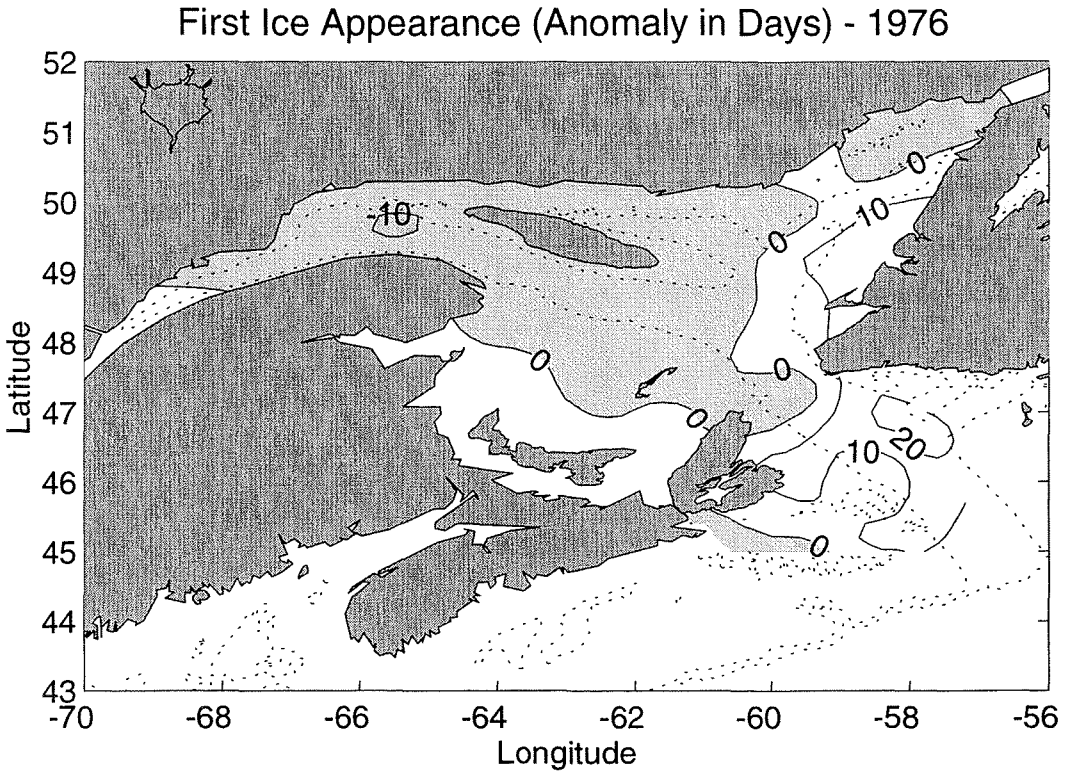
First Ice Appearance (Anomaly in Days) - 1976
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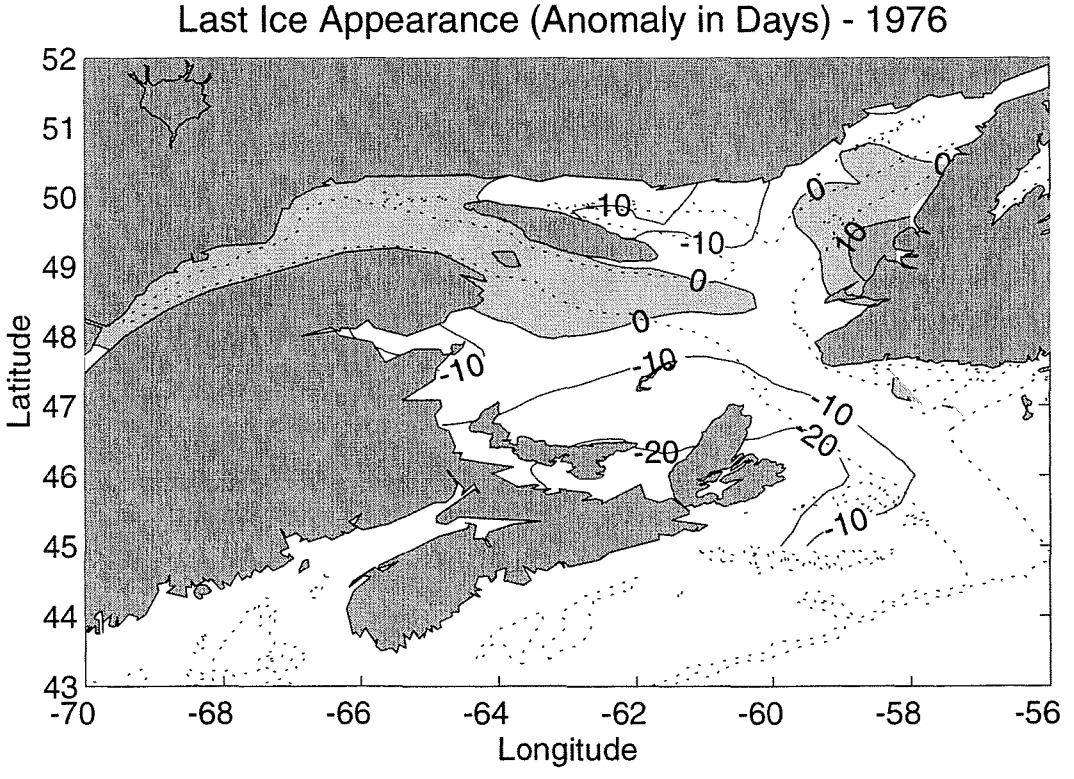
Last Ice Appearance (Anomaly in Days) - 1976
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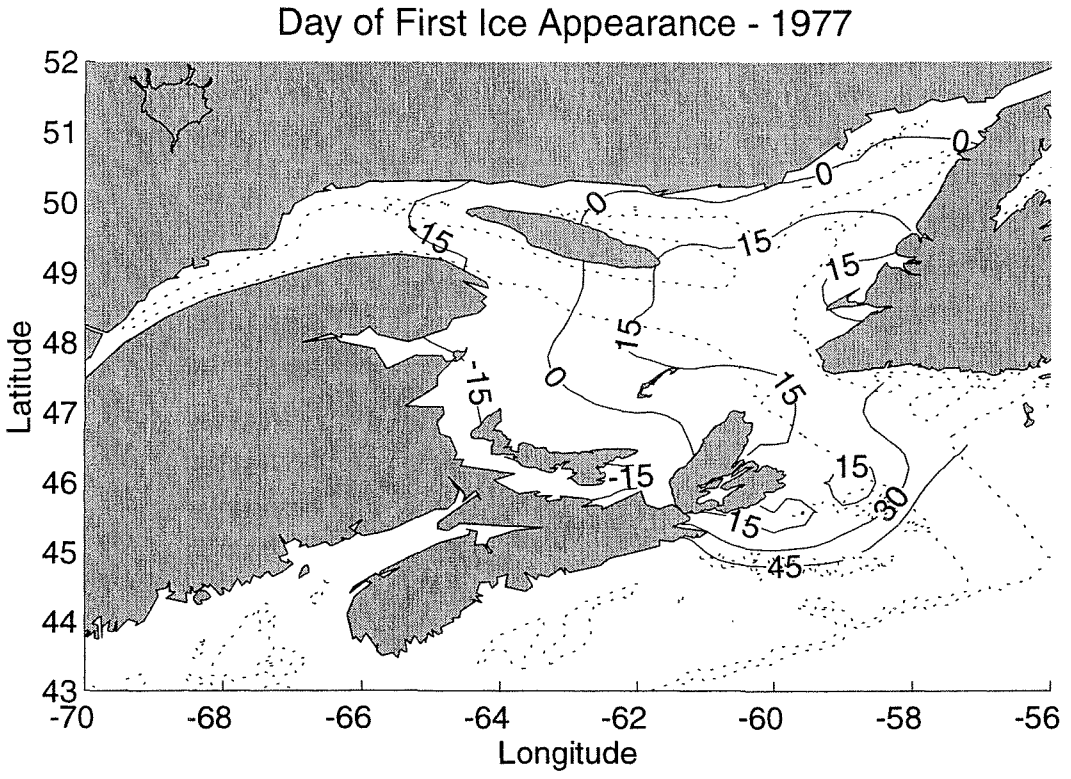
Day of First Ice Appearance - 1977
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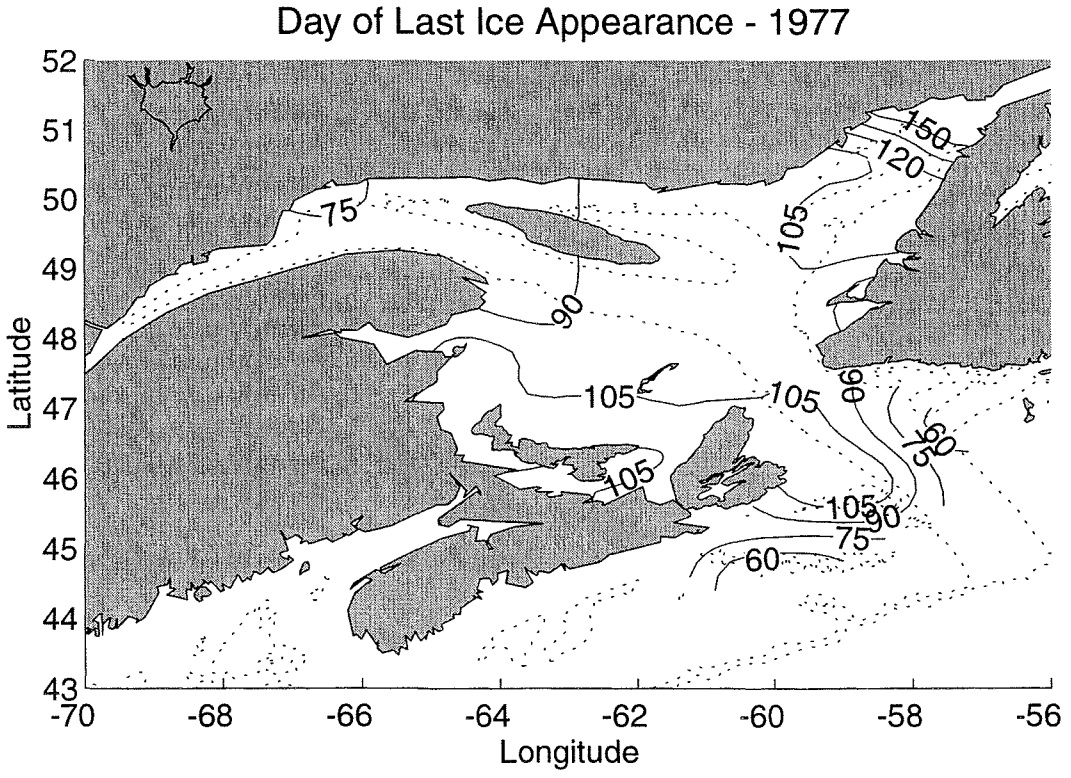
Day of Last Ice Appearance - 1977
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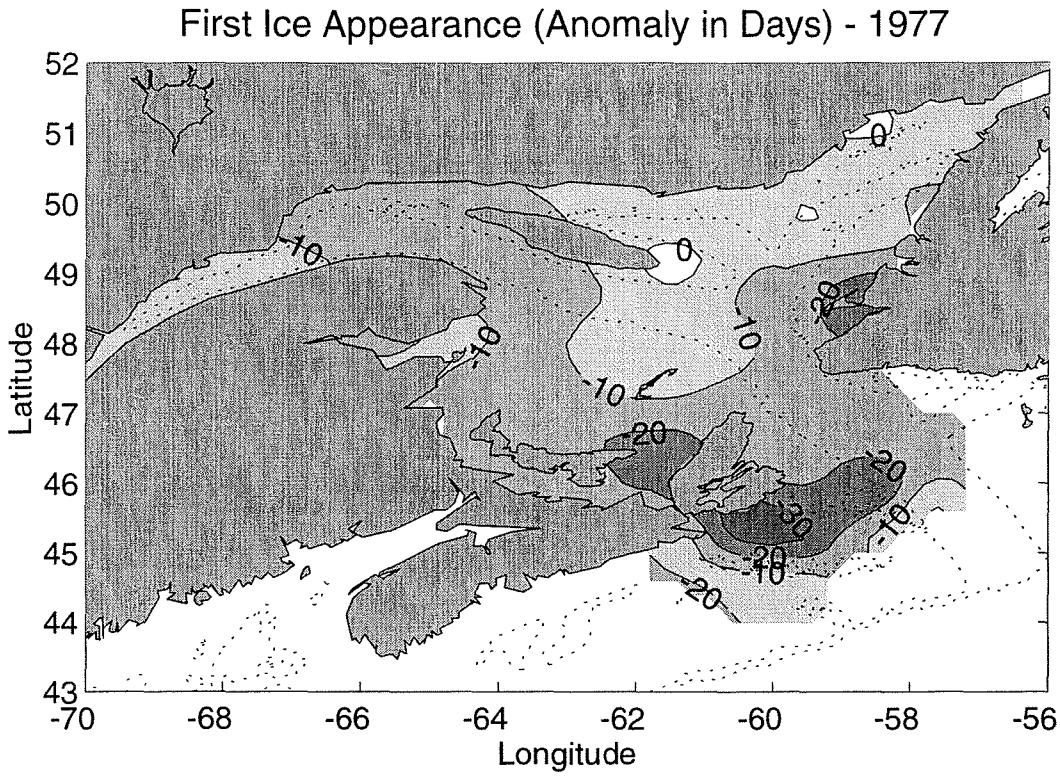
First Ice Appearance (Anomaly in Days) - 1977
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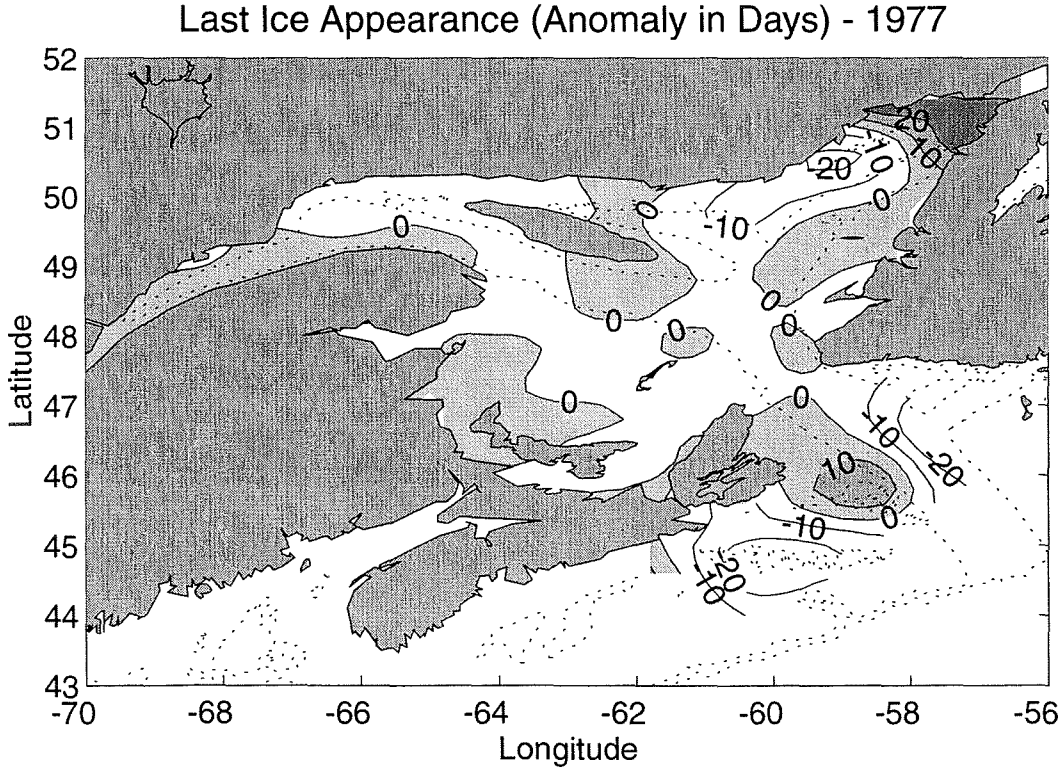
Last Ice Appearance (Anomaly in Days) - 1977
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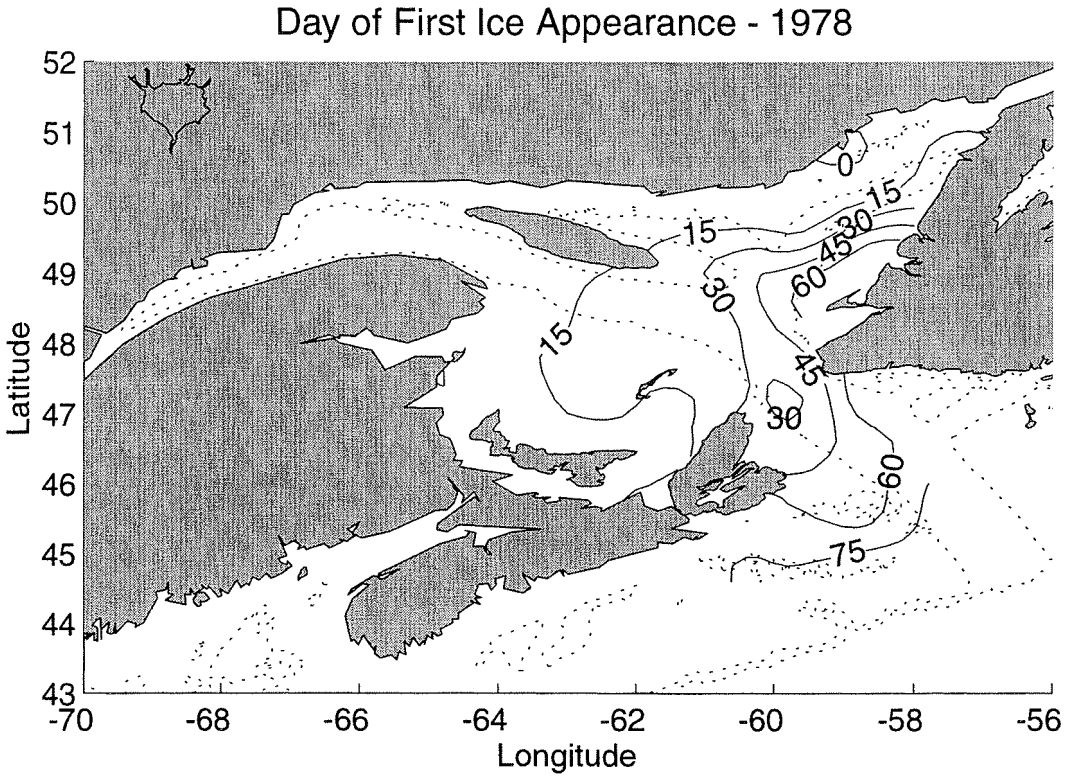
Day of First Ice Appearance - 1978
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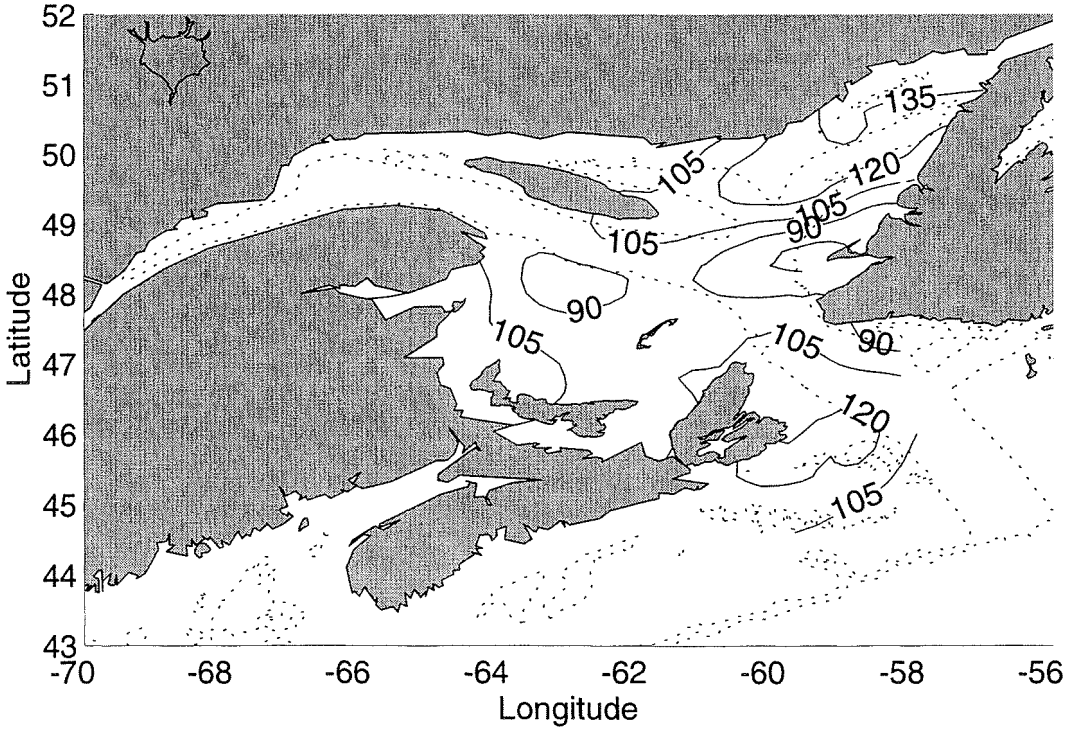
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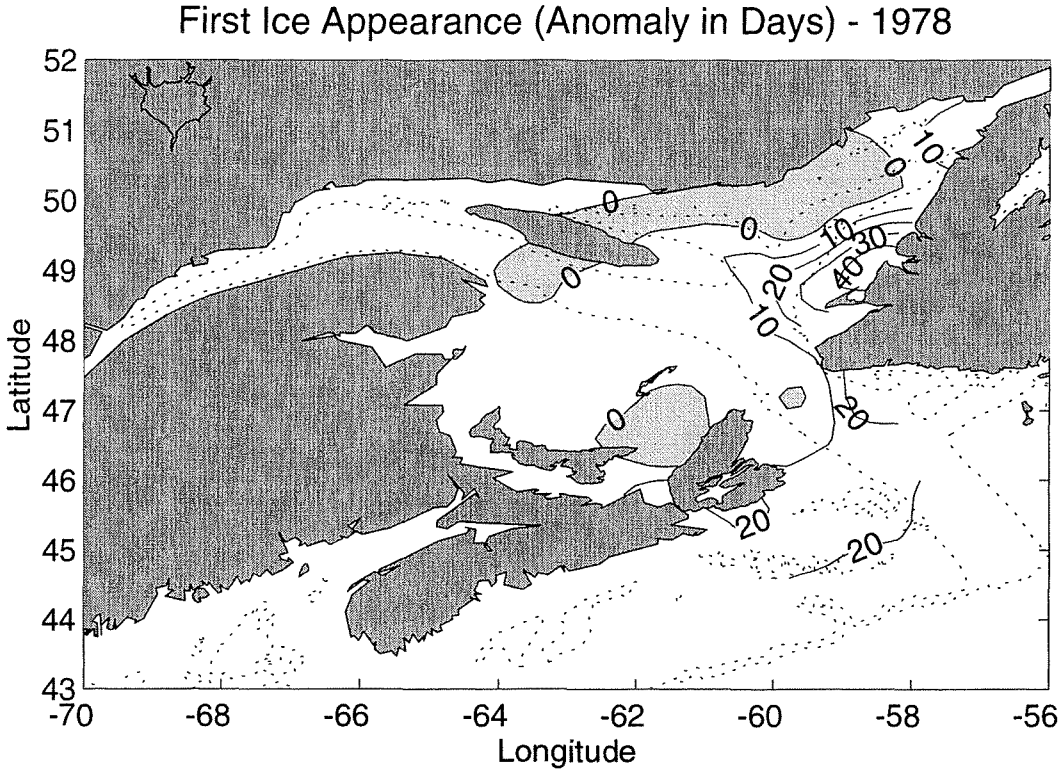
First Ice Appearance (Anomaly in Days) - 1978
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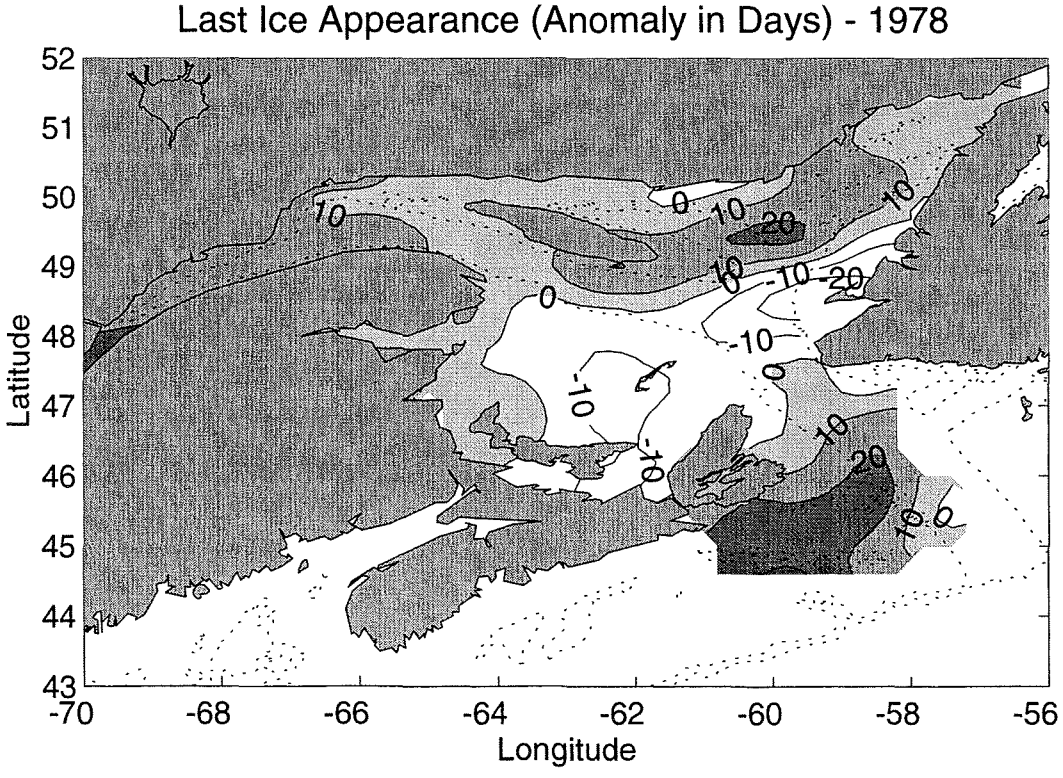
Last Ice Appearance (Anomaly in Days) - 1978
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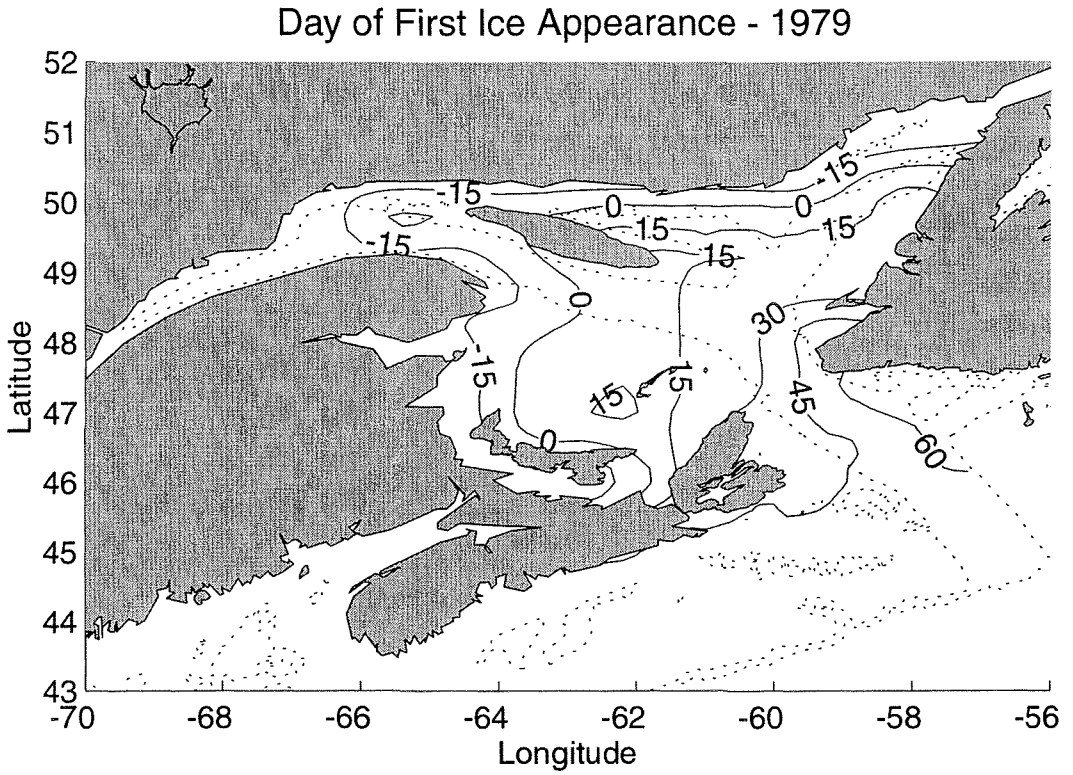
Day of First Ice Appearance - 1979
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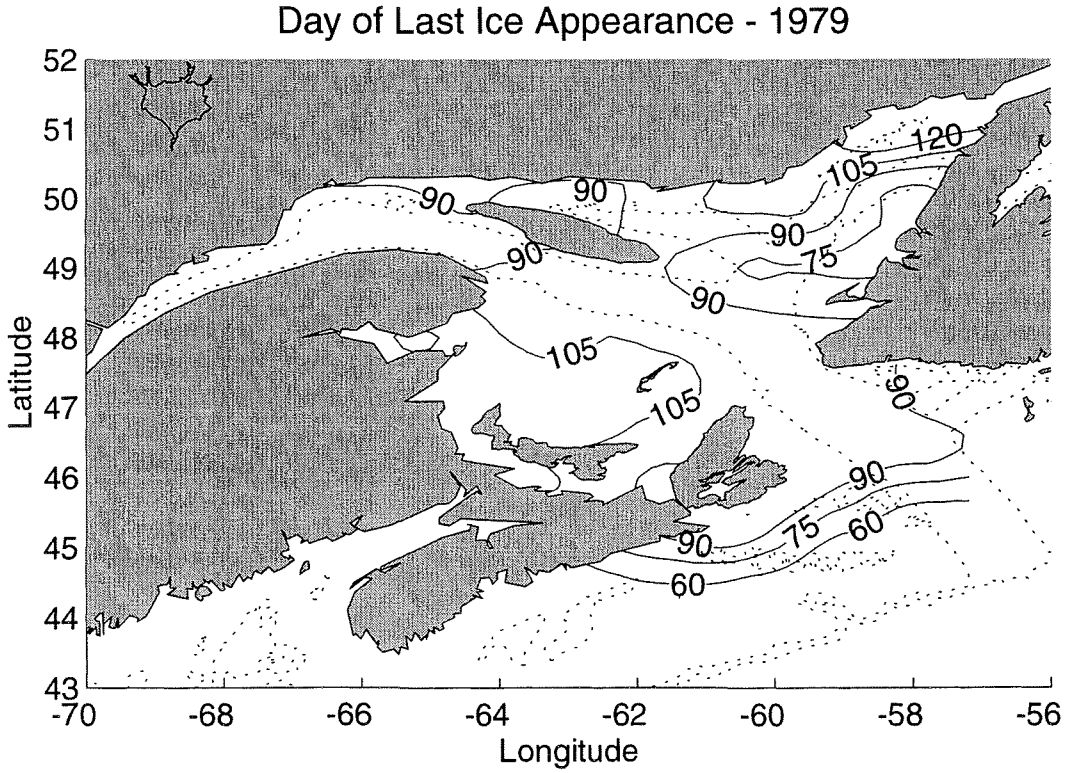
Day of Last Ice Appearance - 1979
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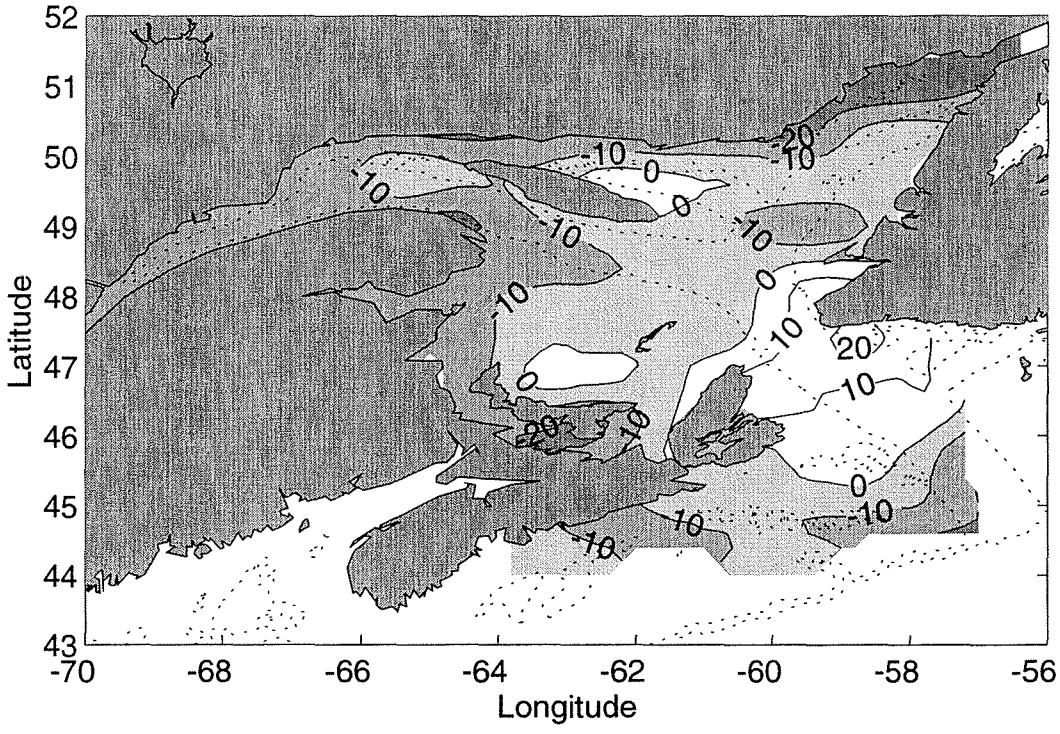
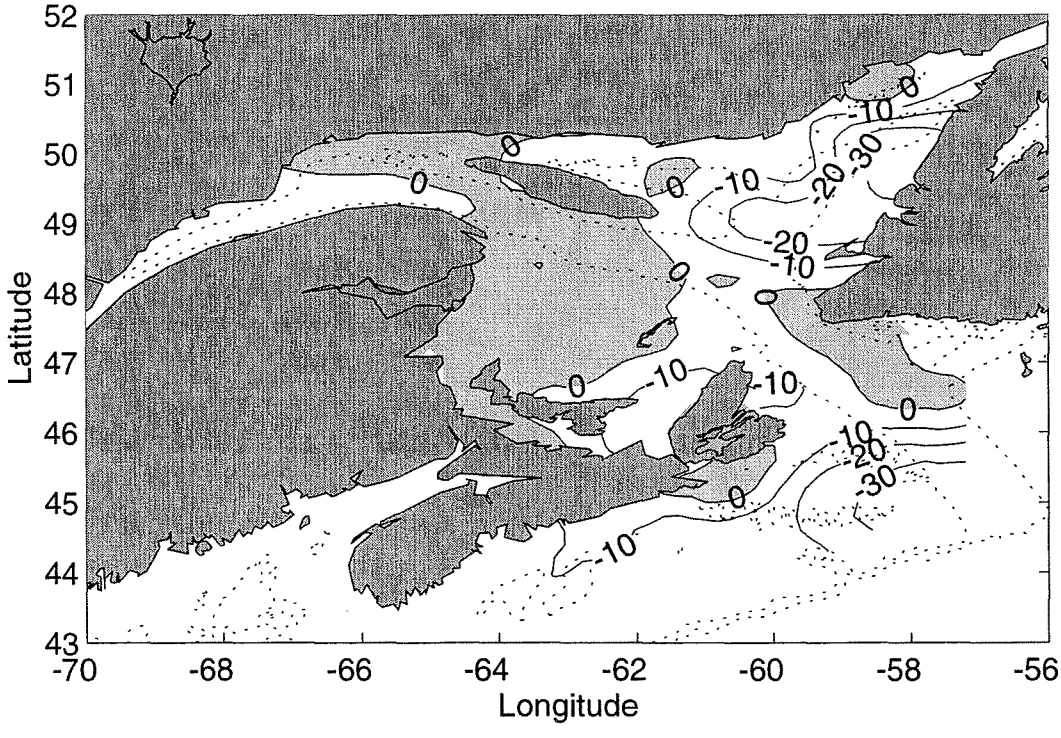
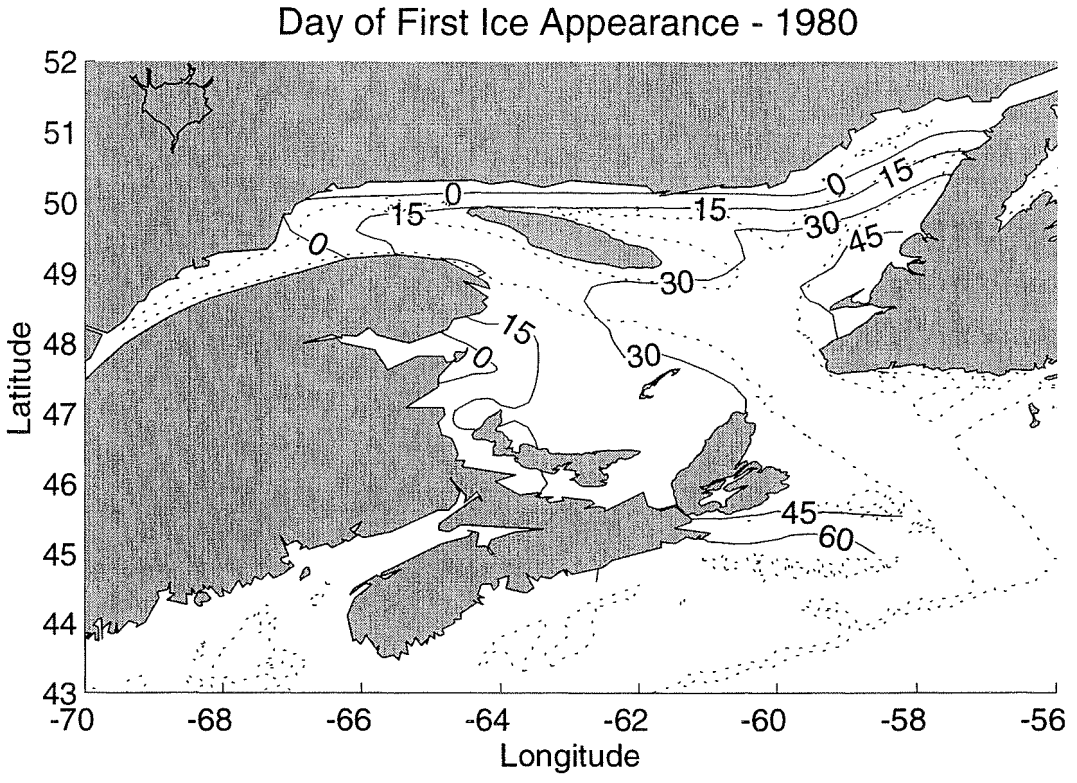
First Ice Appearance (Anomaly in Days) - 1979



Last Ice Appearance (Anomaly in Days) - 1979

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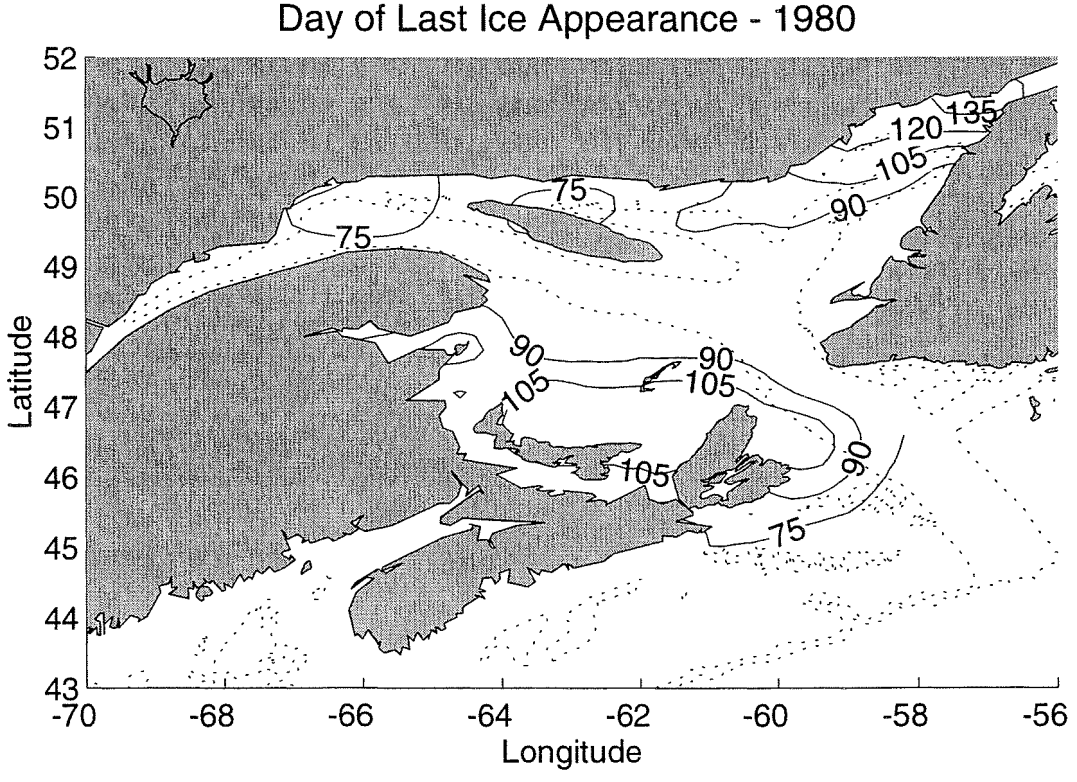
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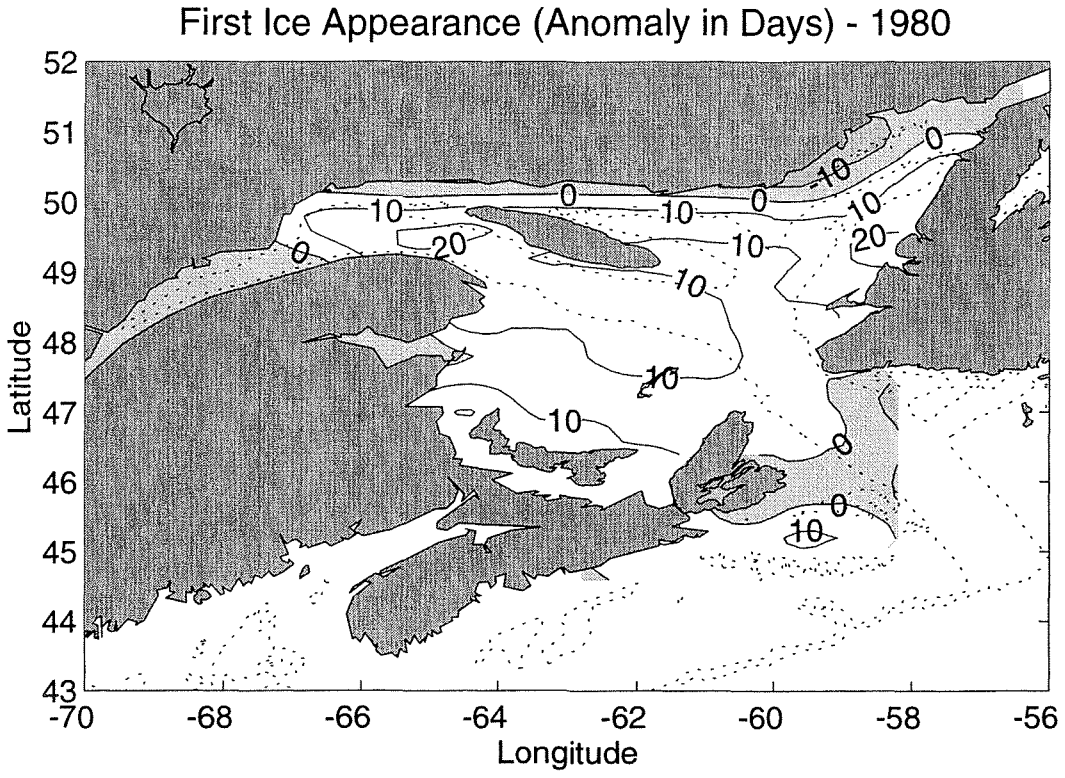
First Ice Appearance (Anomaly in Days) - 1980
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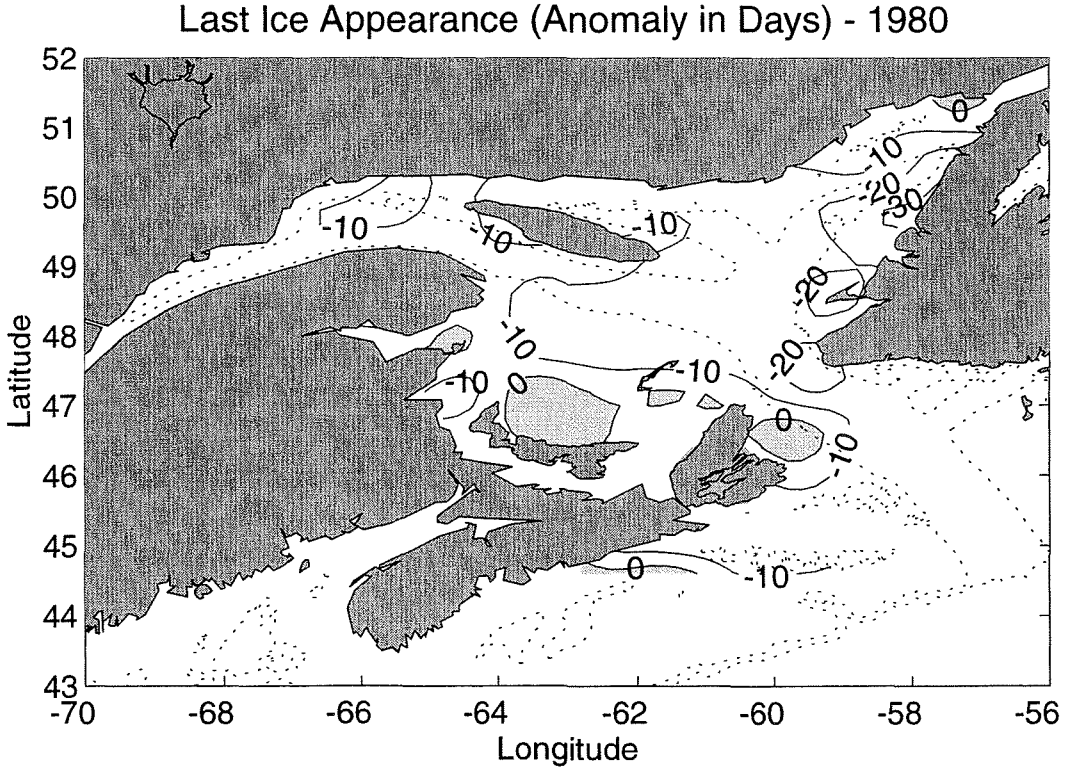
Last Ice Appearance (Anomaly in Days) - 1980
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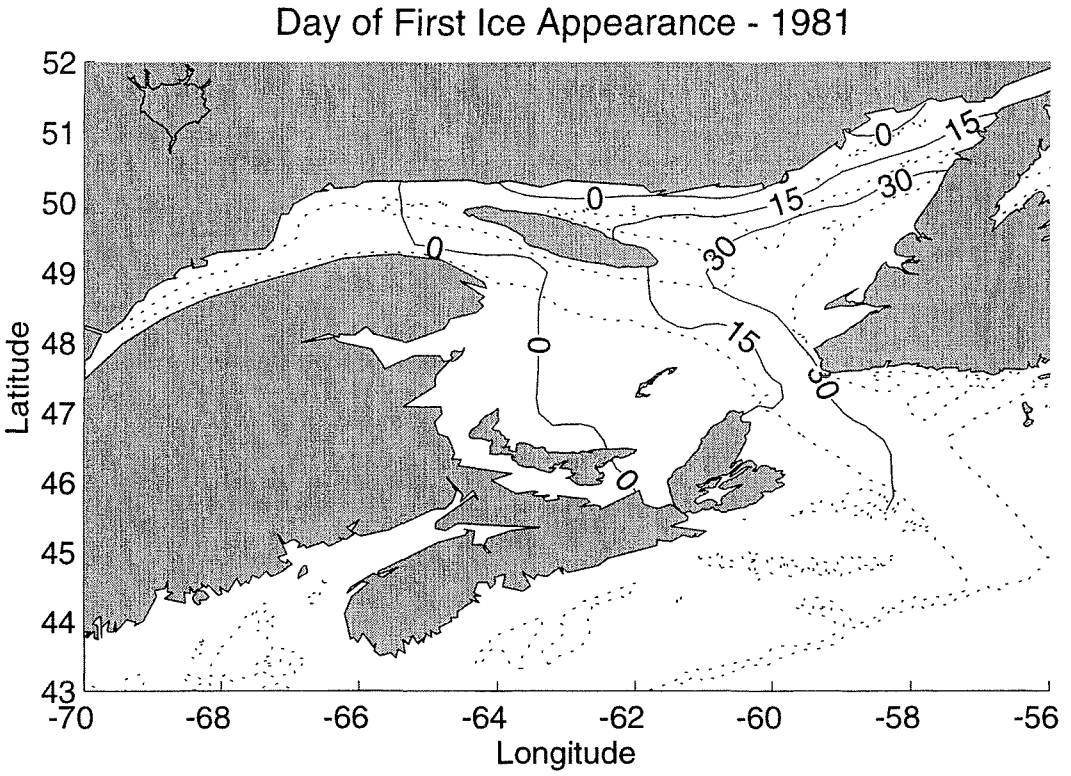
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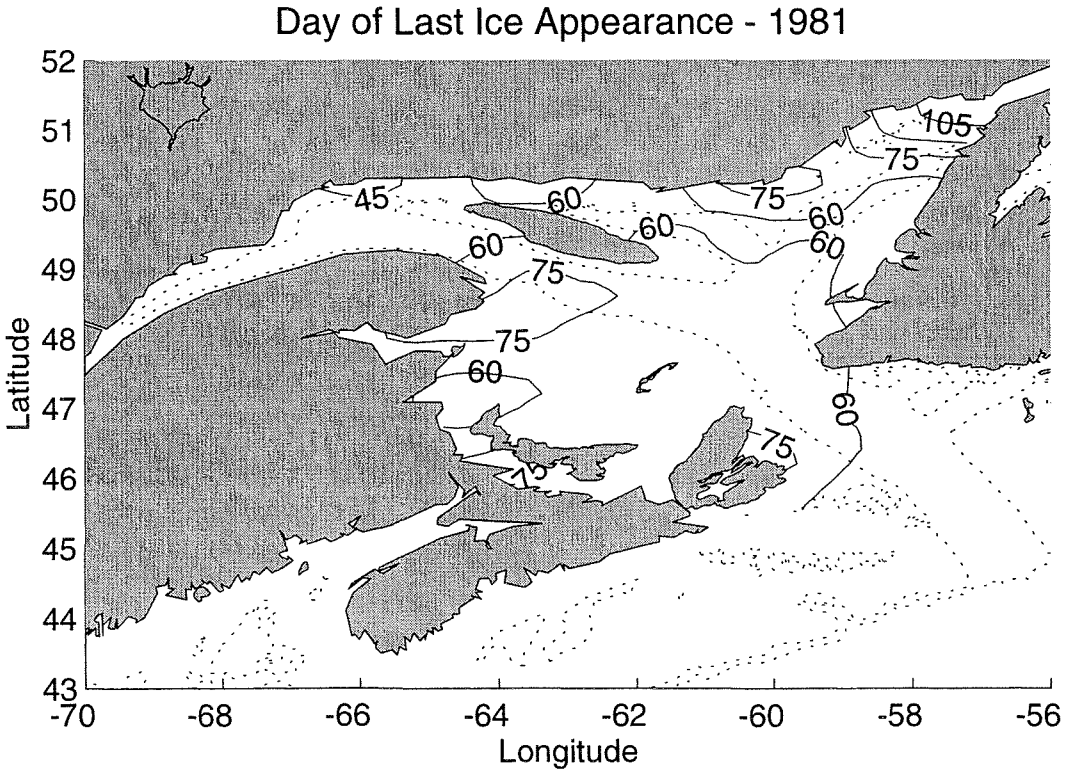
Day of Last Ice Appearance - 1981
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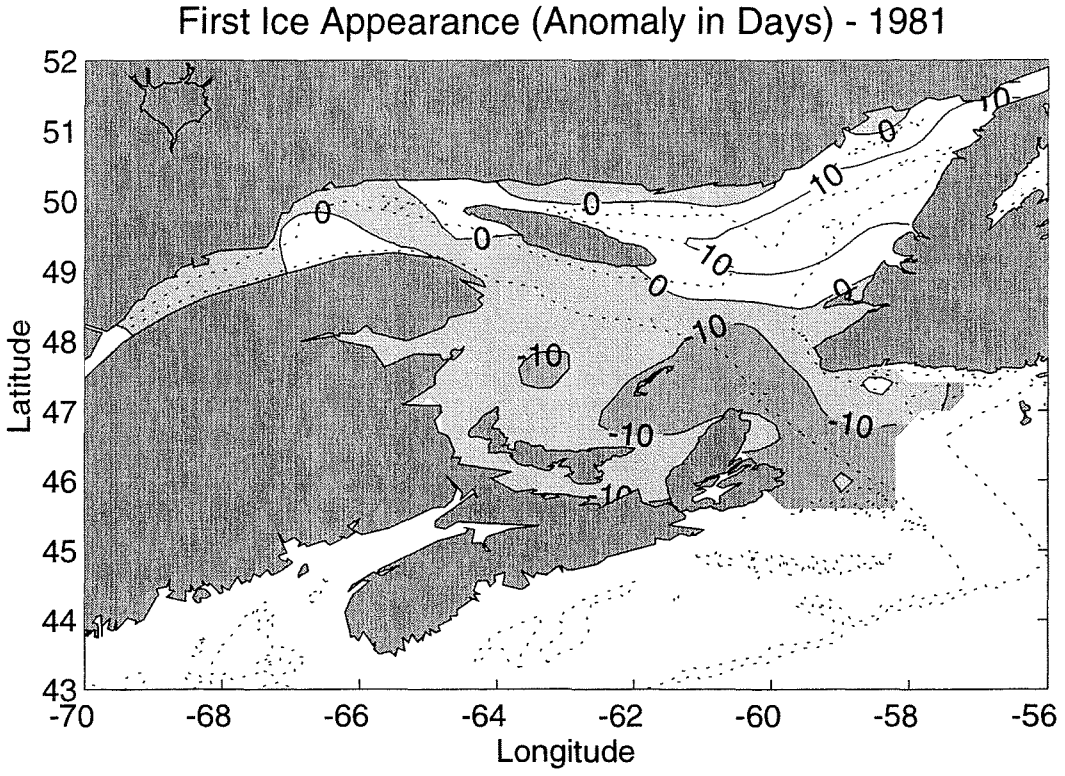
First Ice Appearance (Anomaly in Days) - 1981
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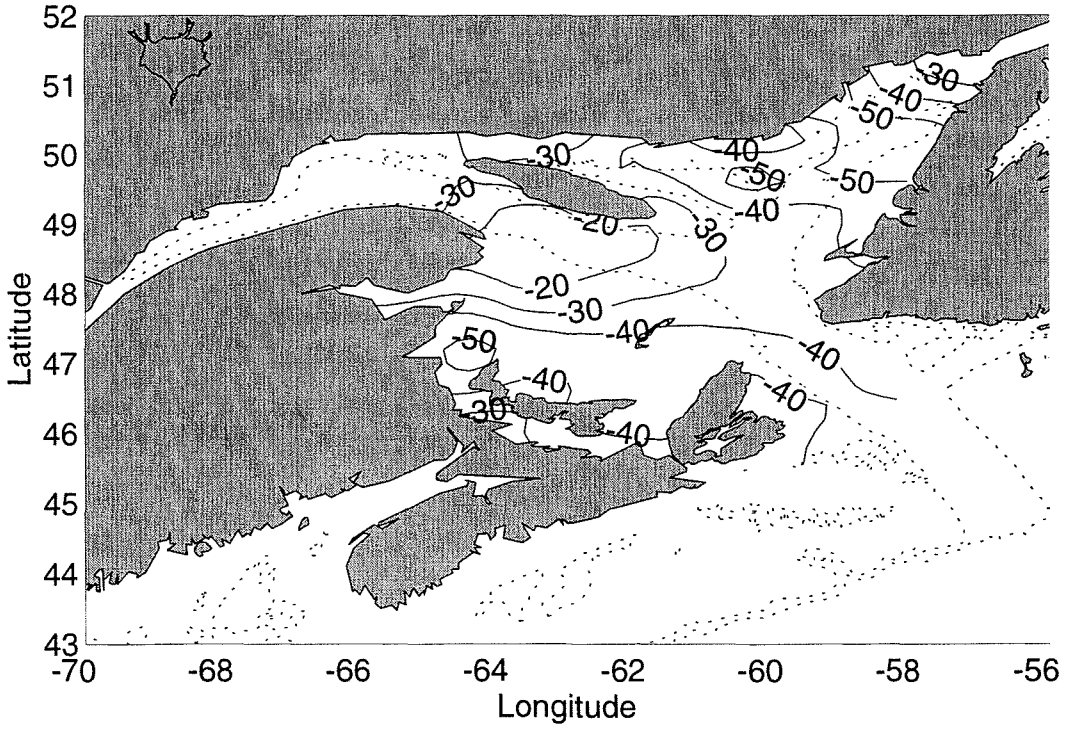
Last Ice Appearance (Anomaly in Days) - 1981
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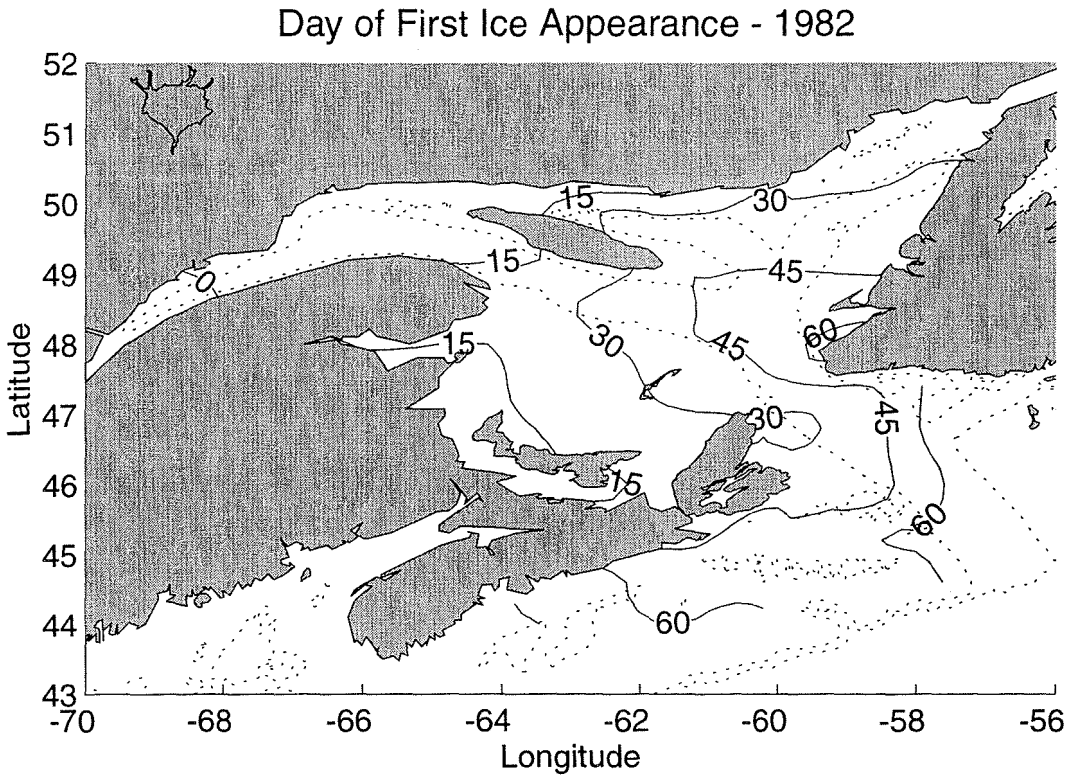
Day of First Ice Appearance - 1982
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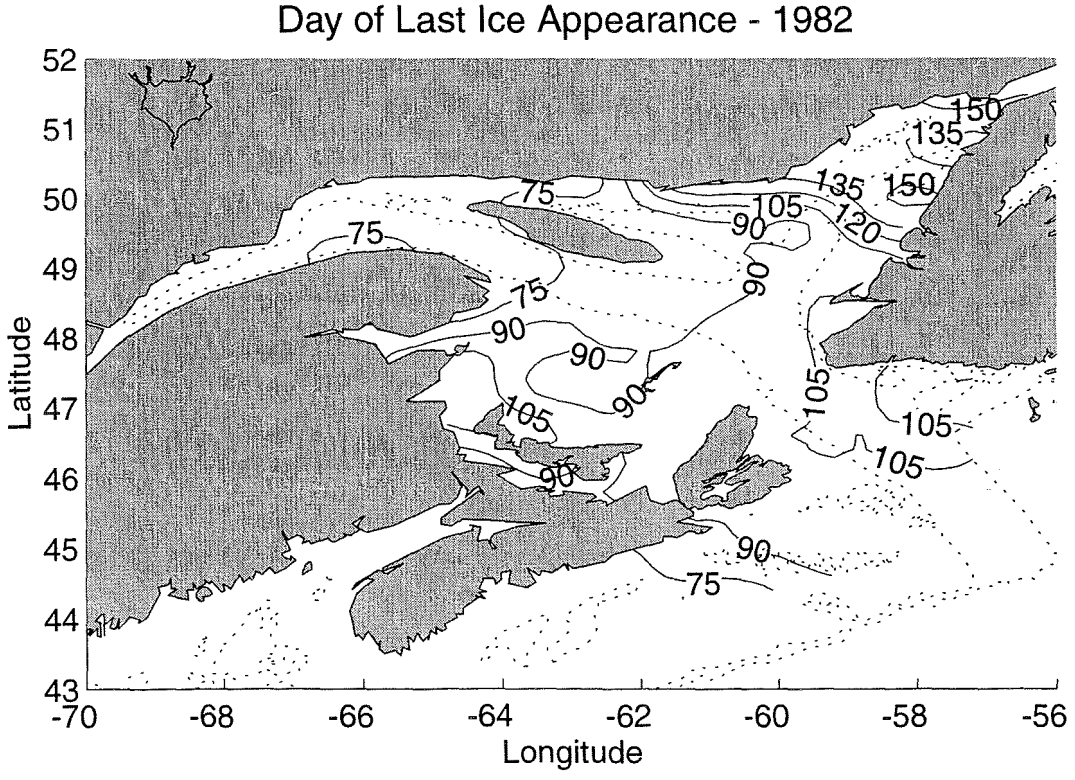
Day of Last Ice Appearance - 1982
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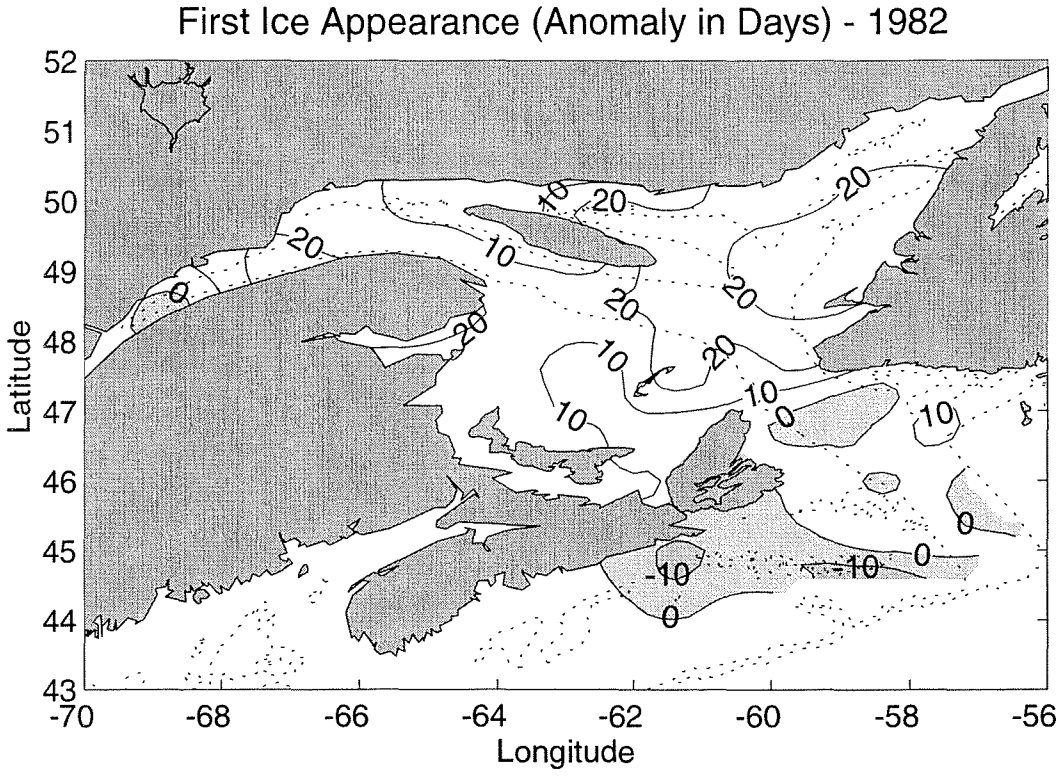
First Ice Appearance (Anomaly in Days) - 1982
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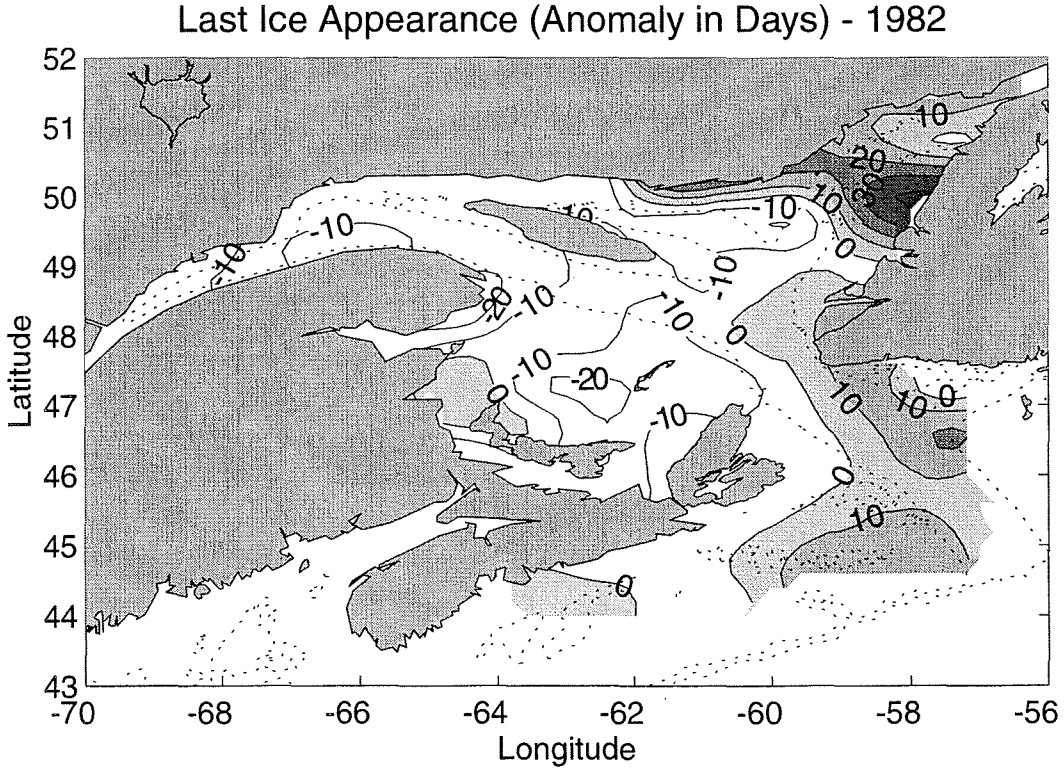
Last Ice Appearance (Anomaly in Days) - 1982
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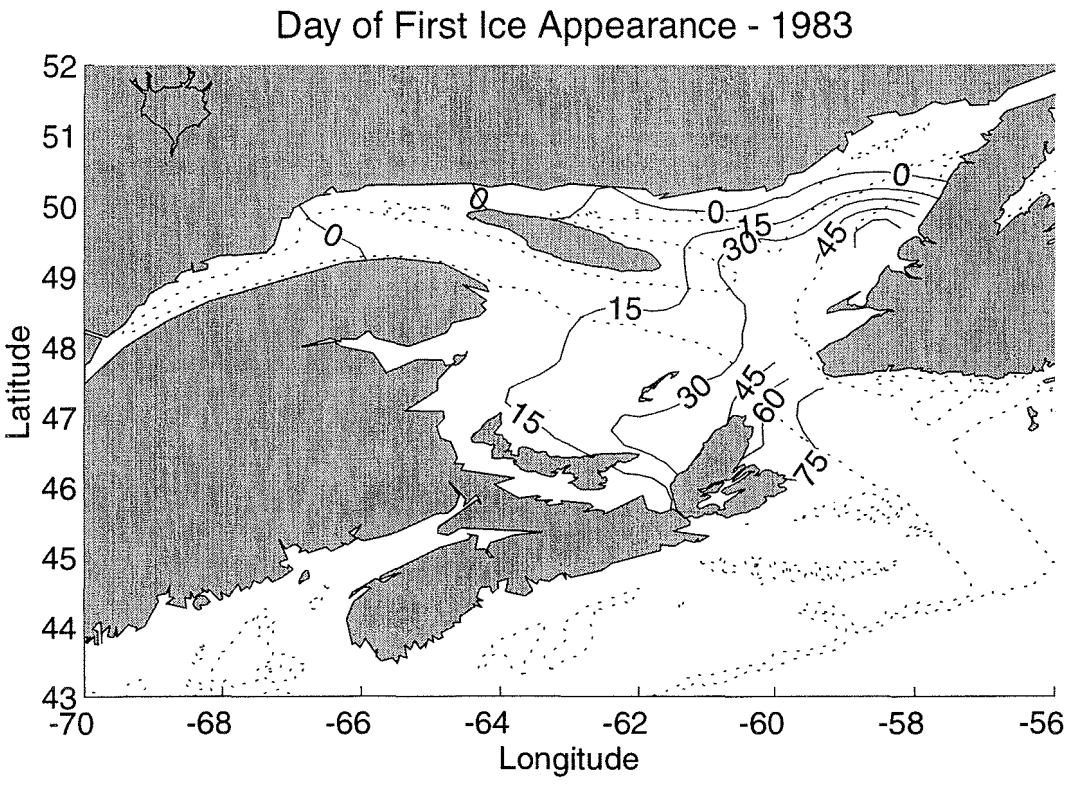
Day of First Ice Appearance - 1983
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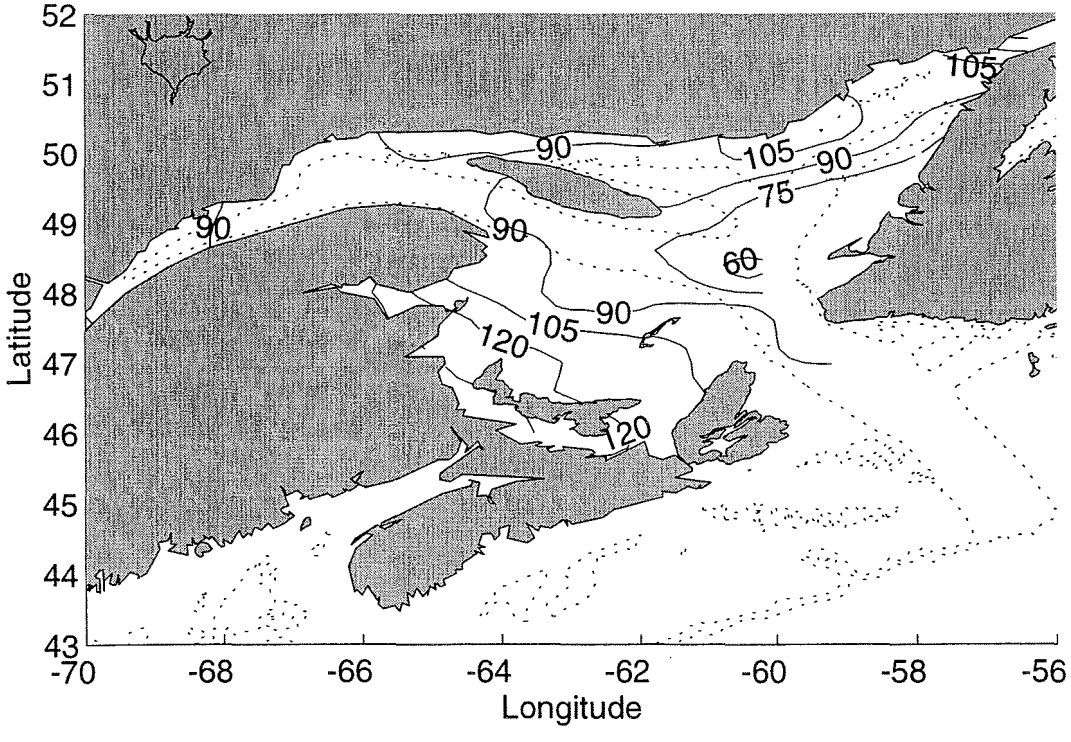
Day of Last Ice Appearance - 1983
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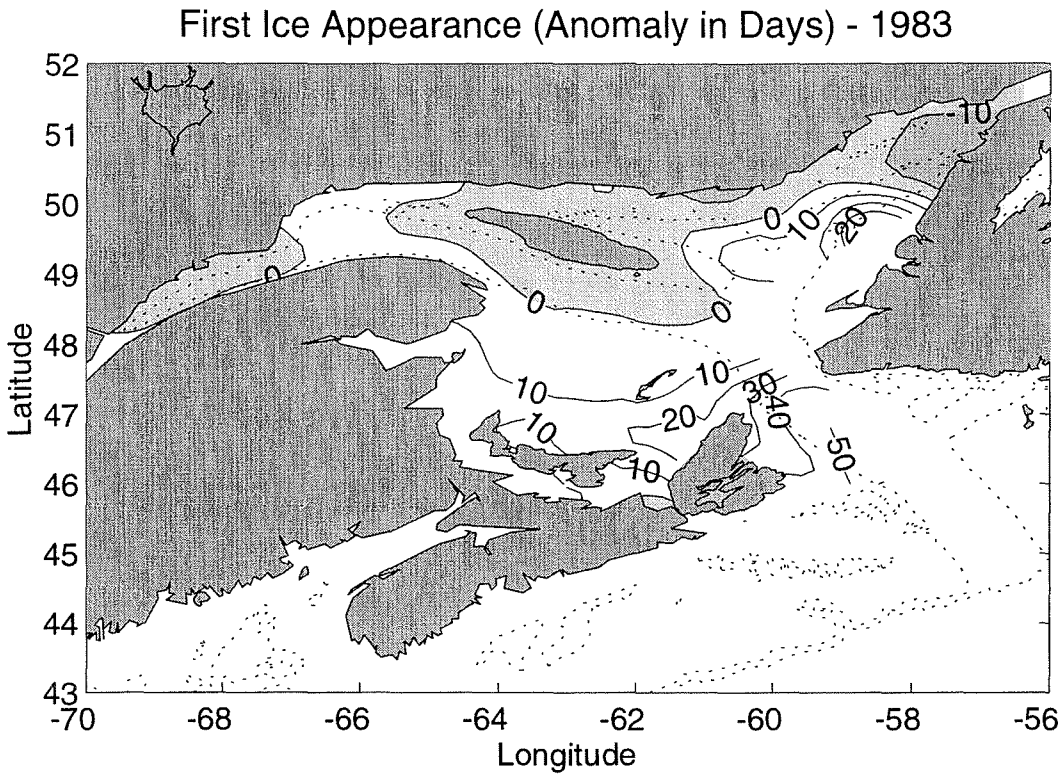
First Ice Appearance (Anomaly in Days) - 1983
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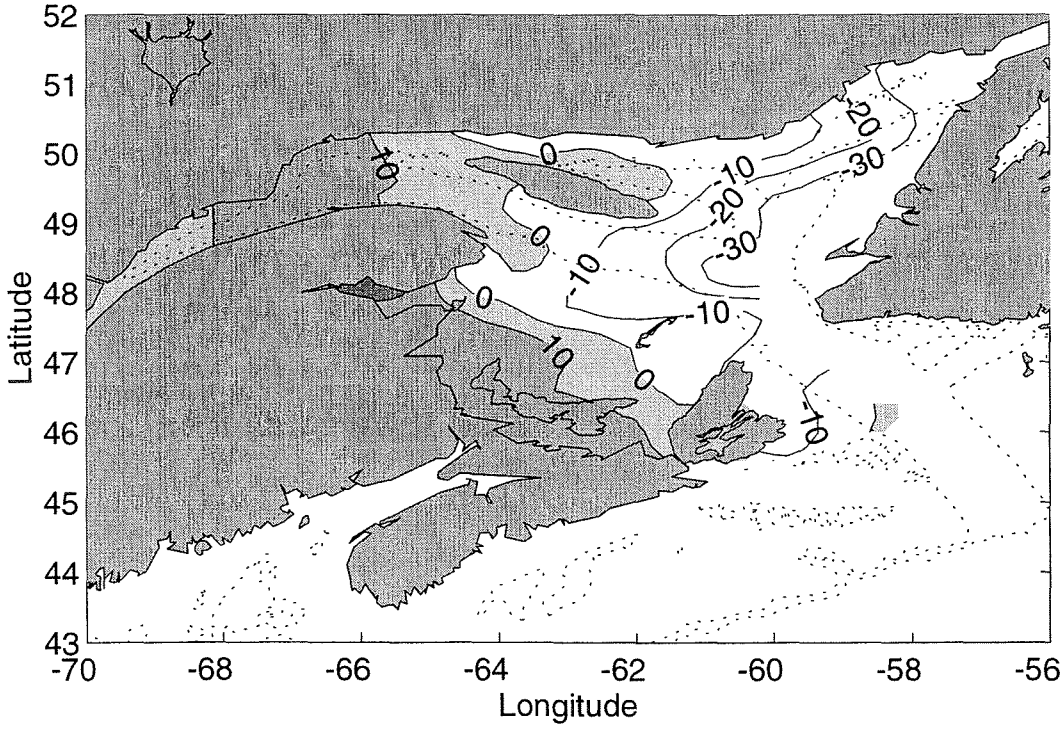
Last Ice Appearance (Anomaly in Days) - 1983
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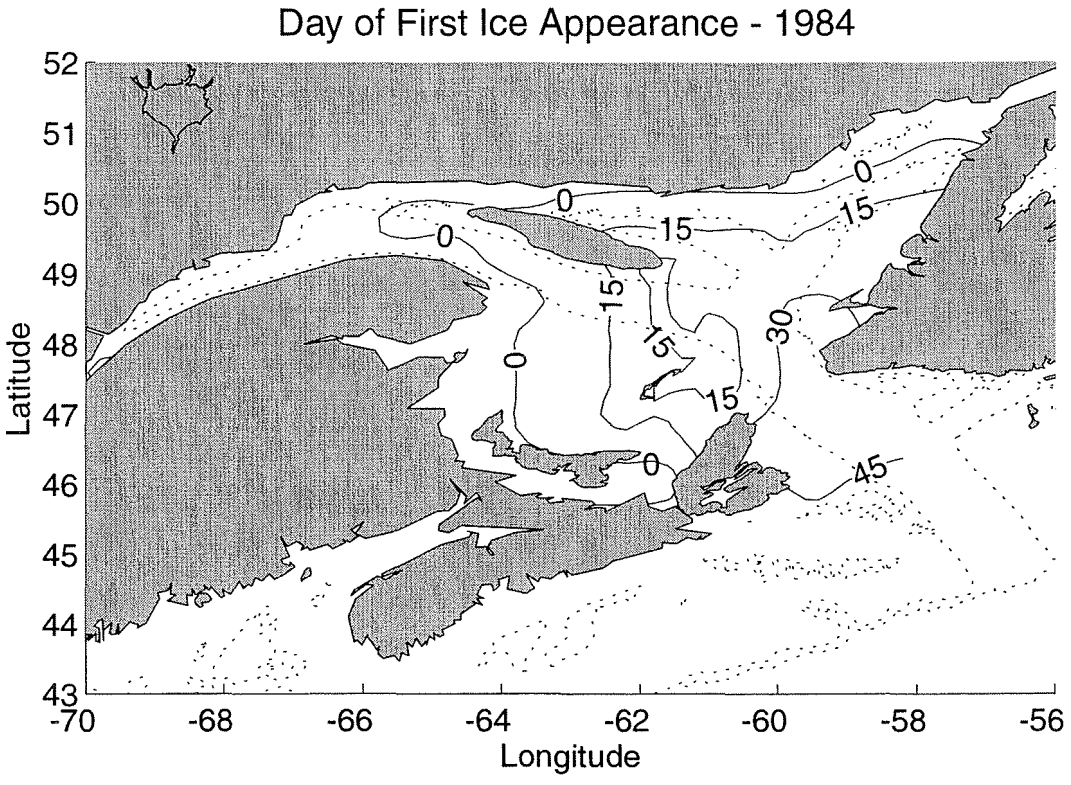
Day of First Ice Appearance - 1984
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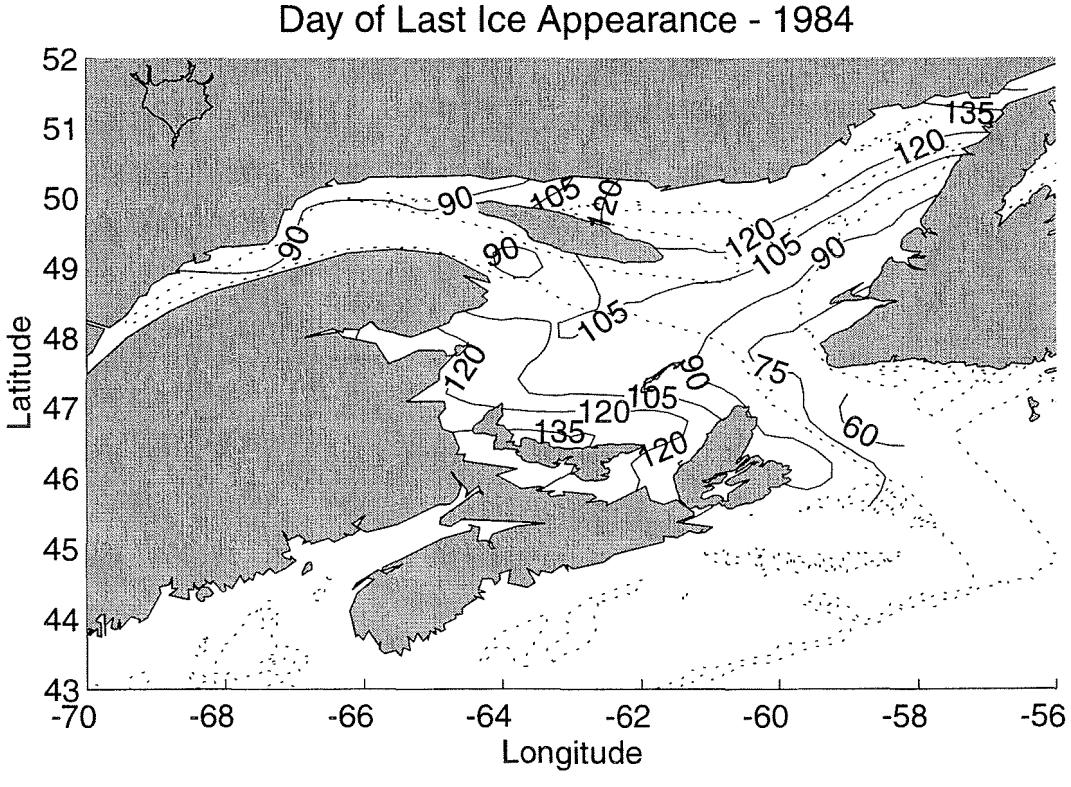
Day of Last Ice Appearance - 1984
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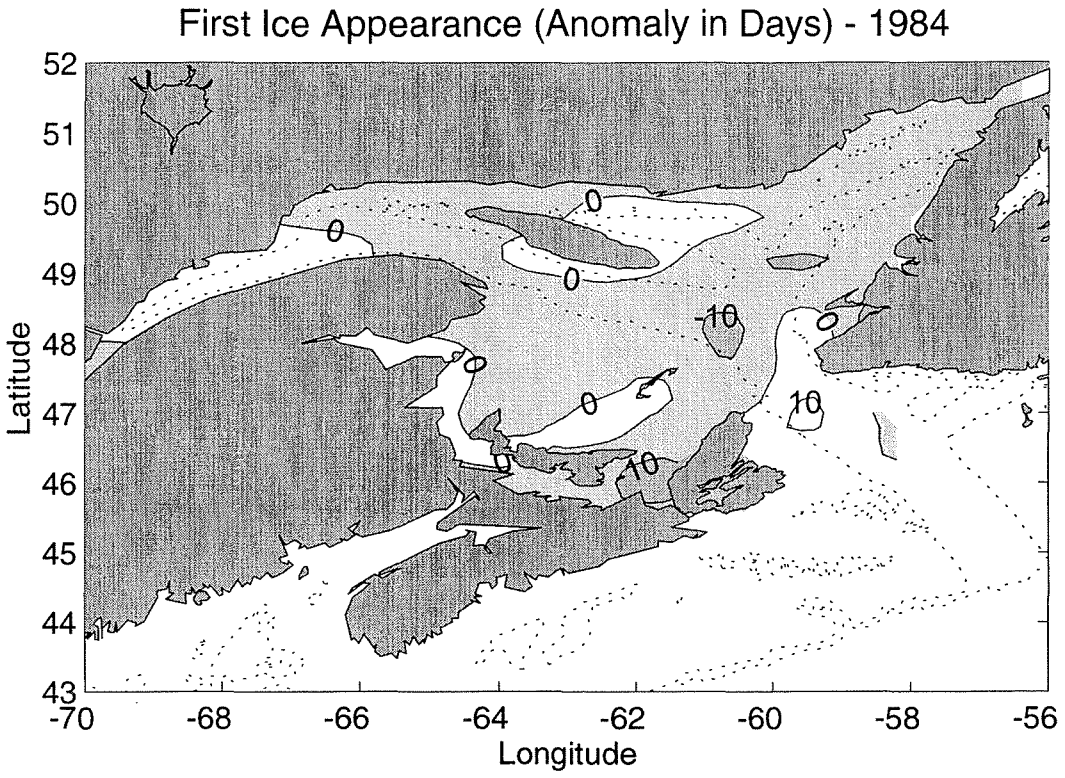
First Ice Appearance (Anomaly in Days) - 1984
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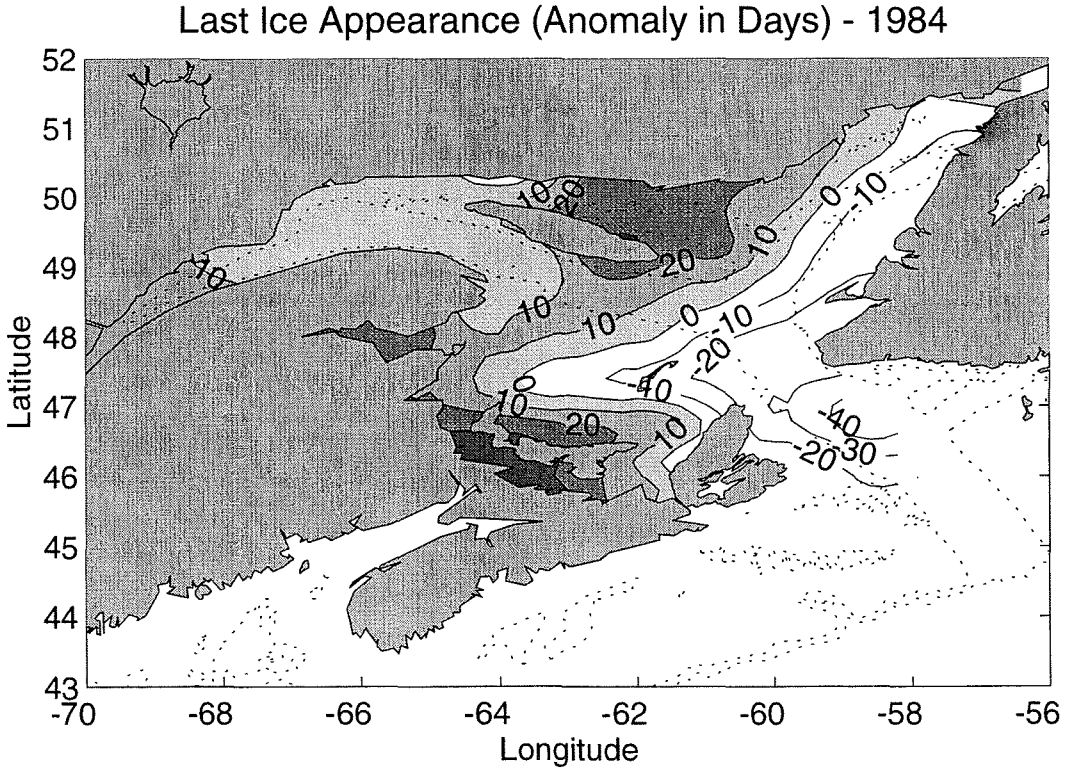
Last Ice Appearance (Anomaly in Days) - 1984
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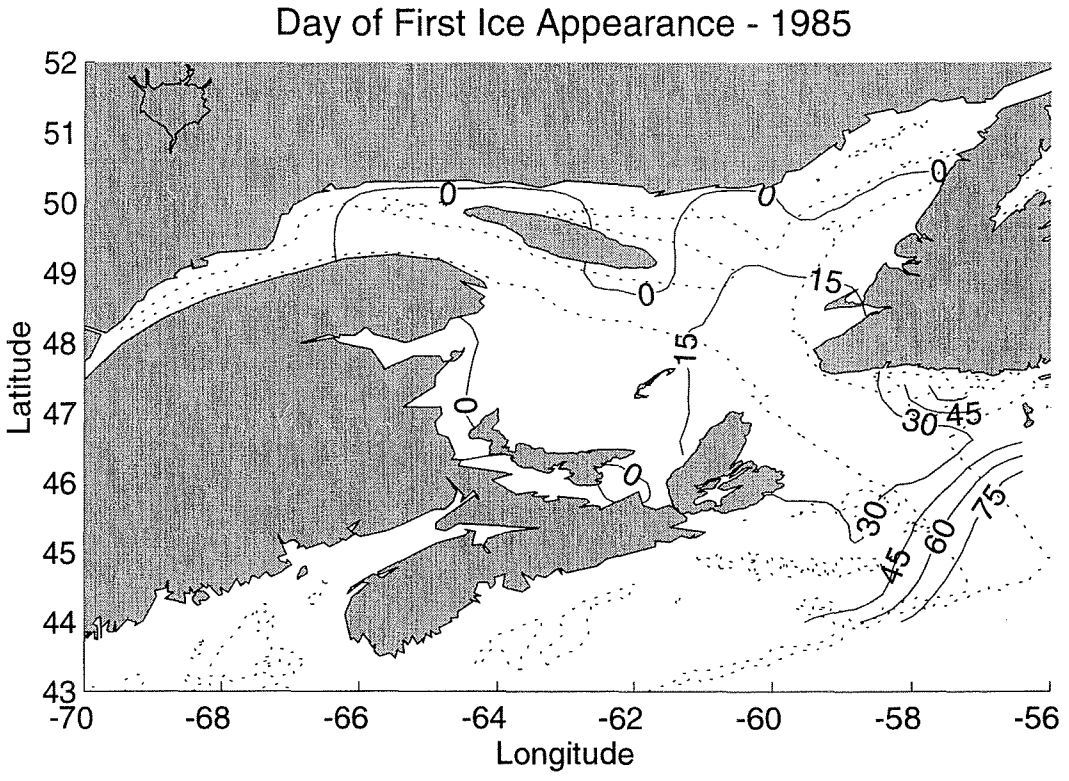
Day of First Ice Appearance - 1985
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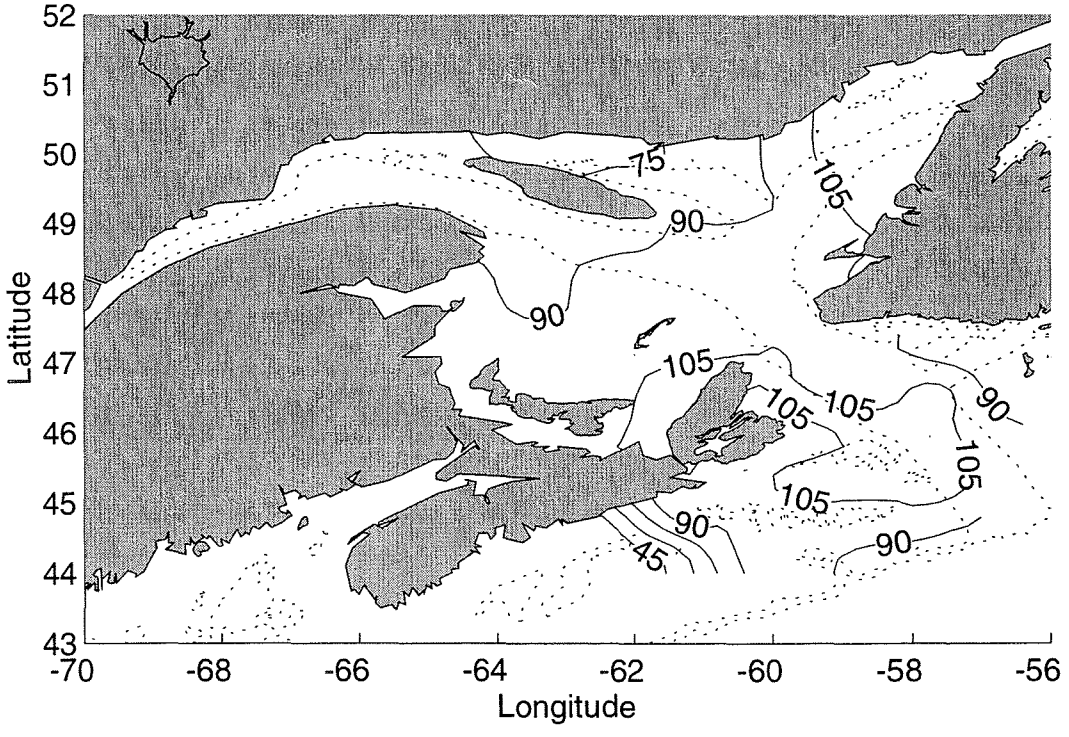
Day of Last Ice Appearance - 1985
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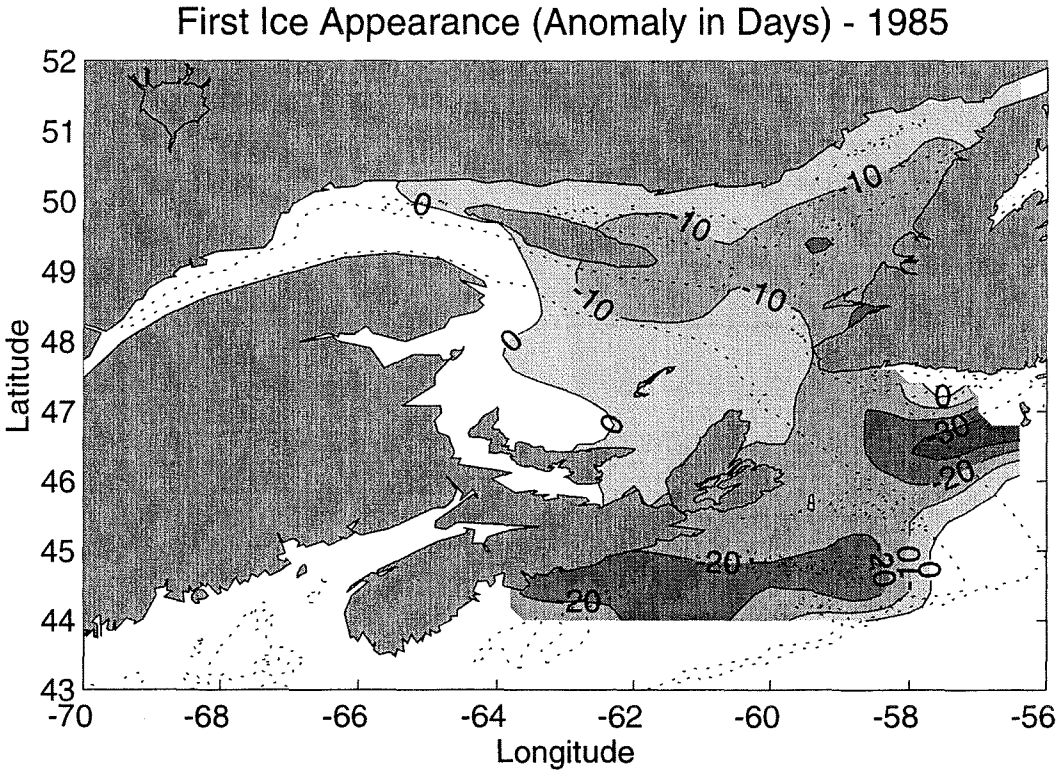
First Ice Appearance (Anomaly in Days) - 1985
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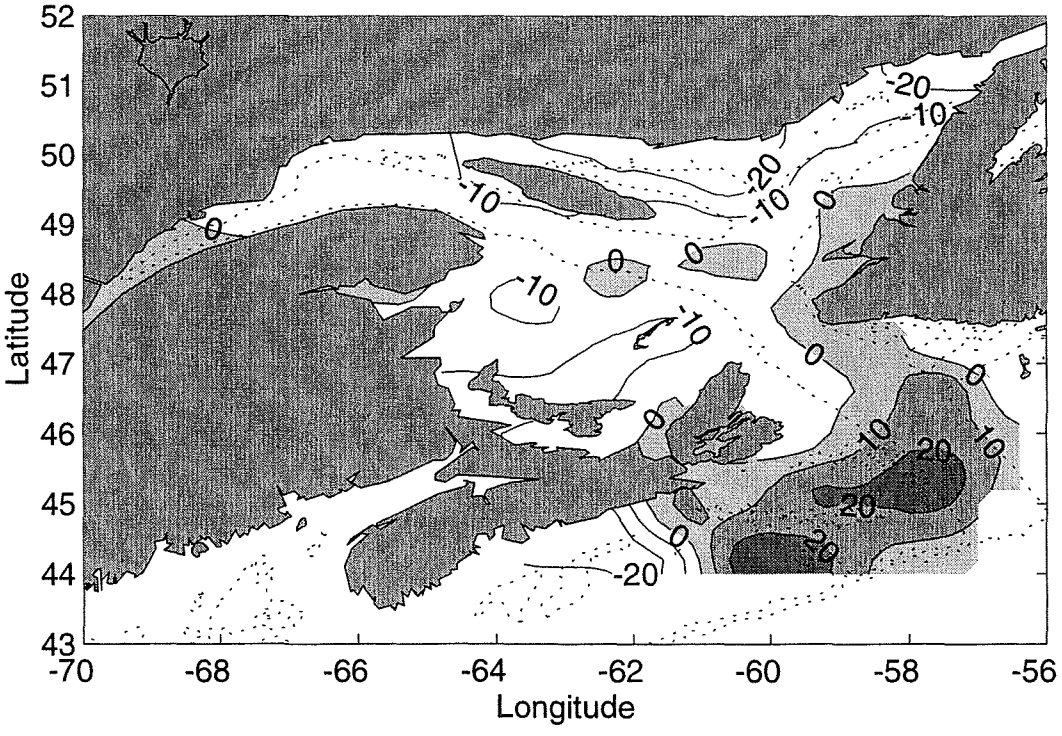
Last Ice Appearance (Anomaly in Days) - 1985
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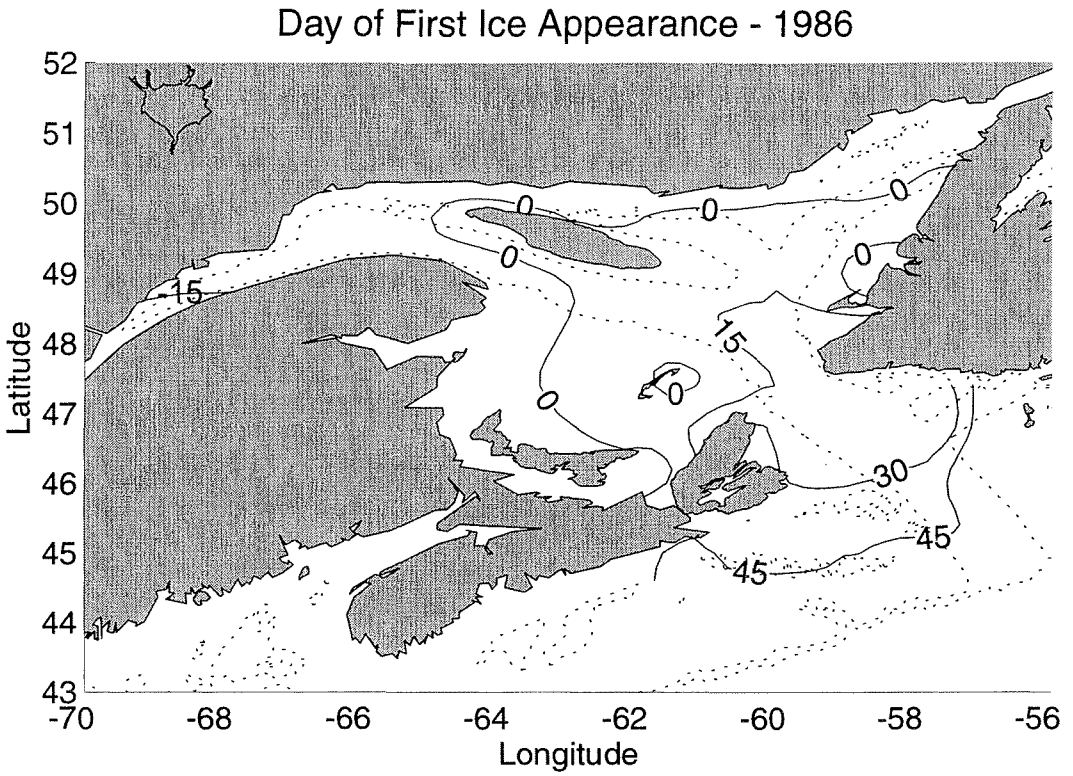
Day of First Ice Appearance - 1986
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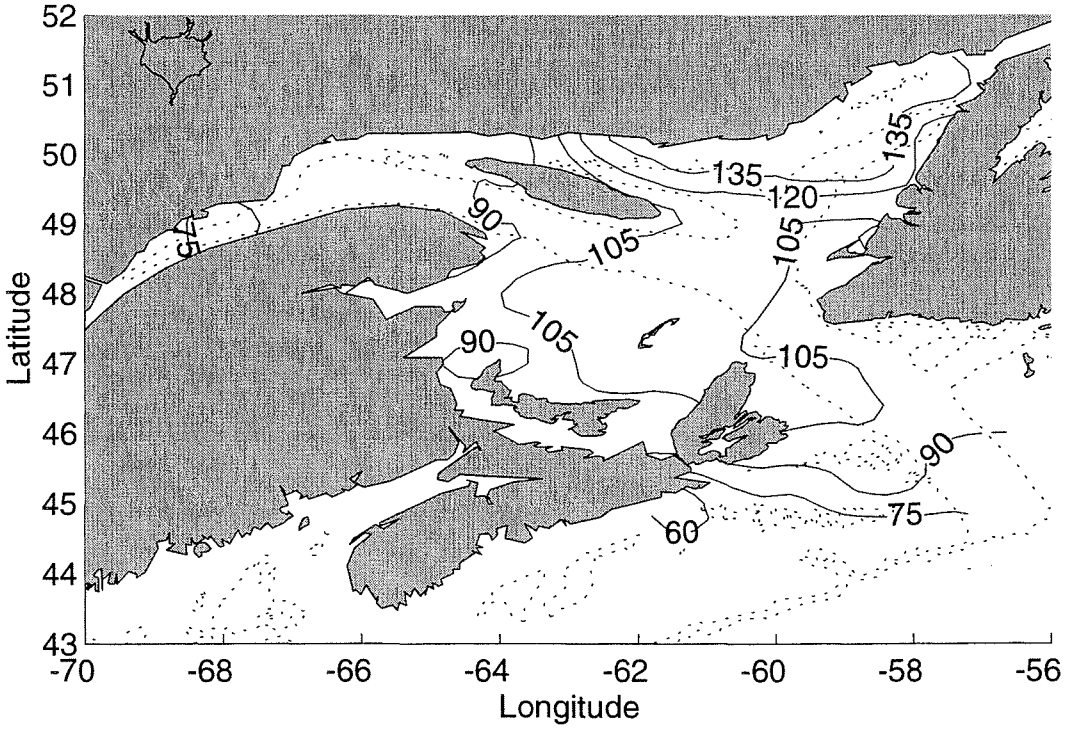
Day of Last Ice Appearance - 1986
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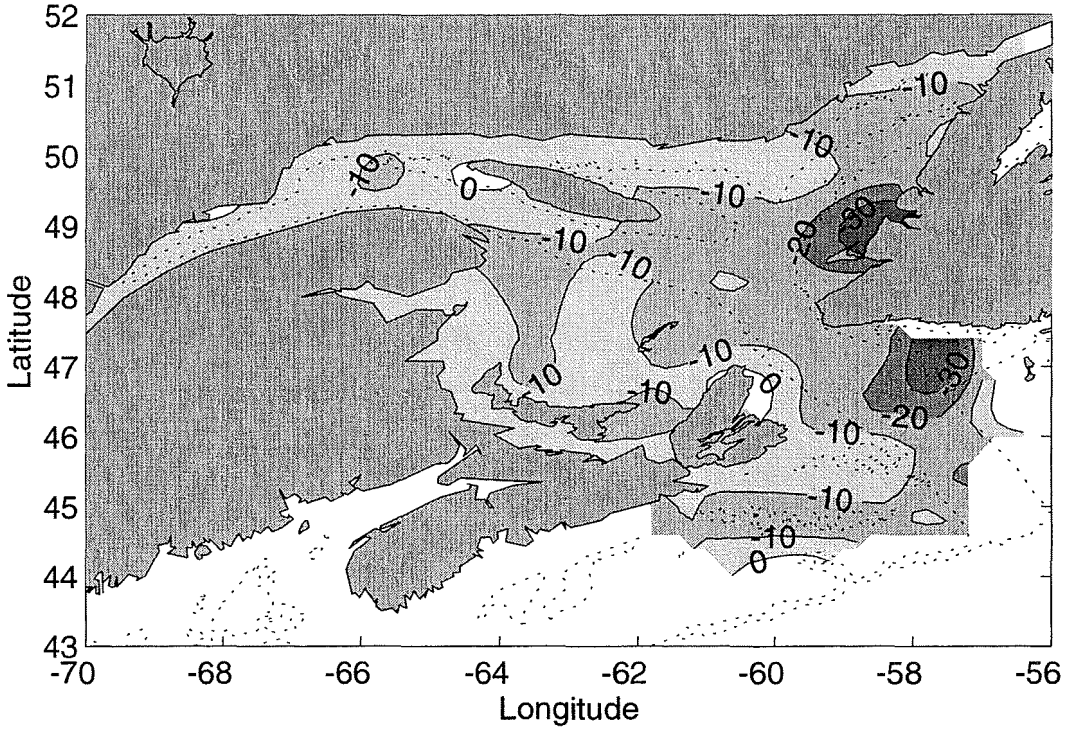
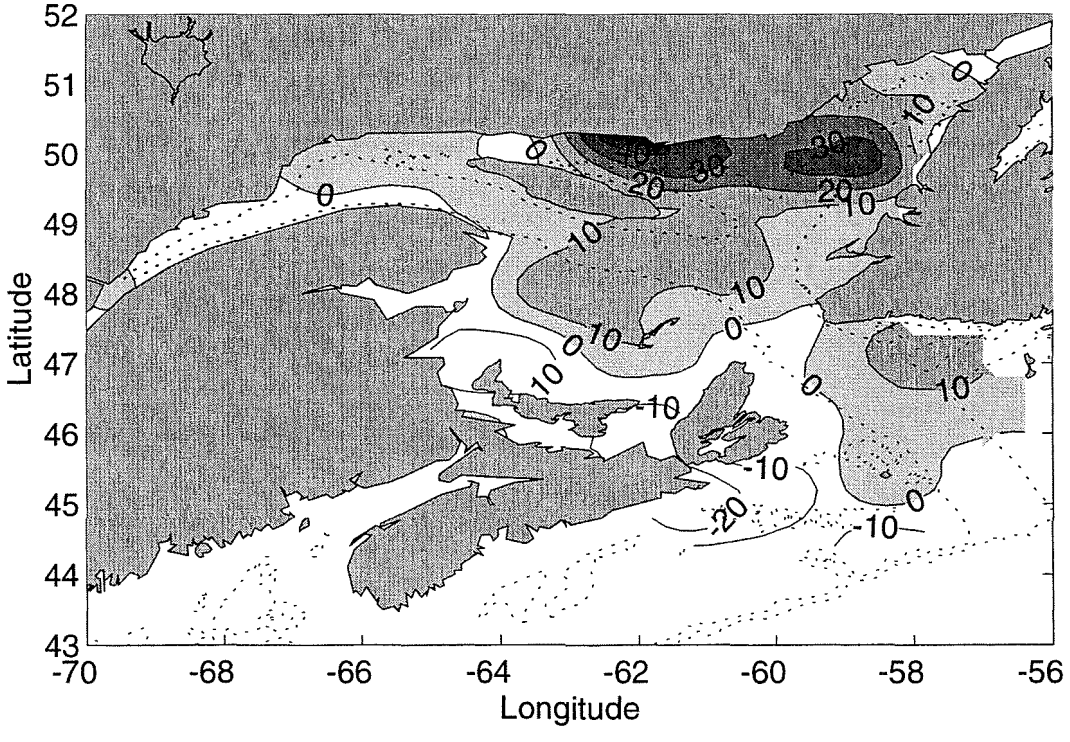
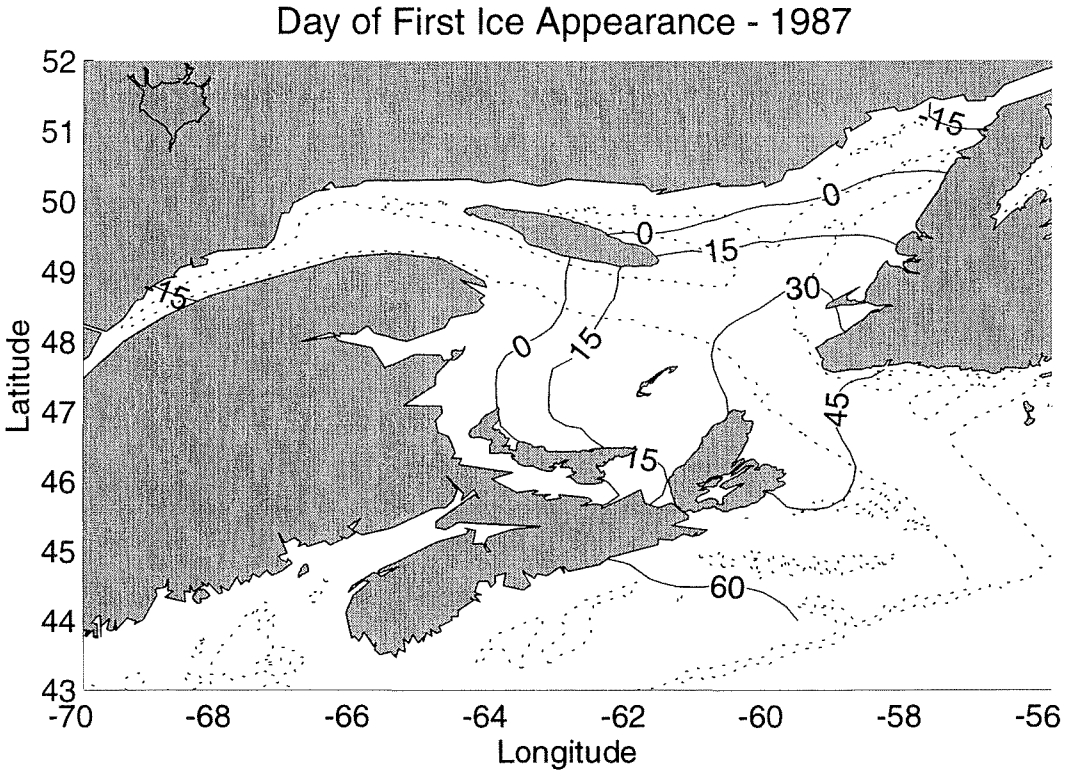
First Ice Appearance (Anomaly in Days) - 1986



Last Ice Appearance (Anomaly in Days) - 1986




Day of First Ice Appearance - 1987
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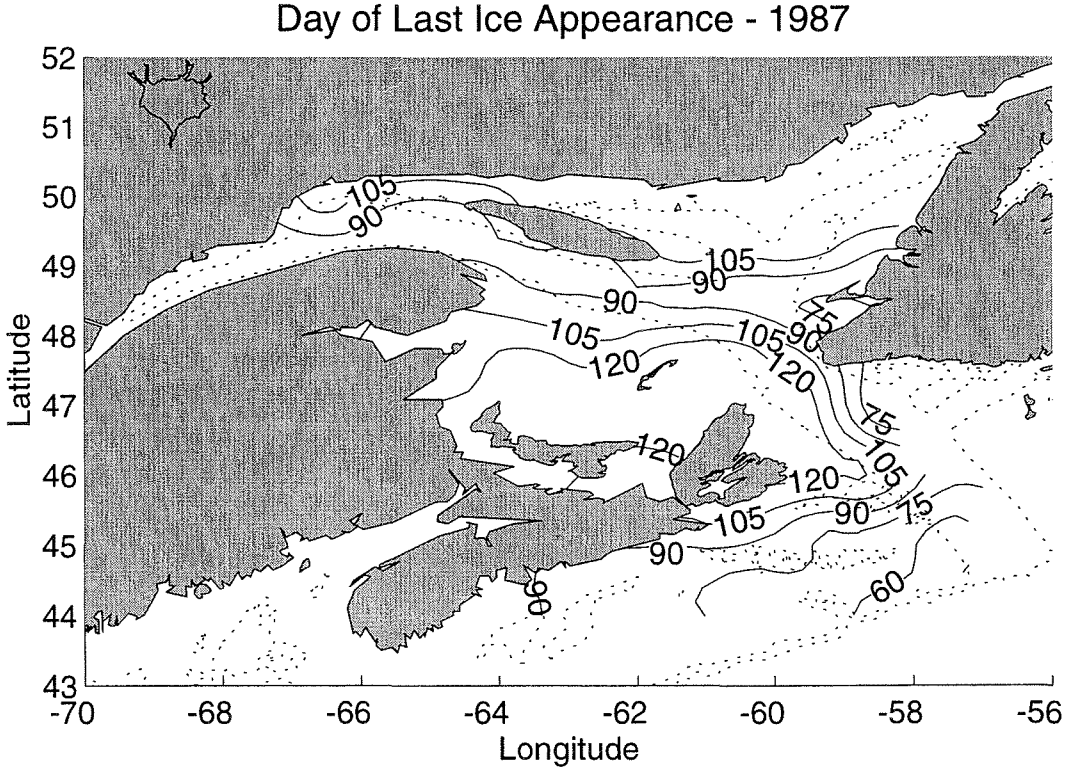
Day of Last Ice Appearance - 1987
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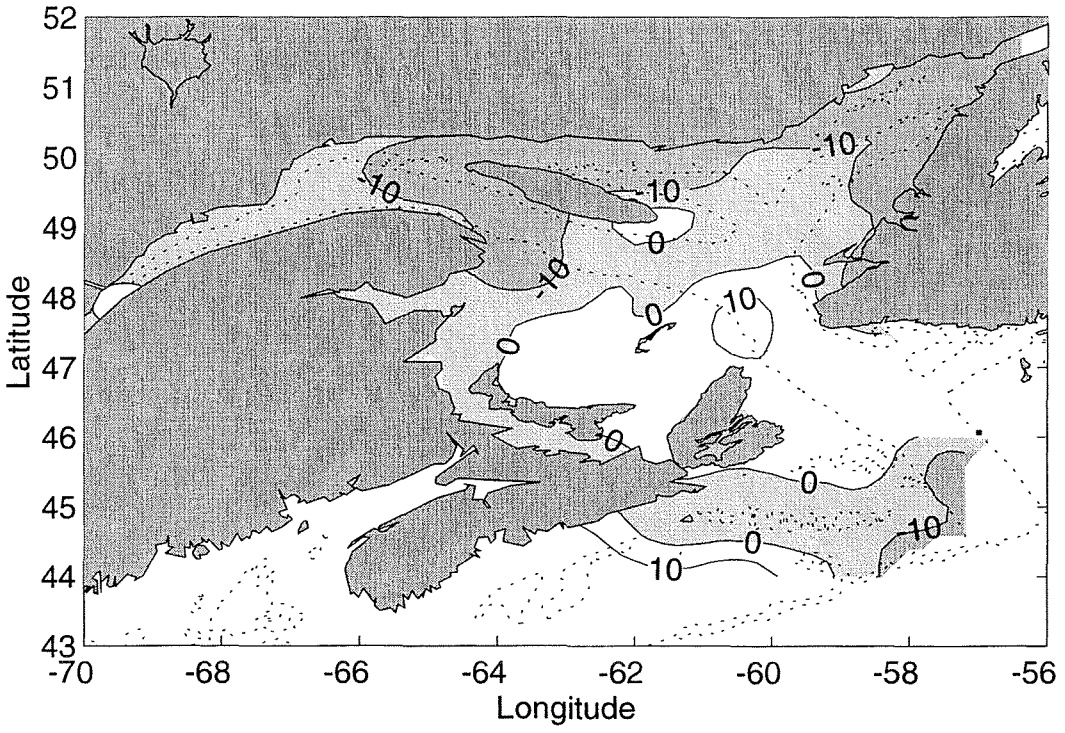
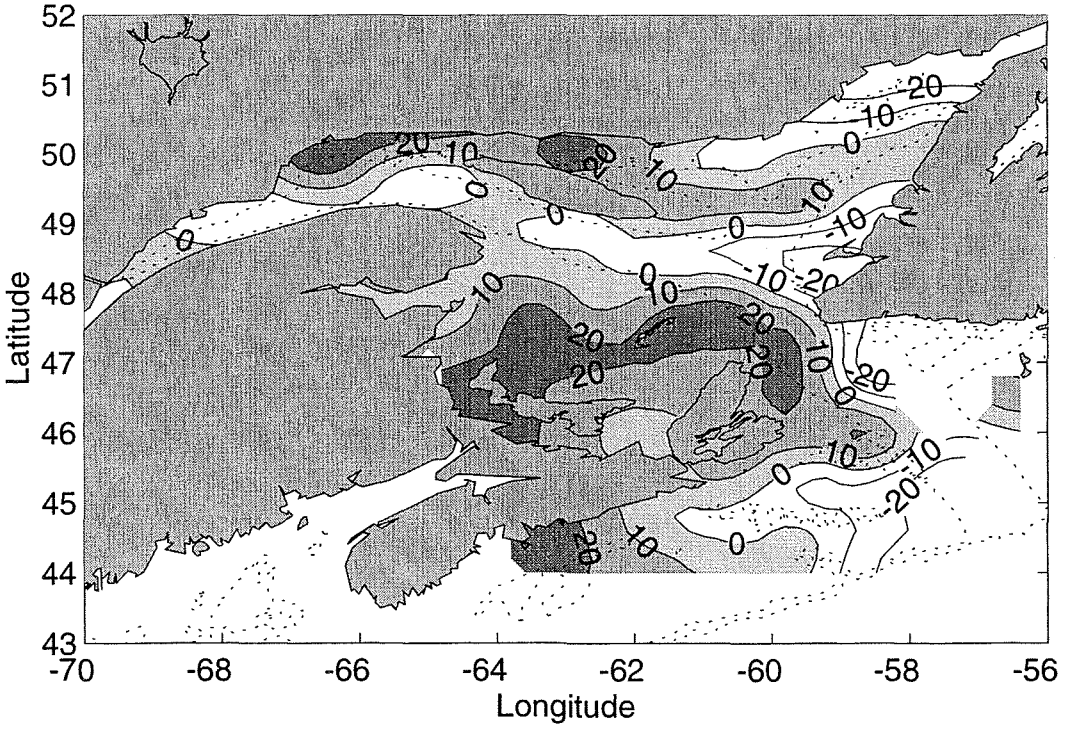
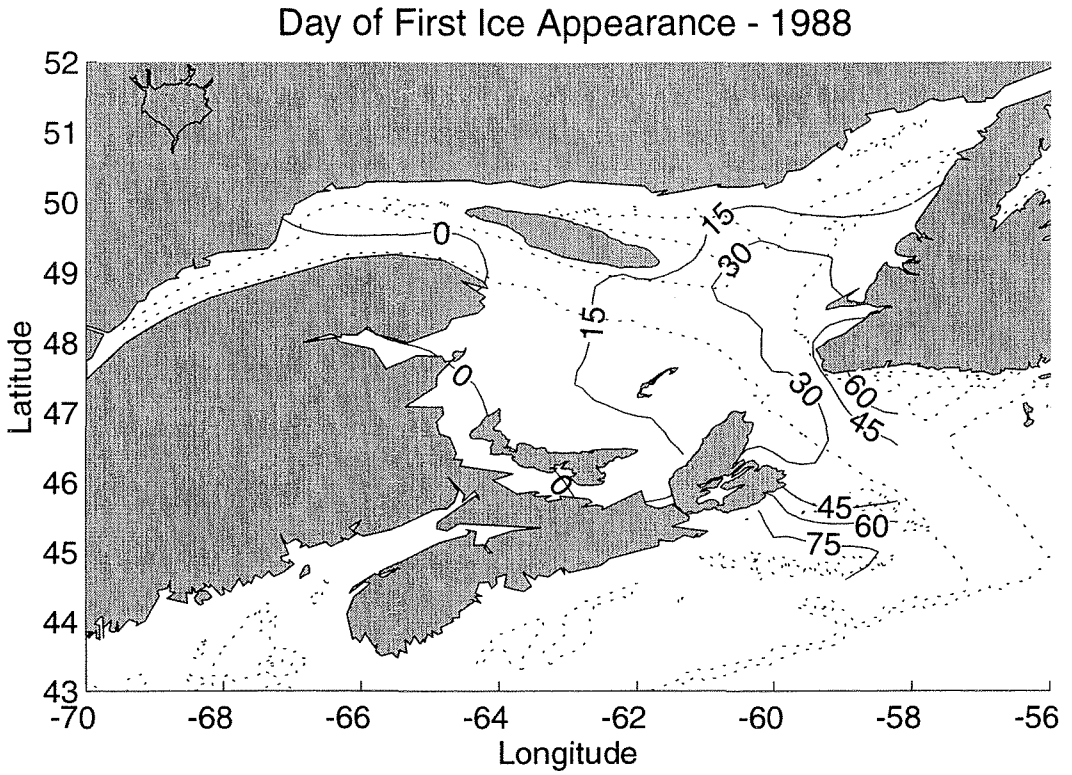
First Ice Appearance (Anomaly in Days) - 1987



Last Ice Appearance (Anomaly in Days) - 1987




Day of First Ice Appearance - 1988
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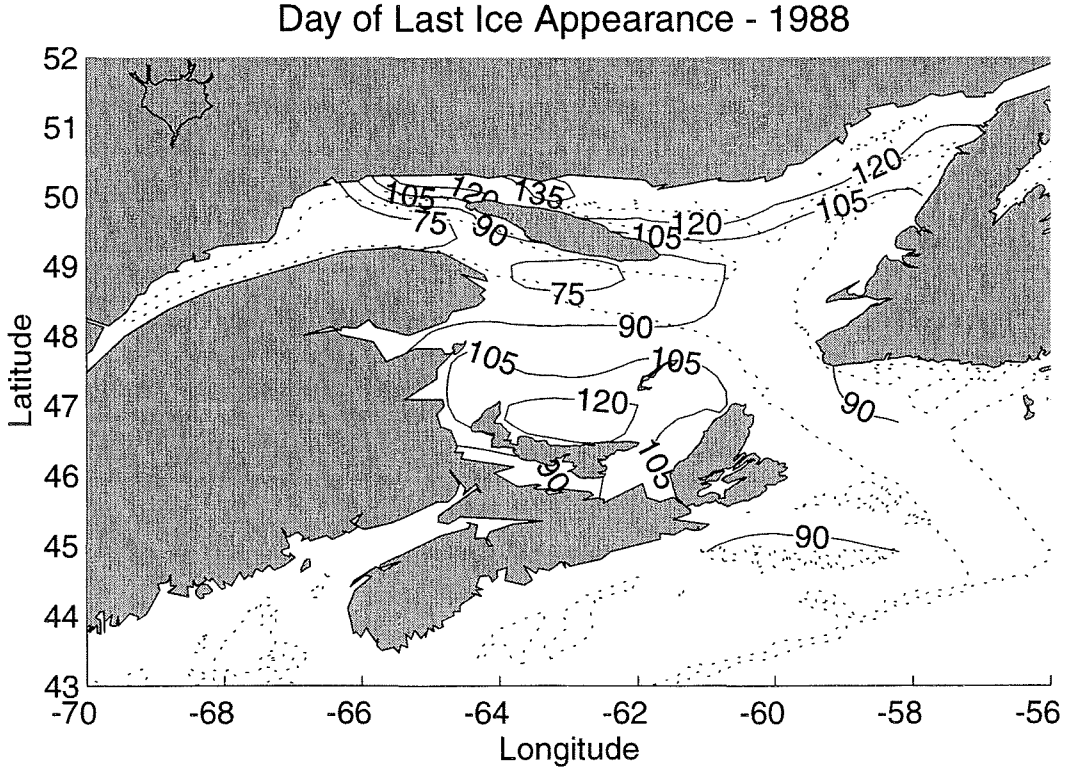
Day of Last Ice Appearance - 1988
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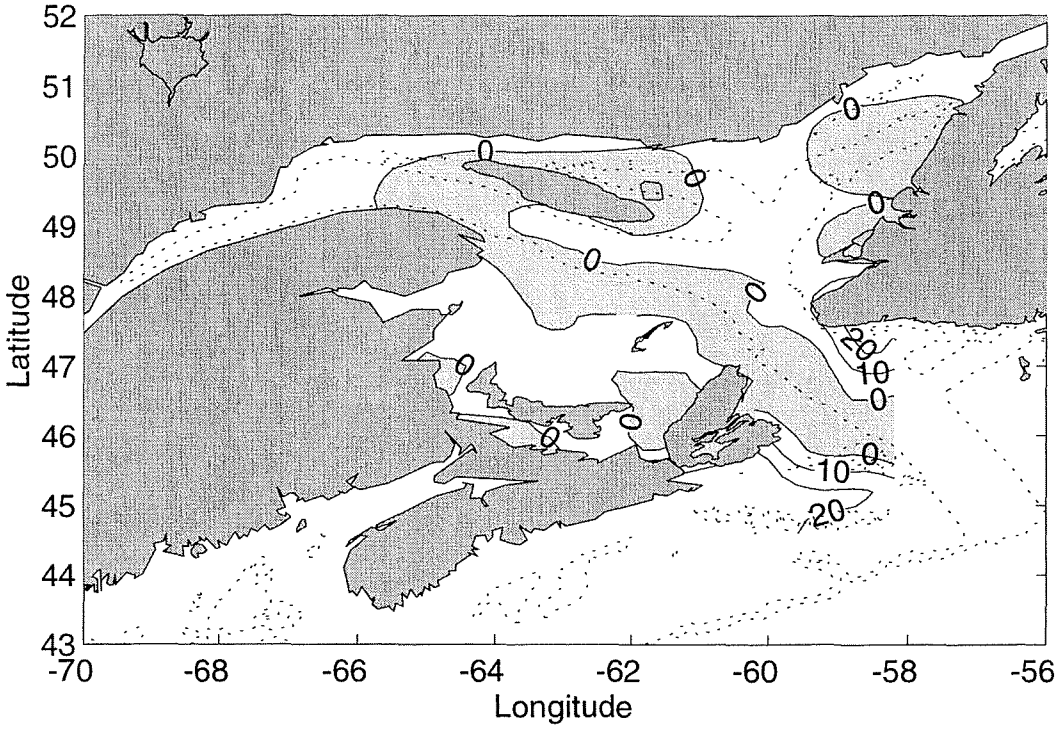
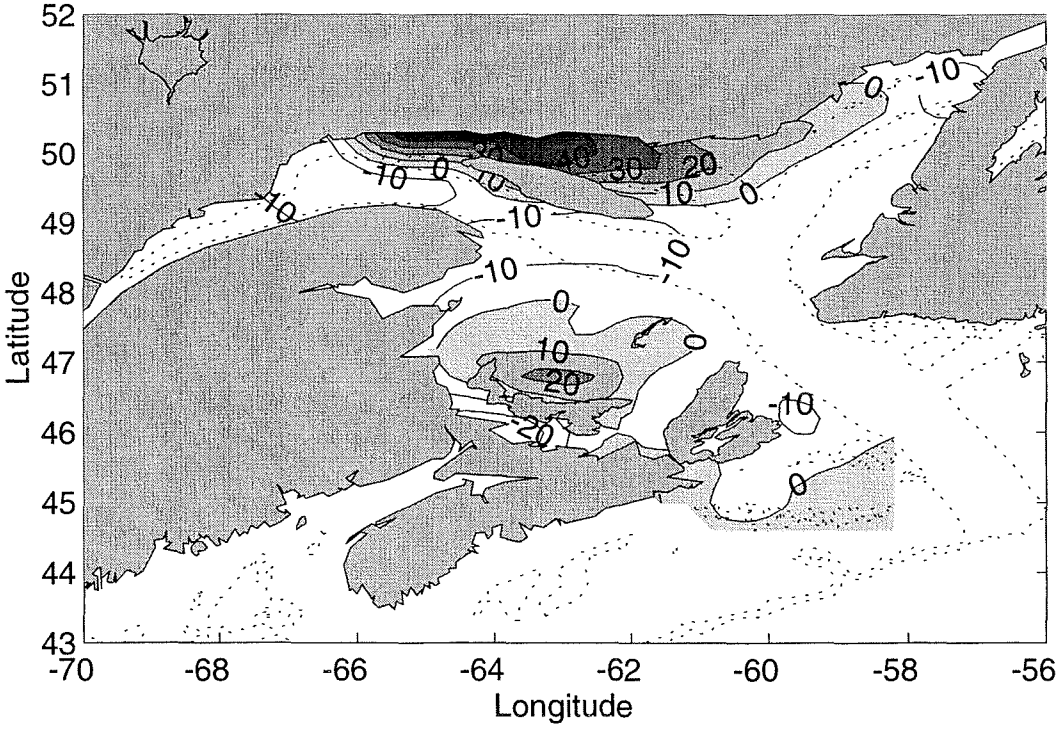
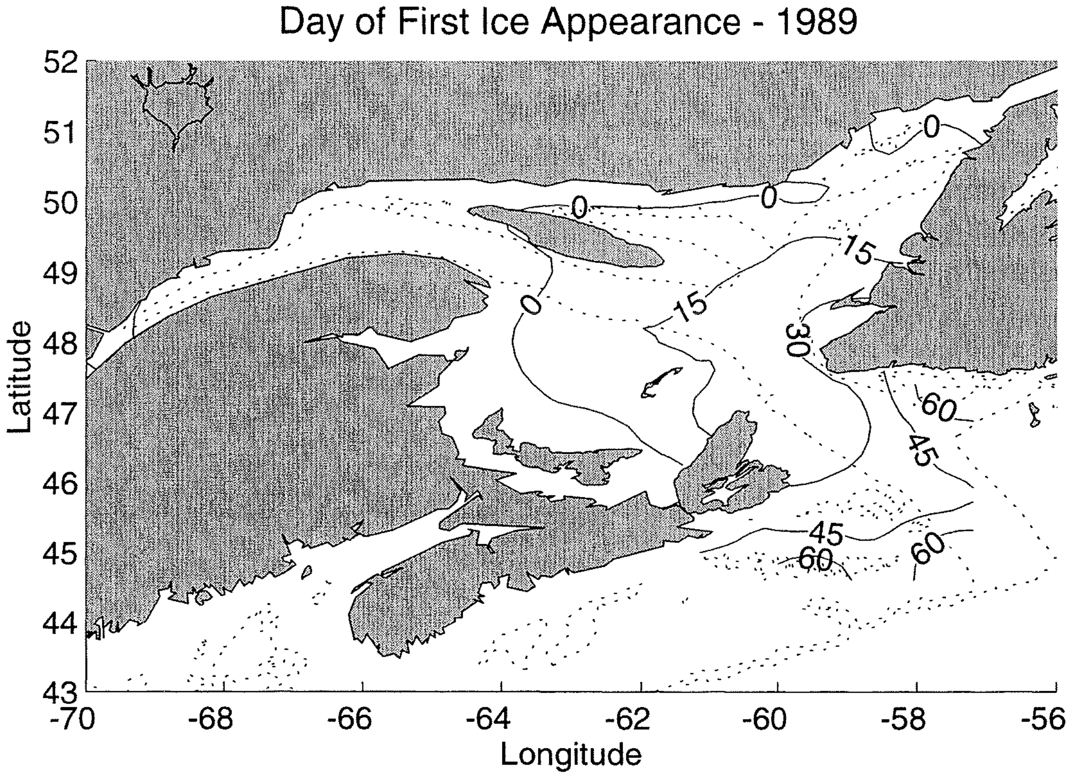
First Ice Appearance (Anomaly in Days) - 1988



Last Ice Appearance (Anomaly in Days) - 1988




Day of First Ice Appearance - 1989
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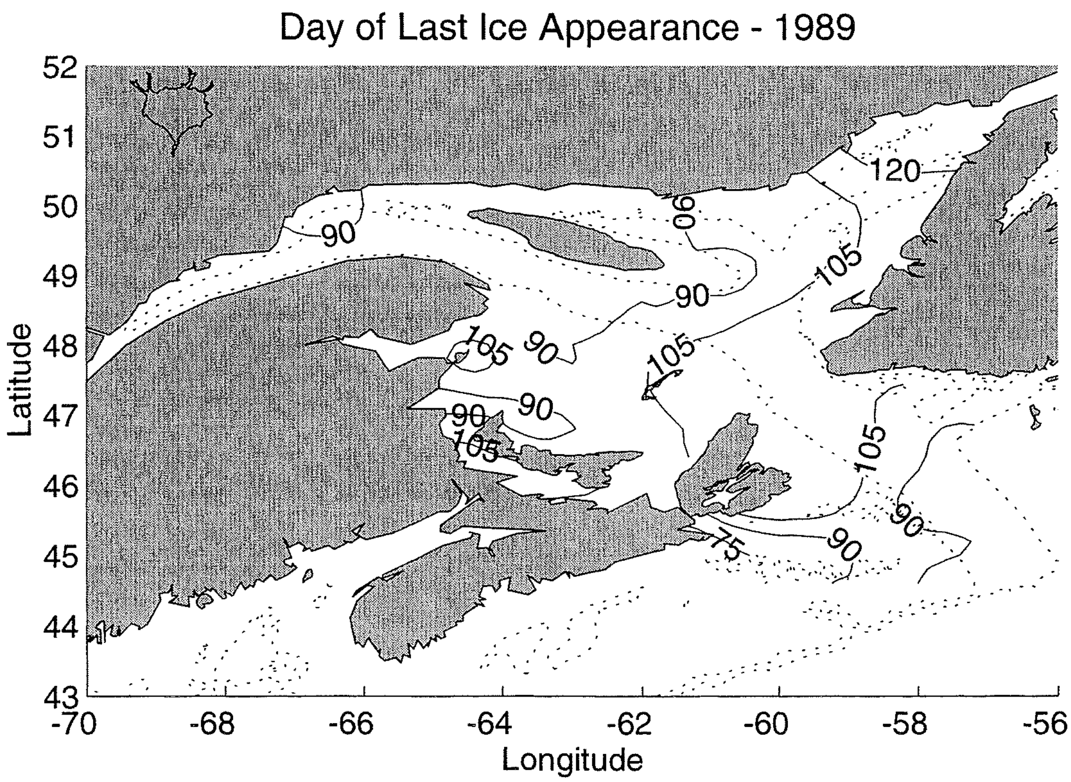
Day of Last Ice Appearance - 1989
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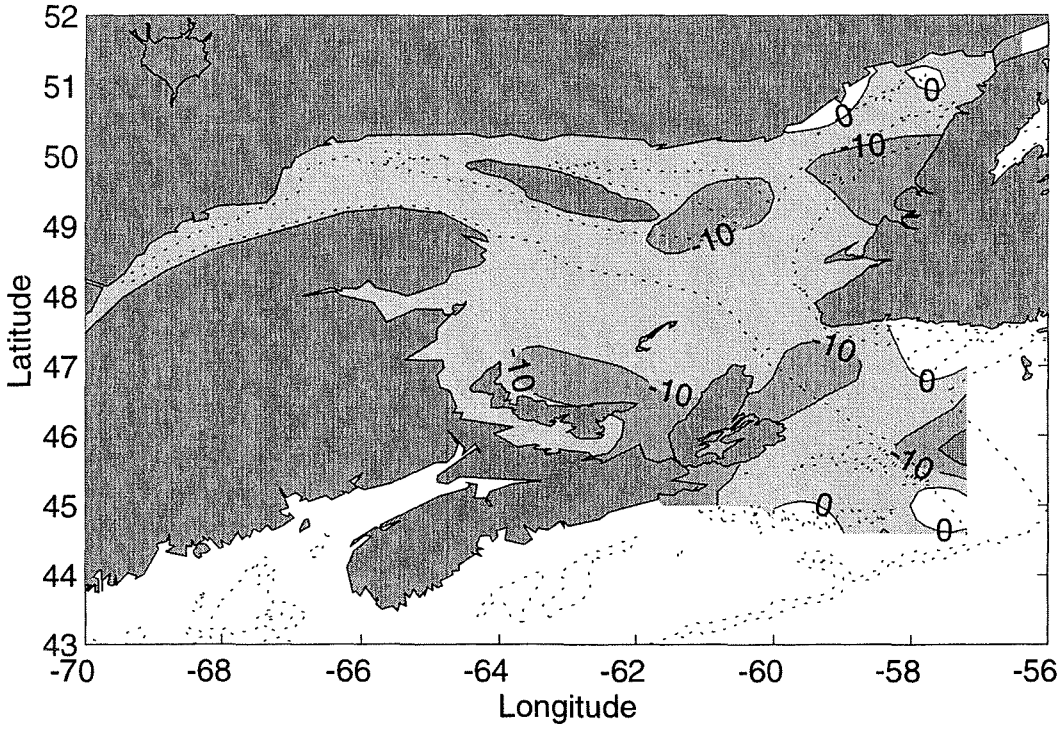
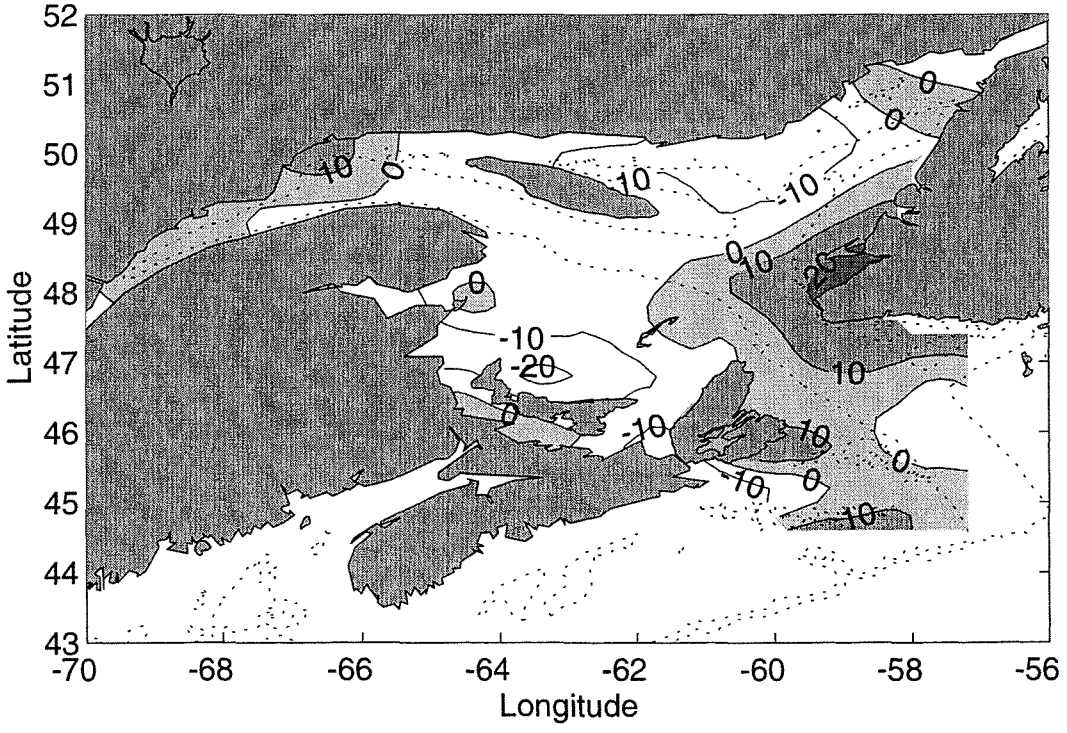
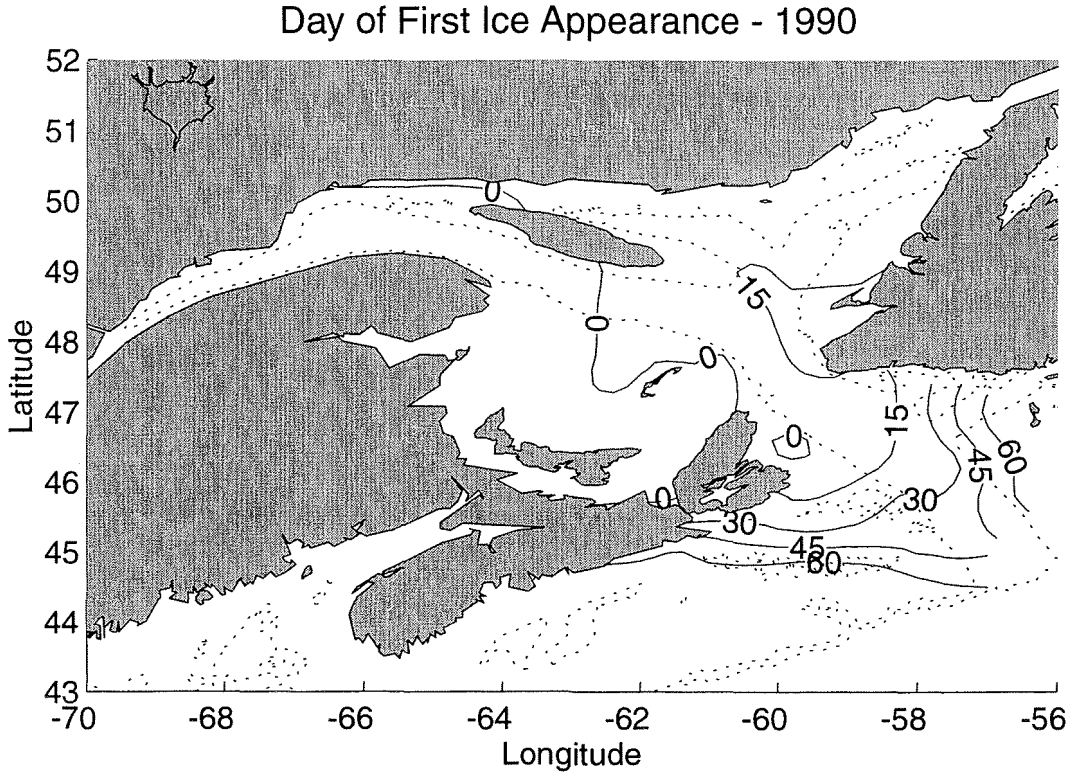
First Ice Appearance (Anomaly in Days) - 1989



Last Ice Appearance (Anomaly in Days) - 1989




Day of First Ice Appearance - 1990
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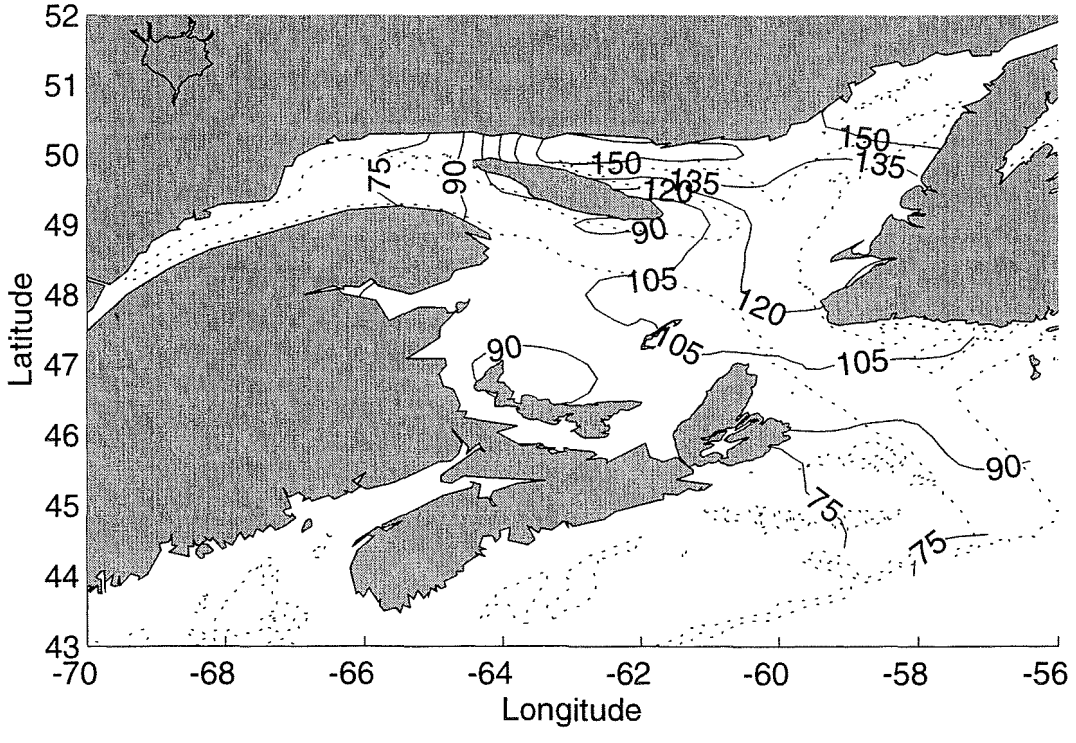
Day of Last Ice Appearance - 1990
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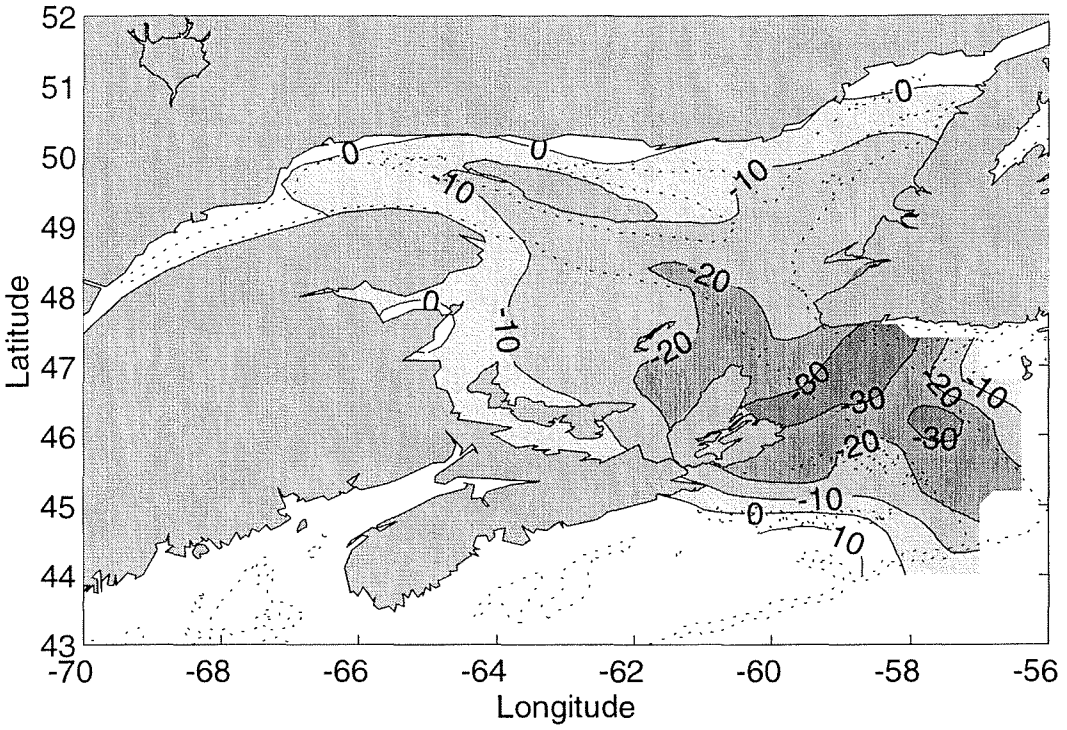
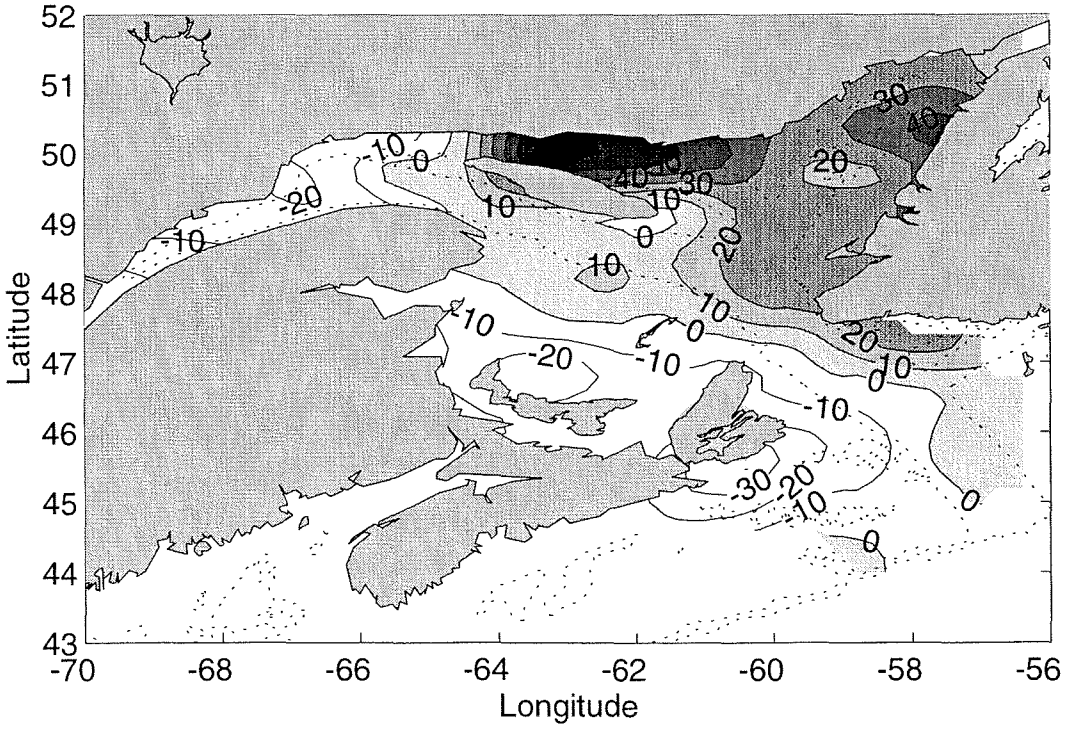
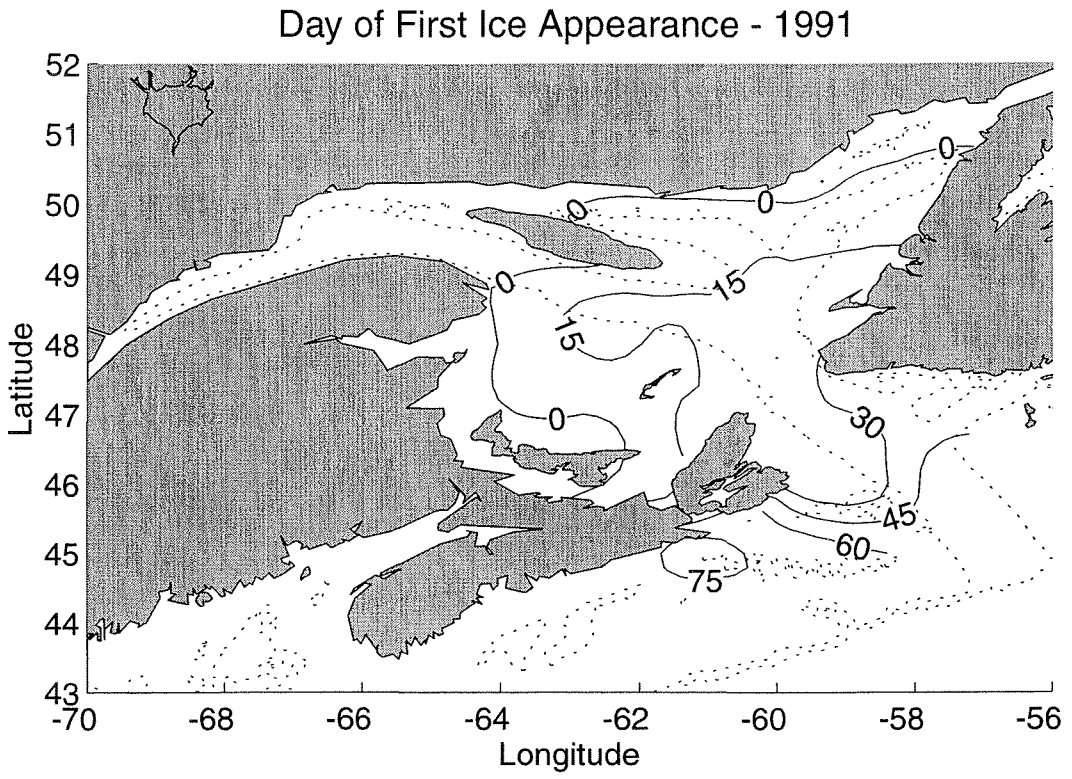
First Ice Appearance (Anomaly in Days) - 1990



Last Ice Appearance (Anomaly in Days) - 1990




Day of First Ice Appearance - 1991
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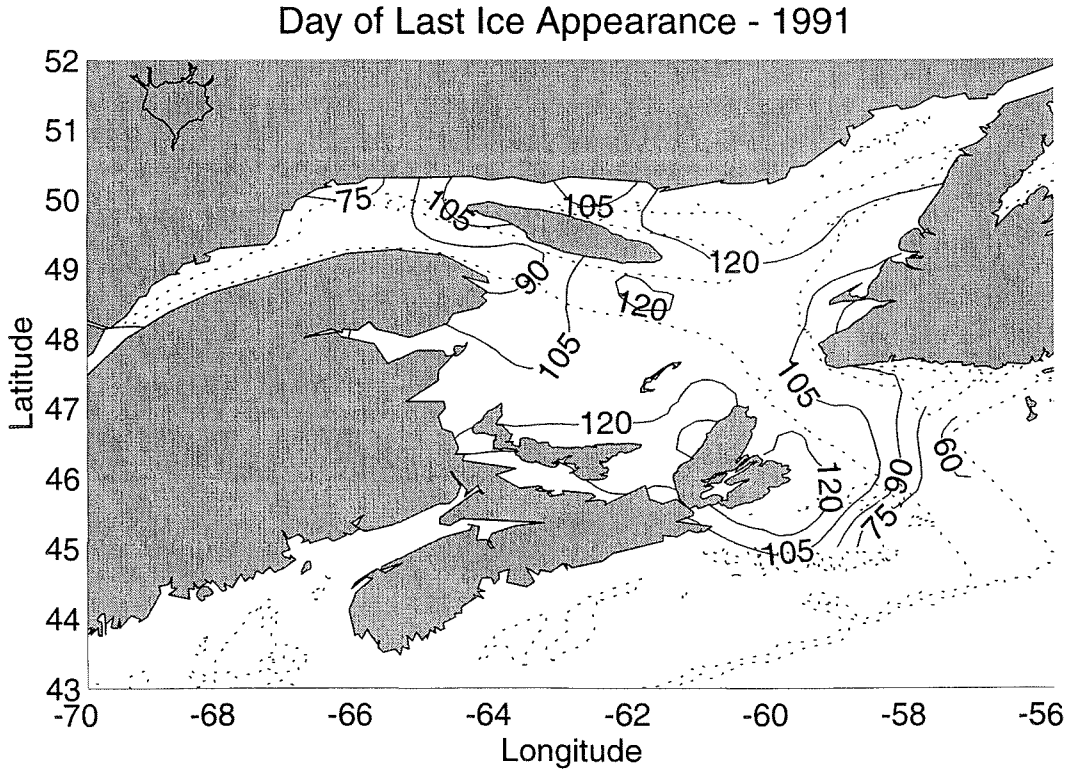
Day of Last Ice Appearance - 1991
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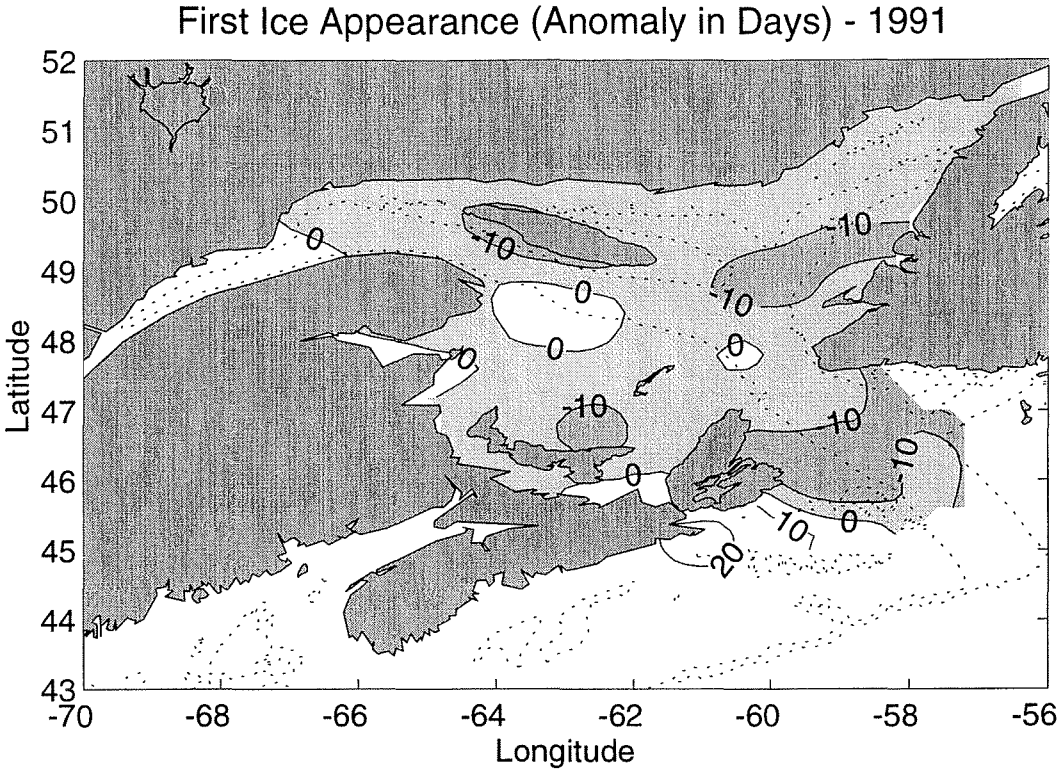
First Ice Appearance (Anomaly in Days) - 1991
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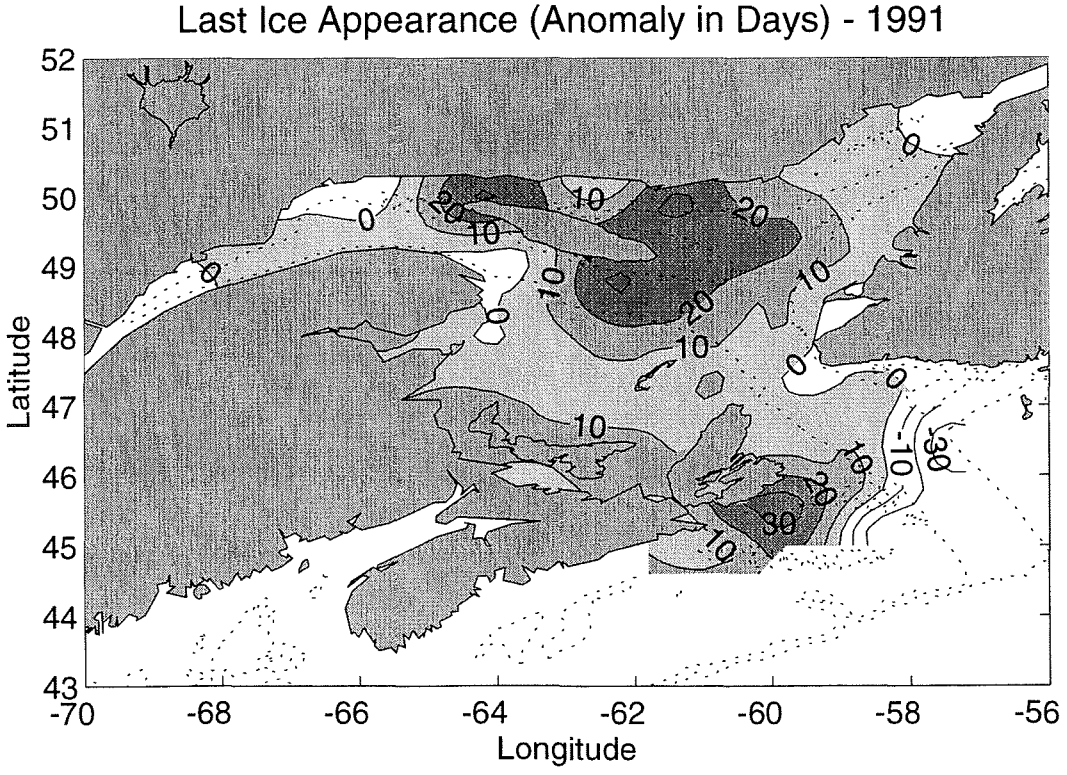
Last Ice Appearance (Anomaly in Days) - 1991
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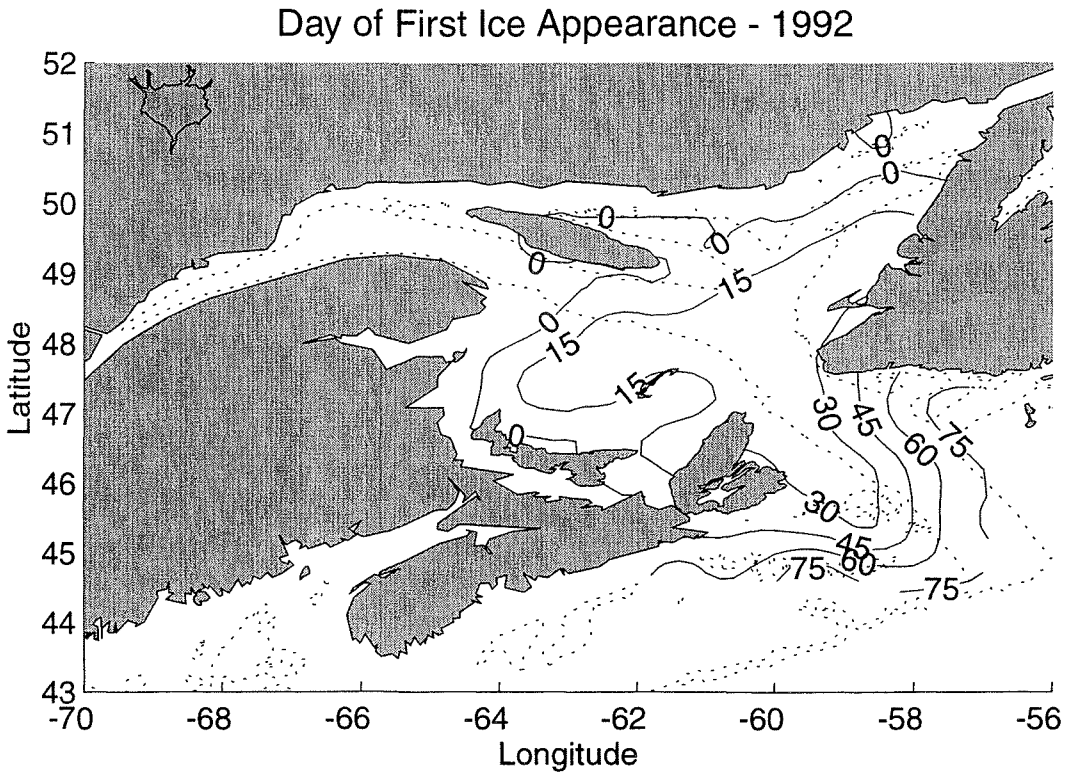
Day of First Ice Appearance - 1992
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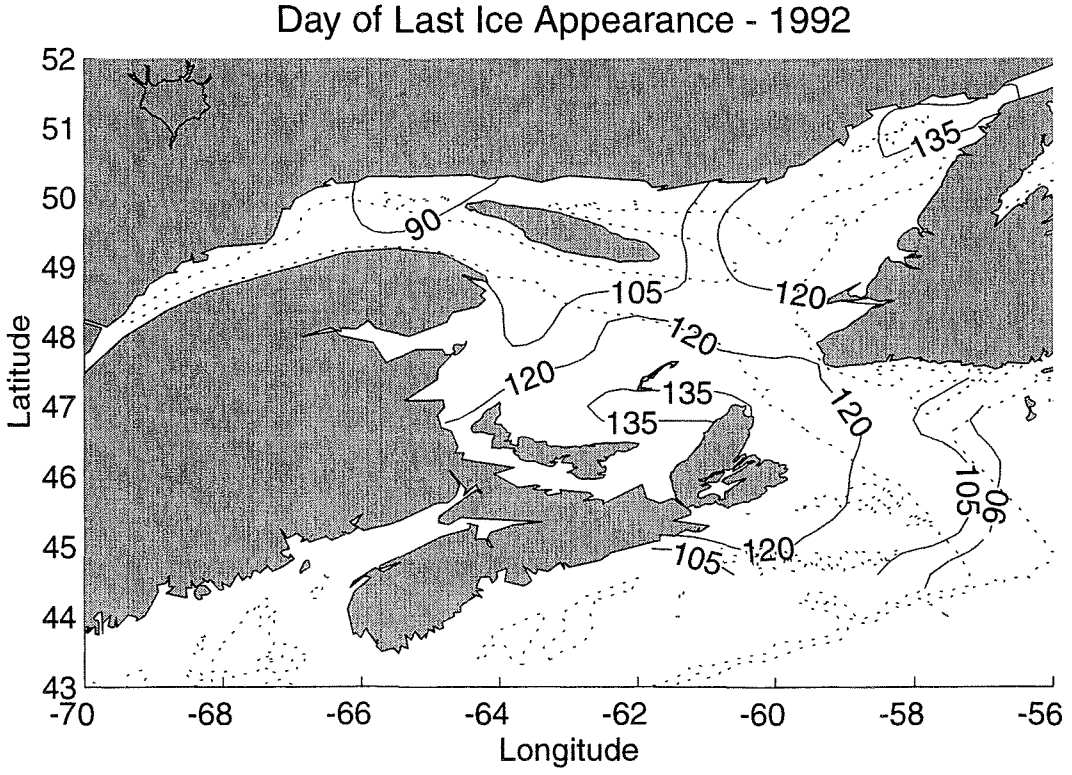
Day of Last Ice Appearance - 1992
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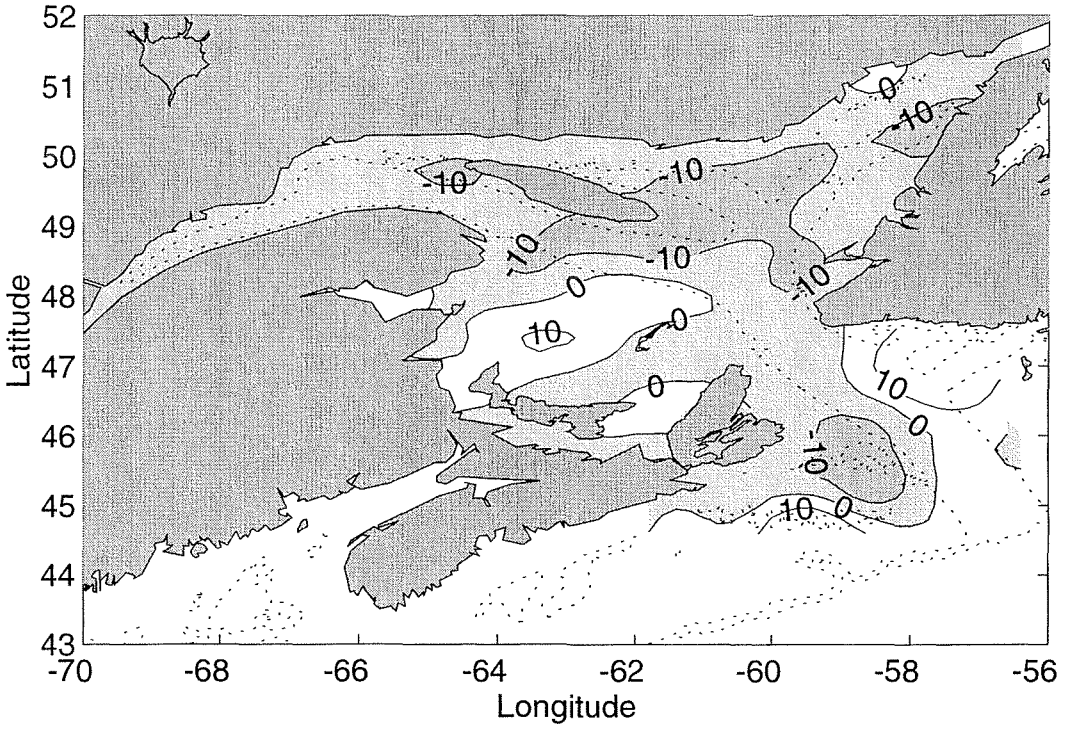
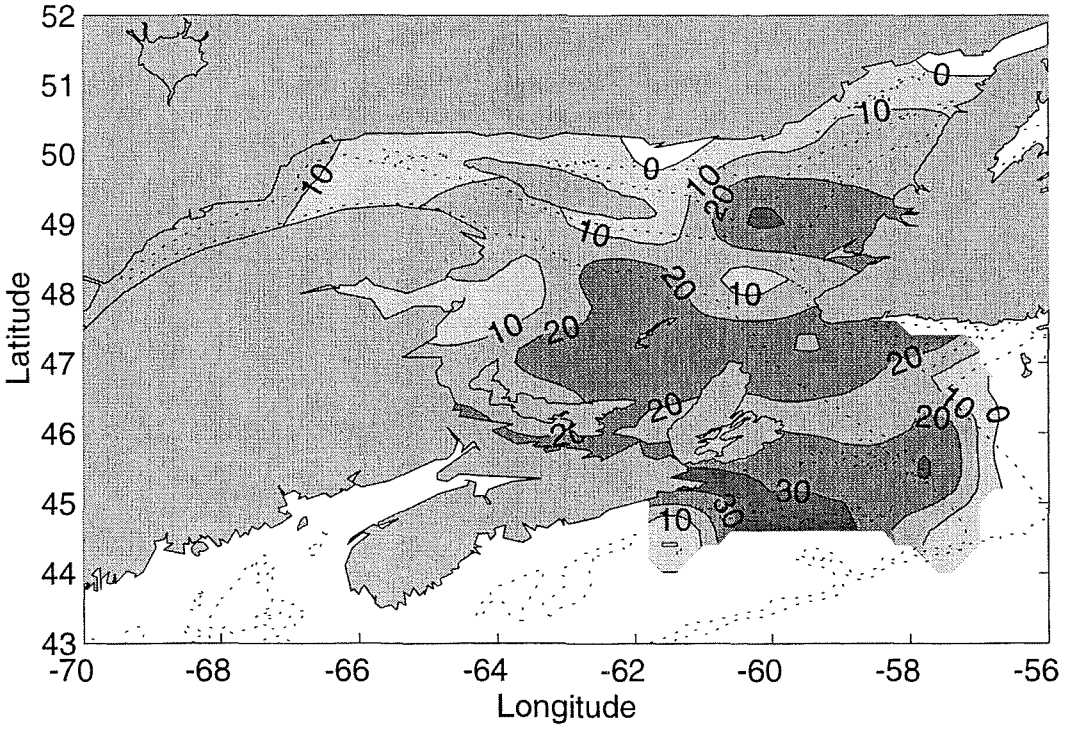
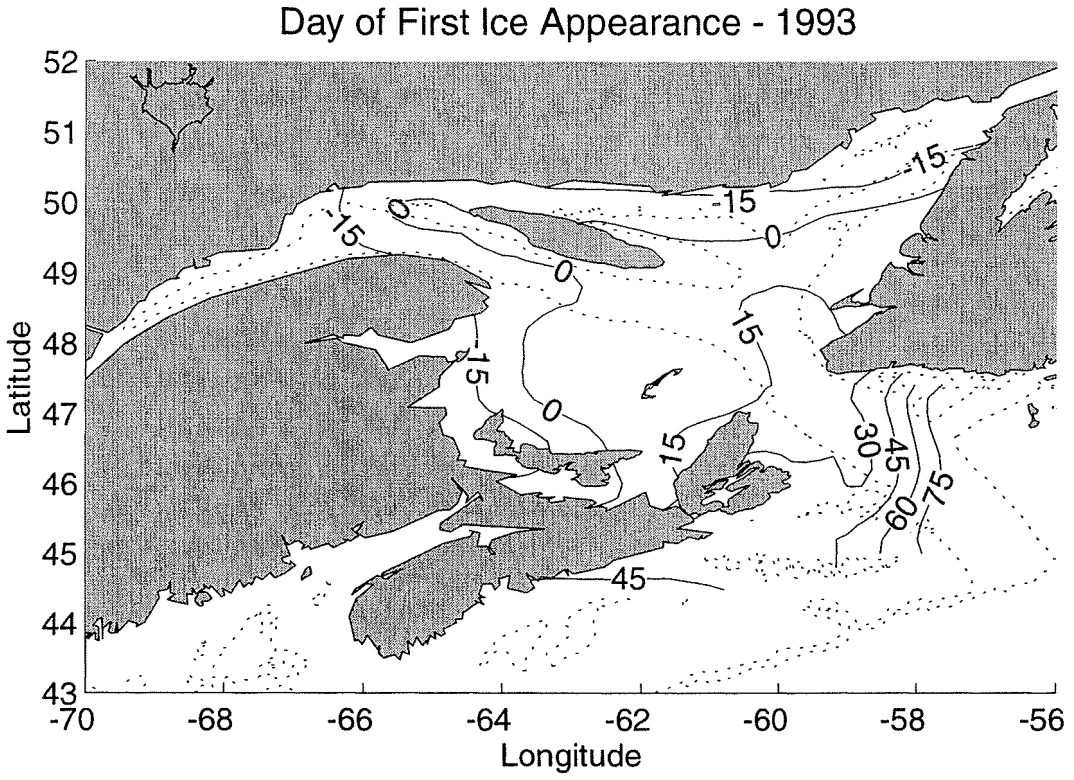
First Ice Appearance (Anomaly in Days) - 1992



Last Ice Appearance (Anomaly in Days) - 1992




Day of First Ice Appearance - 1993
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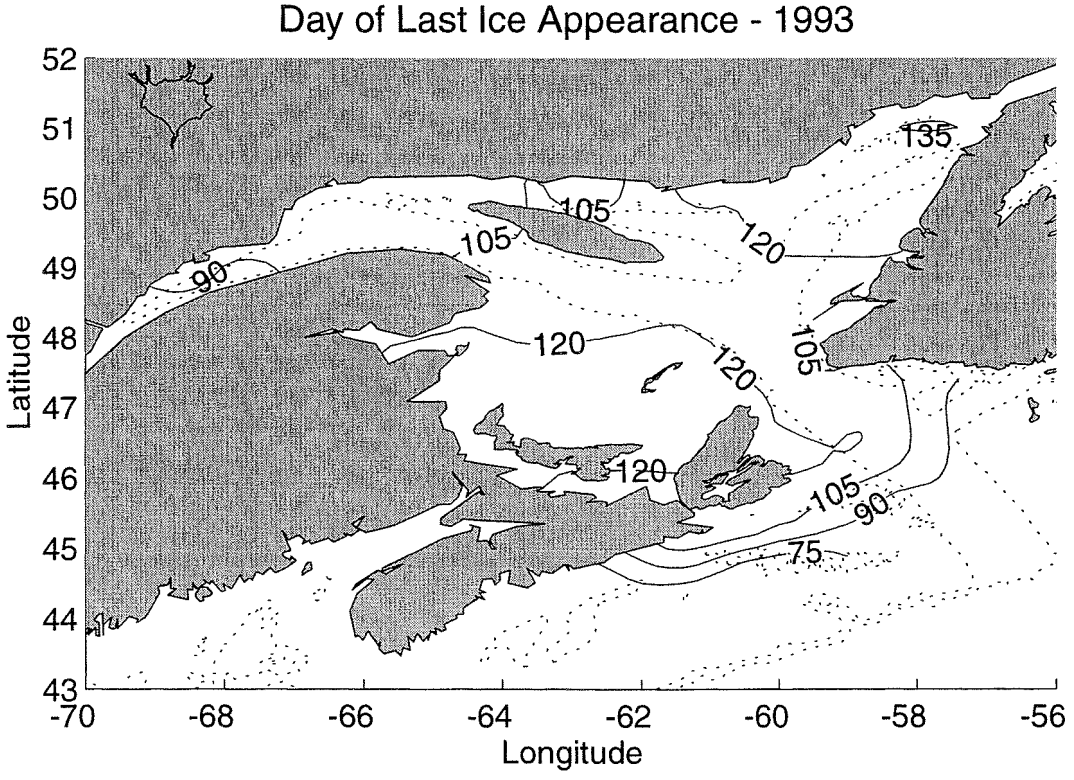
Day of Last Ice Appearance - 1993
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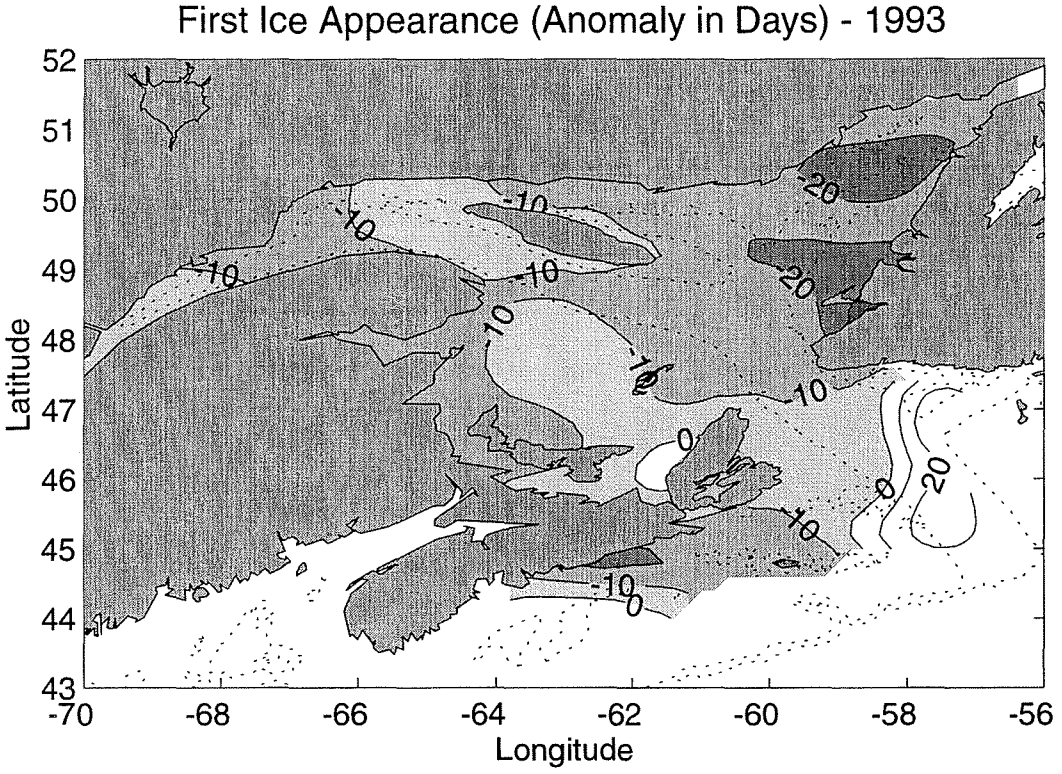
First Ice Appearance (Anomaly in Days) - 1993
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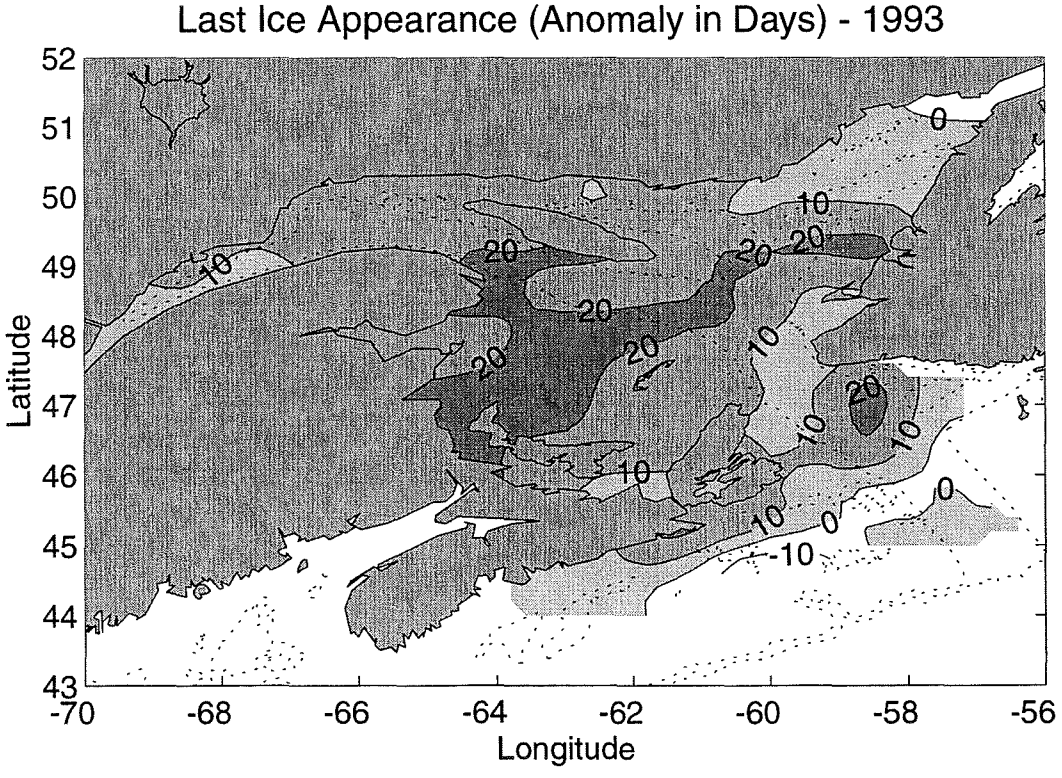
Last Ice Appearance (Anomaly in Days) - 1993
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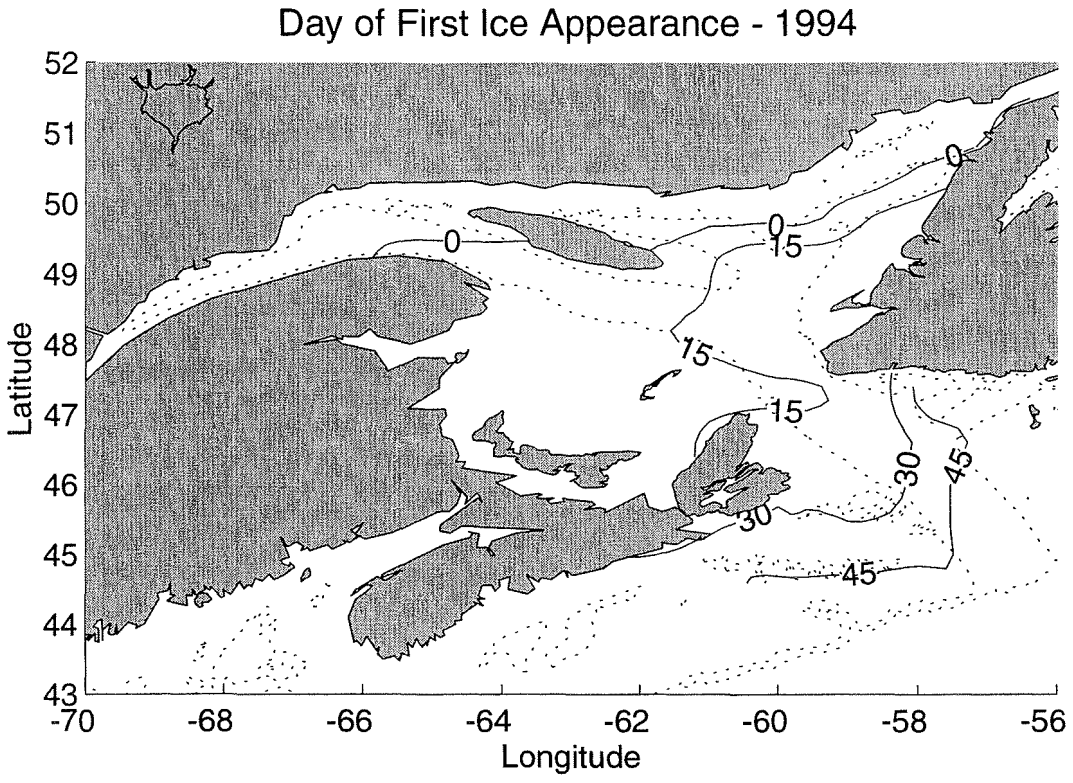
Day of First Ice Appearance - 1994
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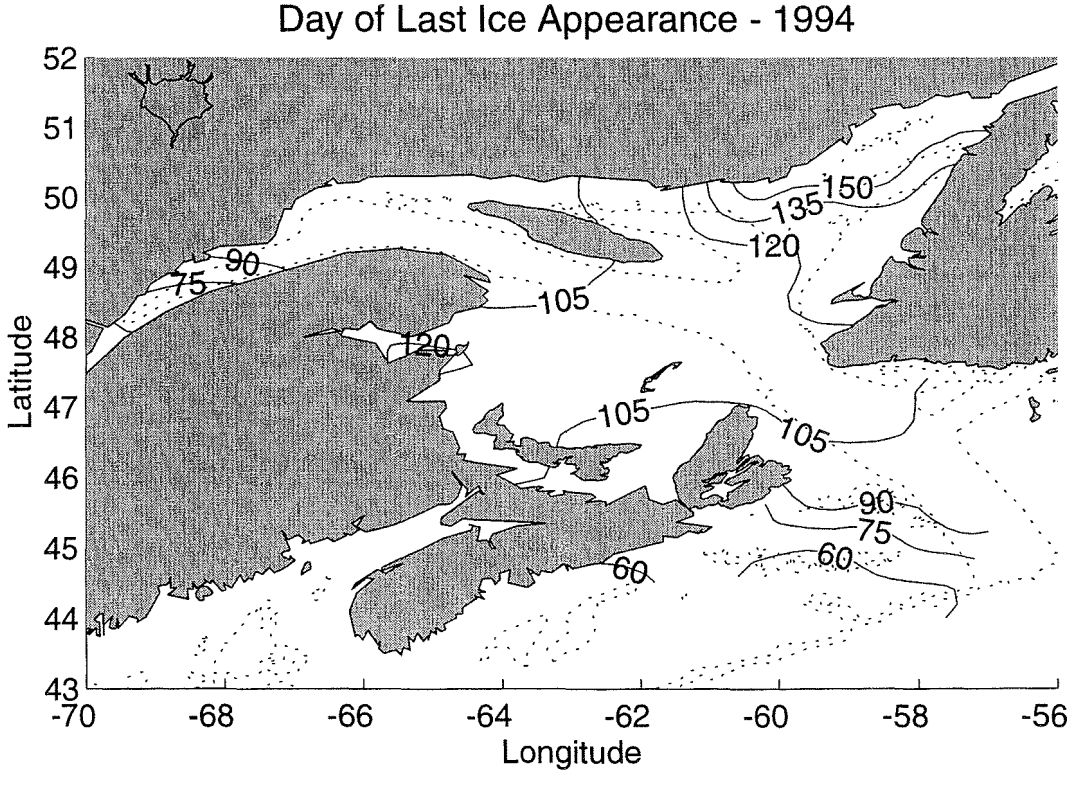
Day of Last Ice Appearance - 1994
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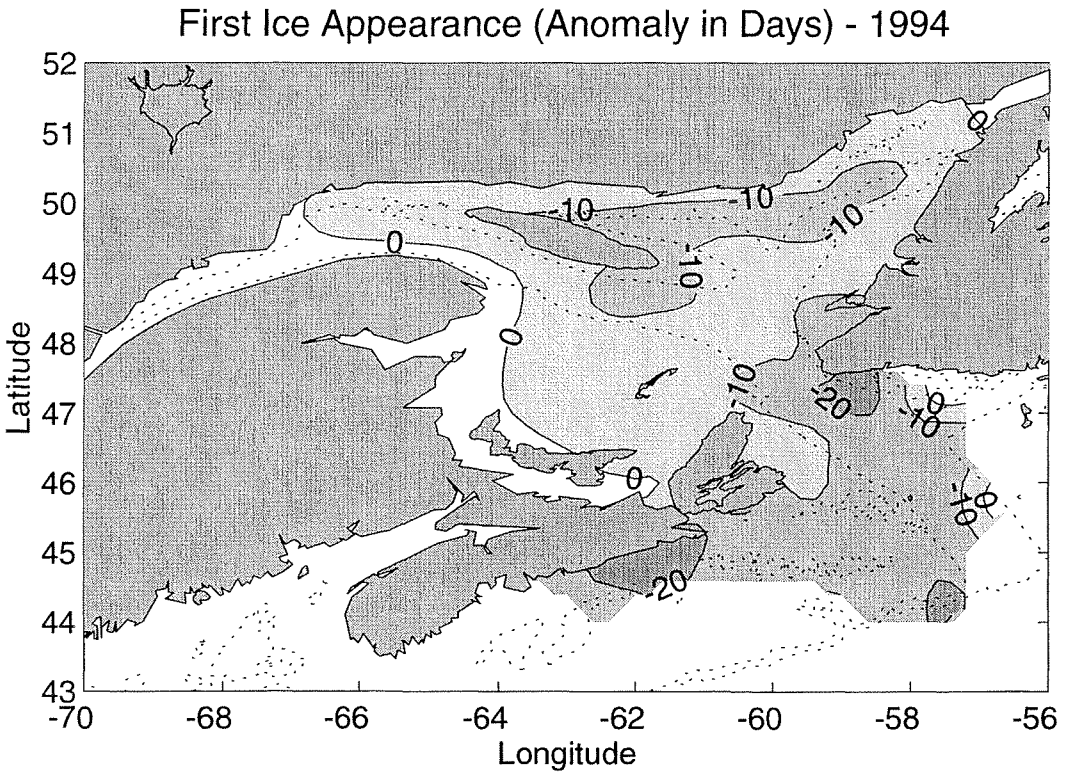
First Ice Appearance (Anomaly in Days) - 1994
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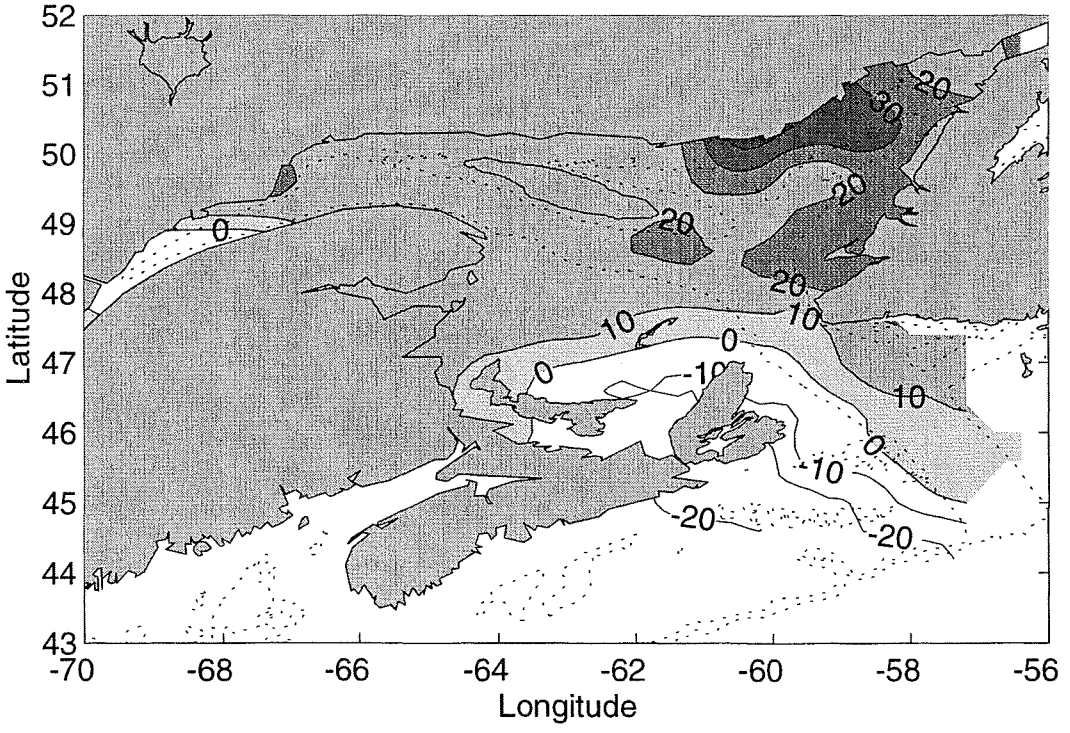
Last Ice Appearance (Anomaly in Days) - 1994
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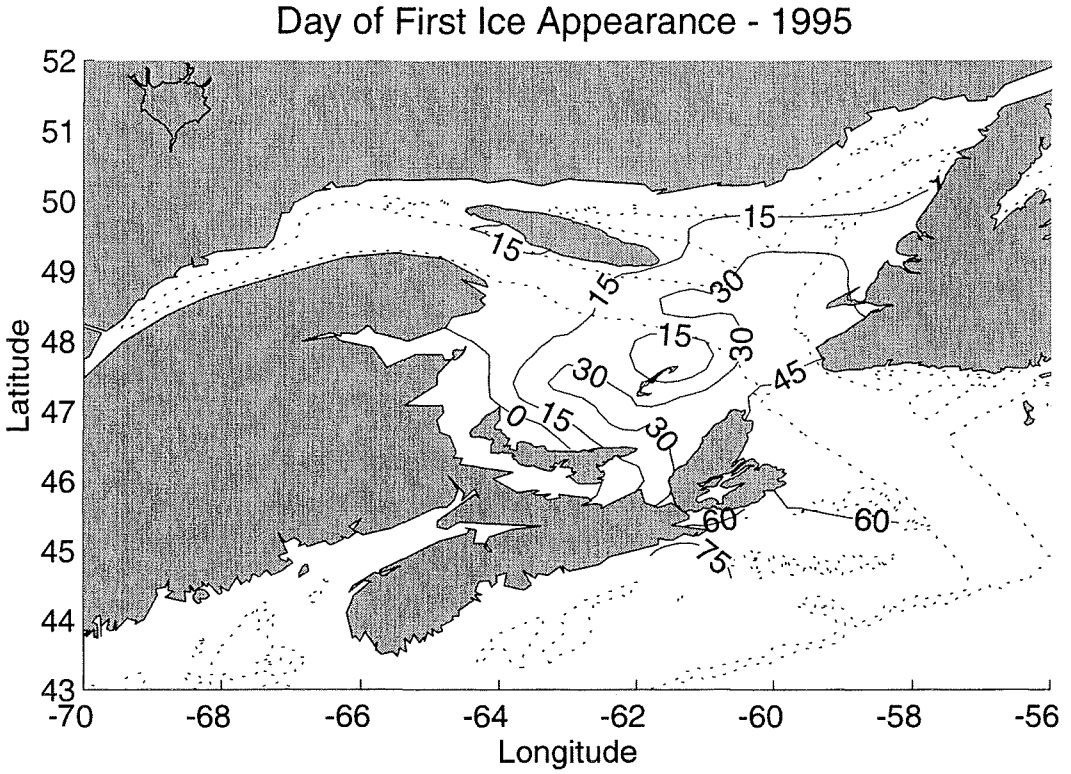
Day of First Ice Appearance - 1995
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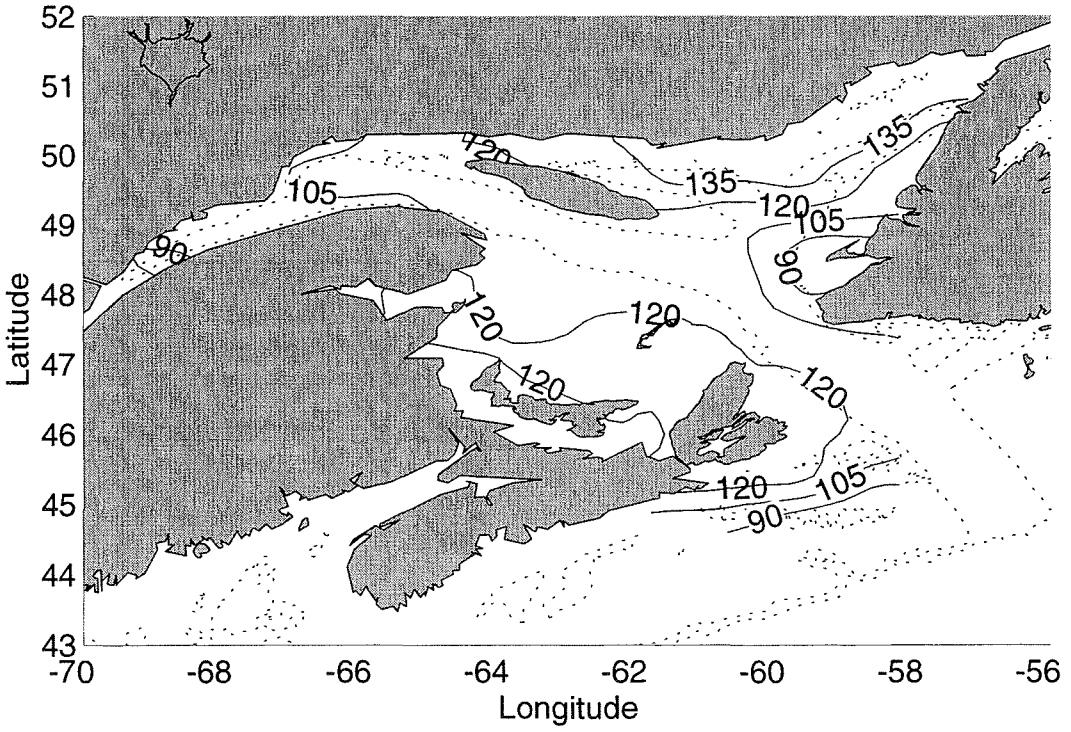
Day of Last Ice Appearance - 1995
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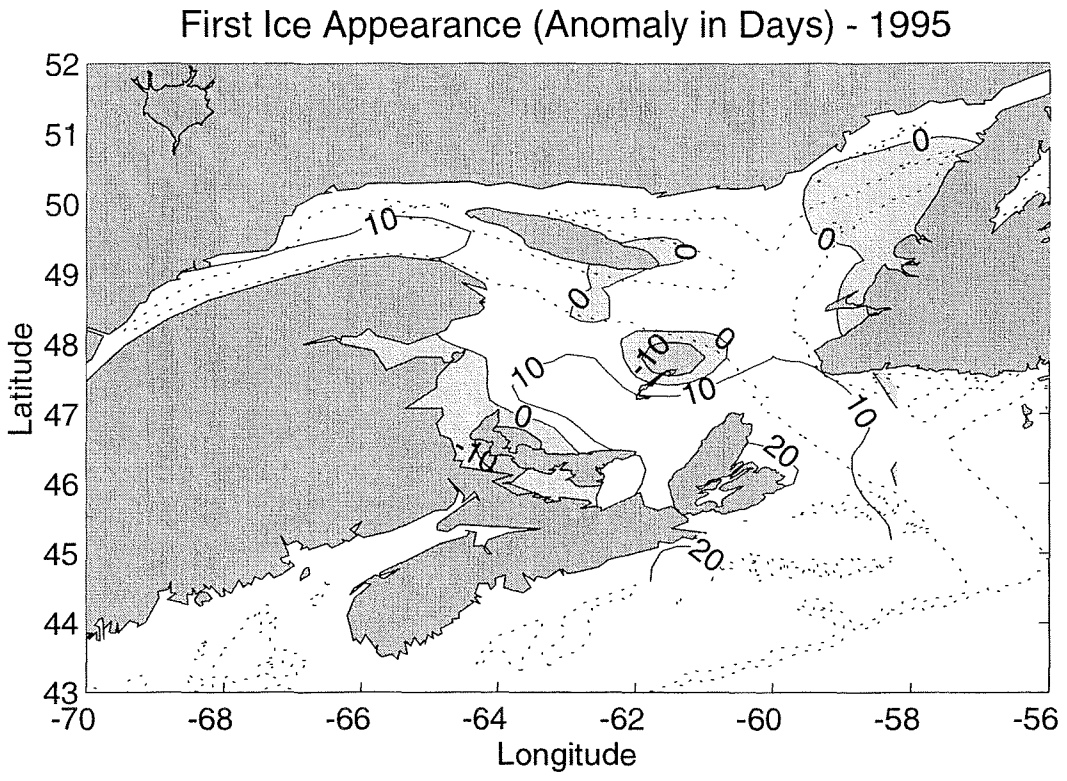
First Ice Appearance (Anomaly in Days) - 1995
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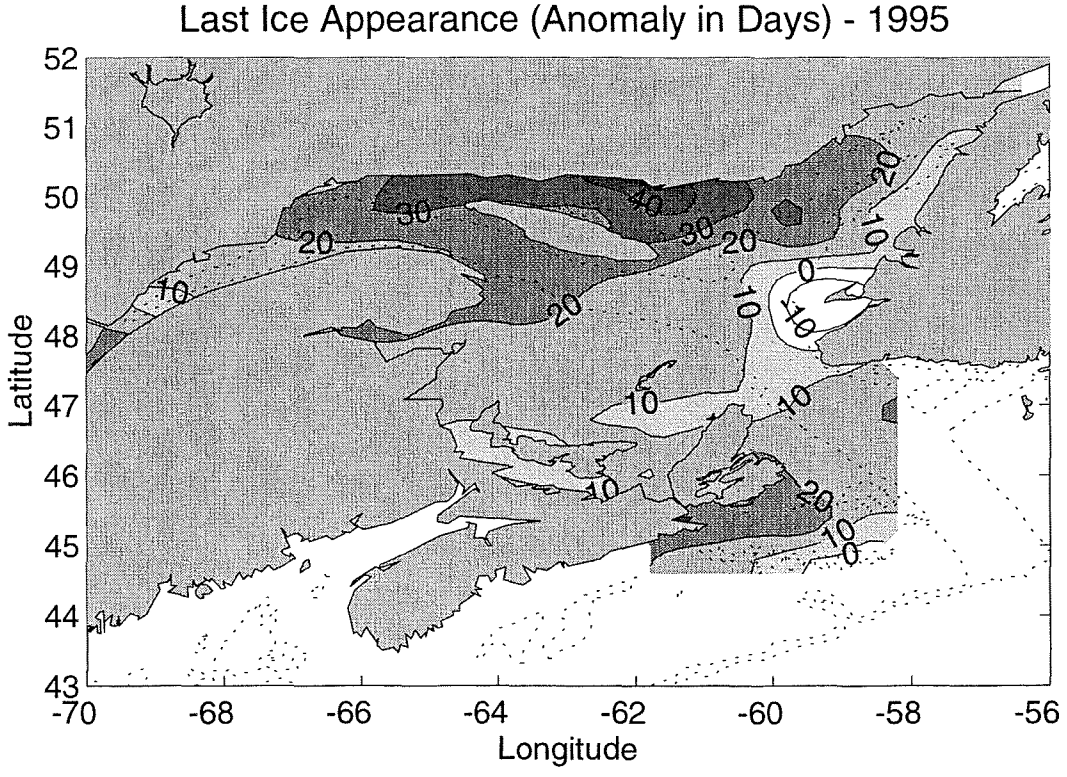
Last Ice Appearance (Anomaly in Days) - 1995
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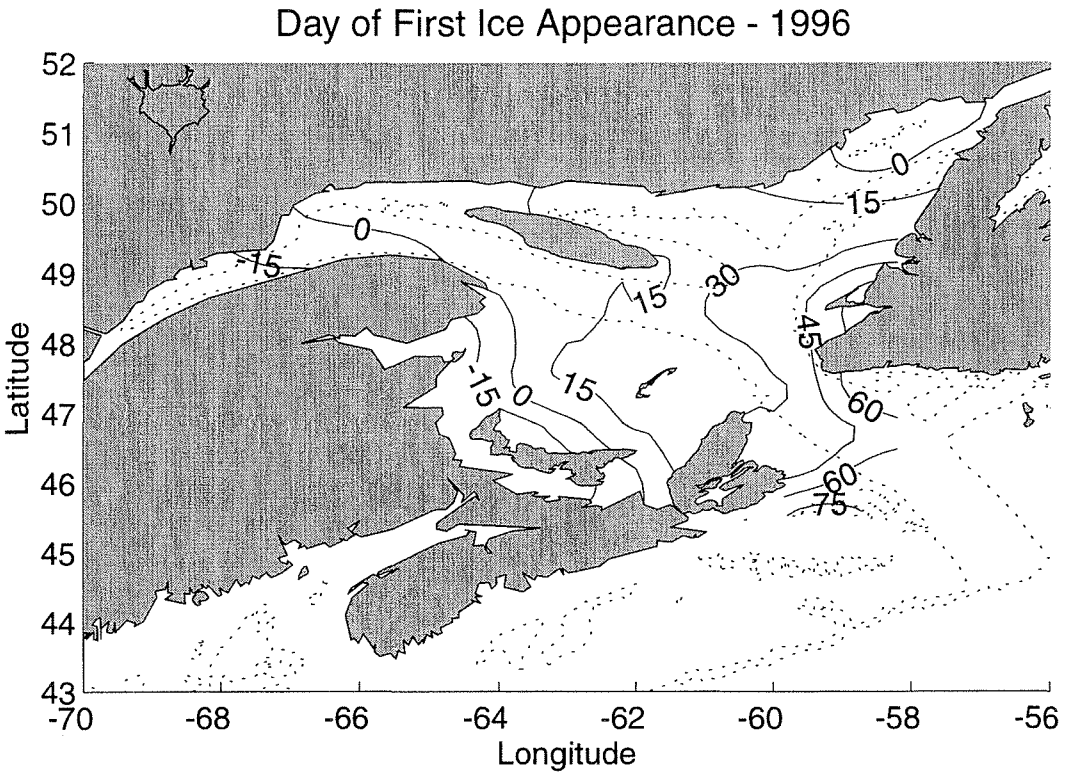
Day of First Ice Appearance - 1996
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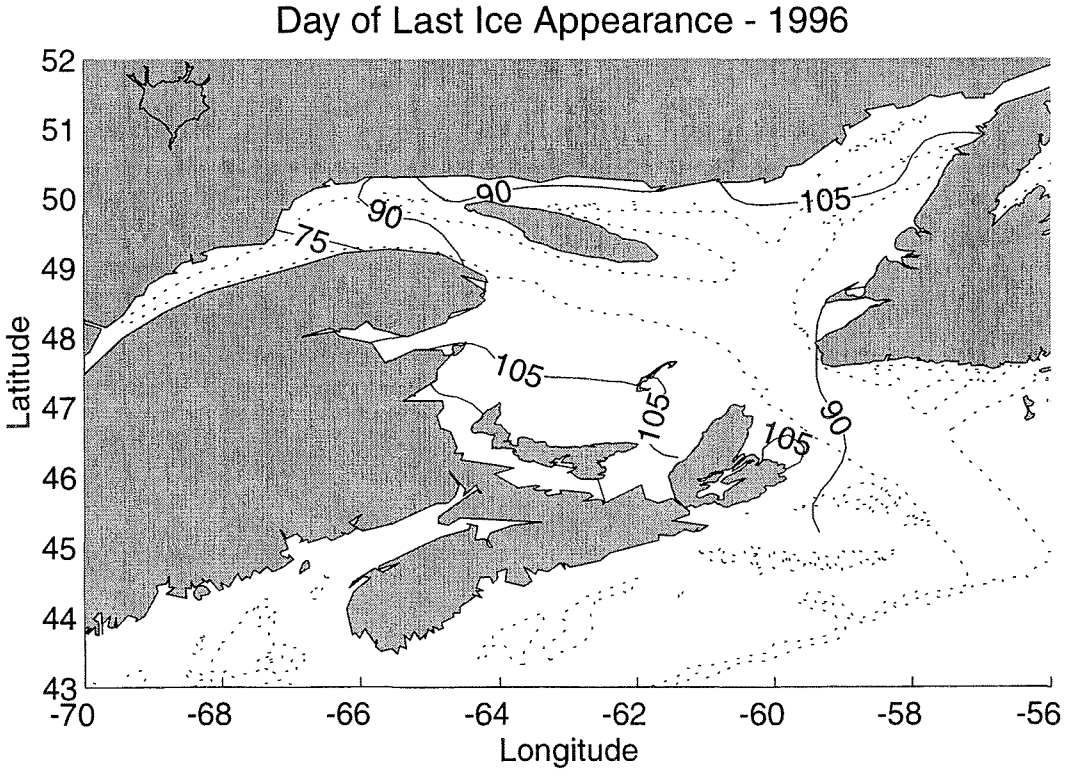
Day of Last Ice Appearance - 1996
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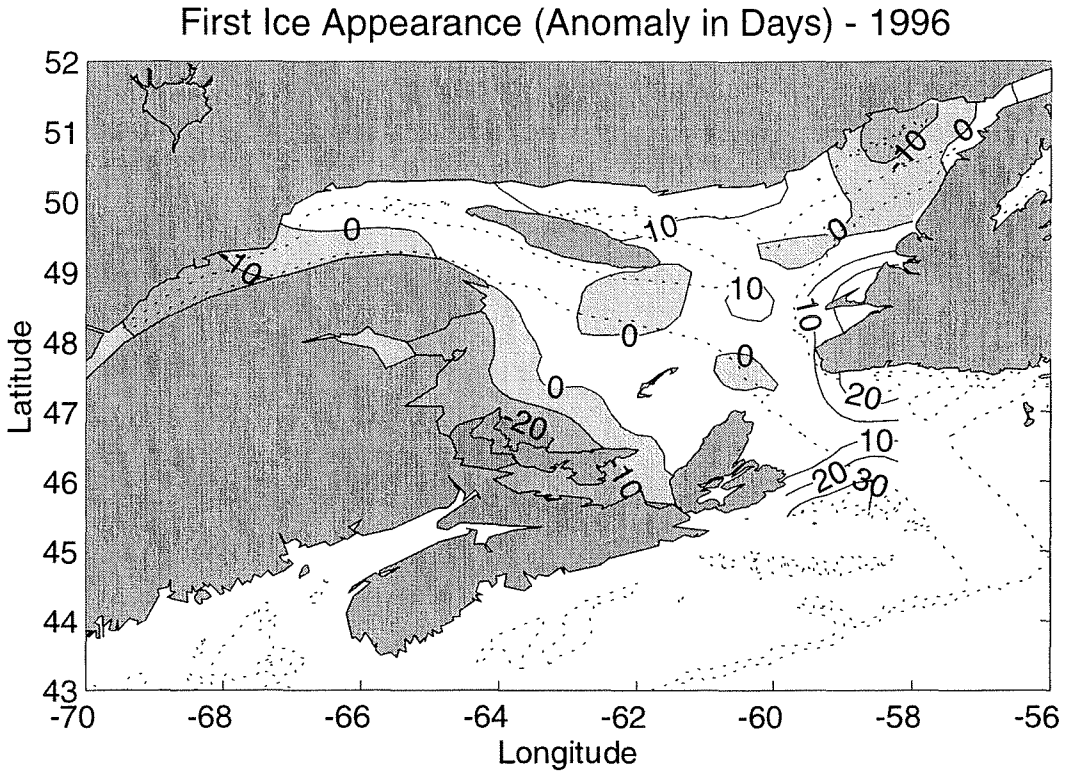
First Ice Appearance (Anomaly in Days) - 1996
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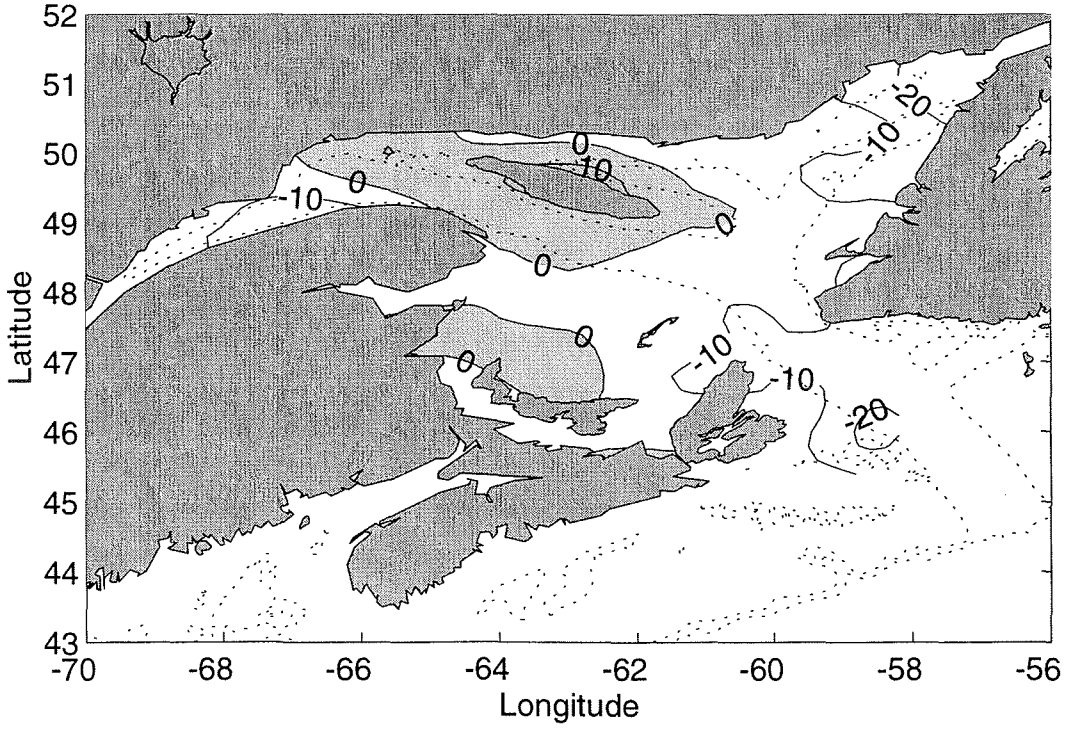
Last Ice Appearance (Anomaly in Days) - 1996
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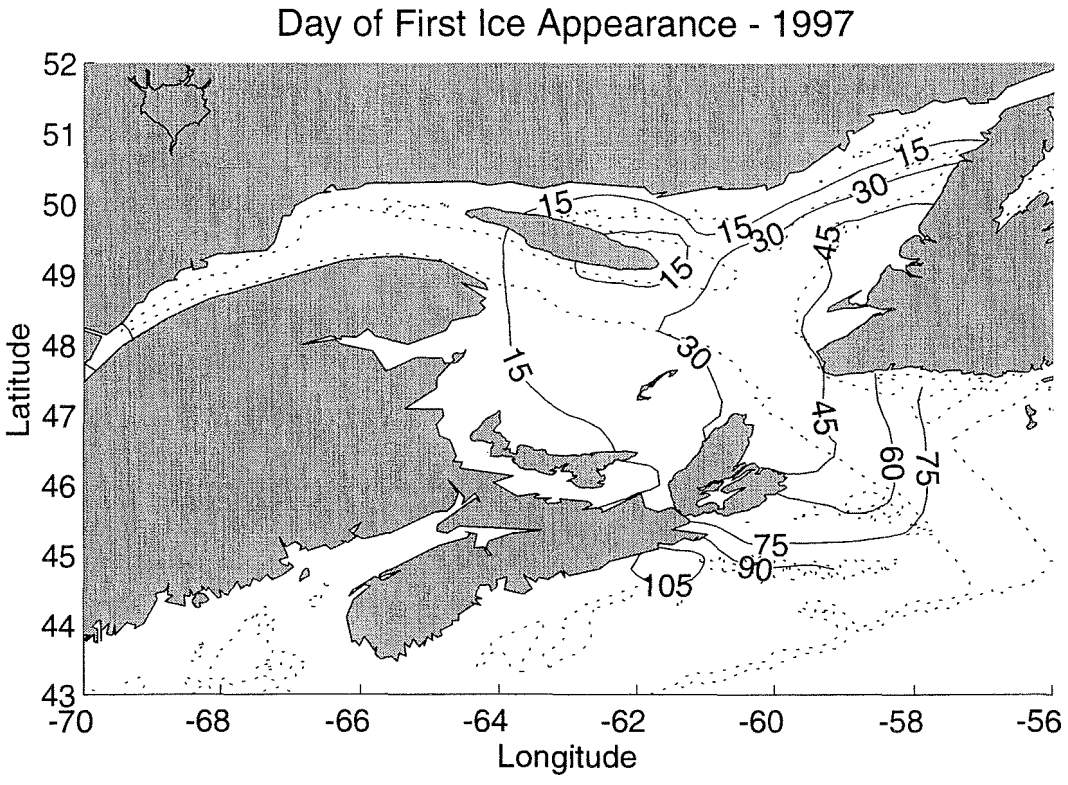
Day of First Ice Appearance - 1997
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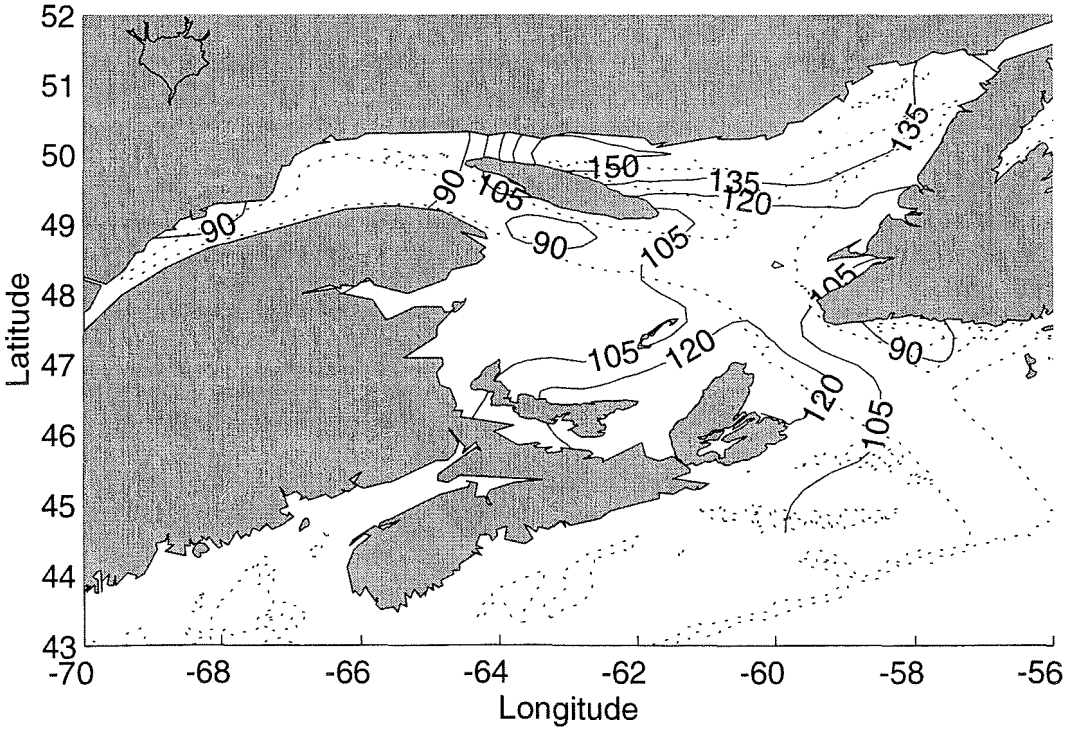
Day of Last Ice Appearance - 1997
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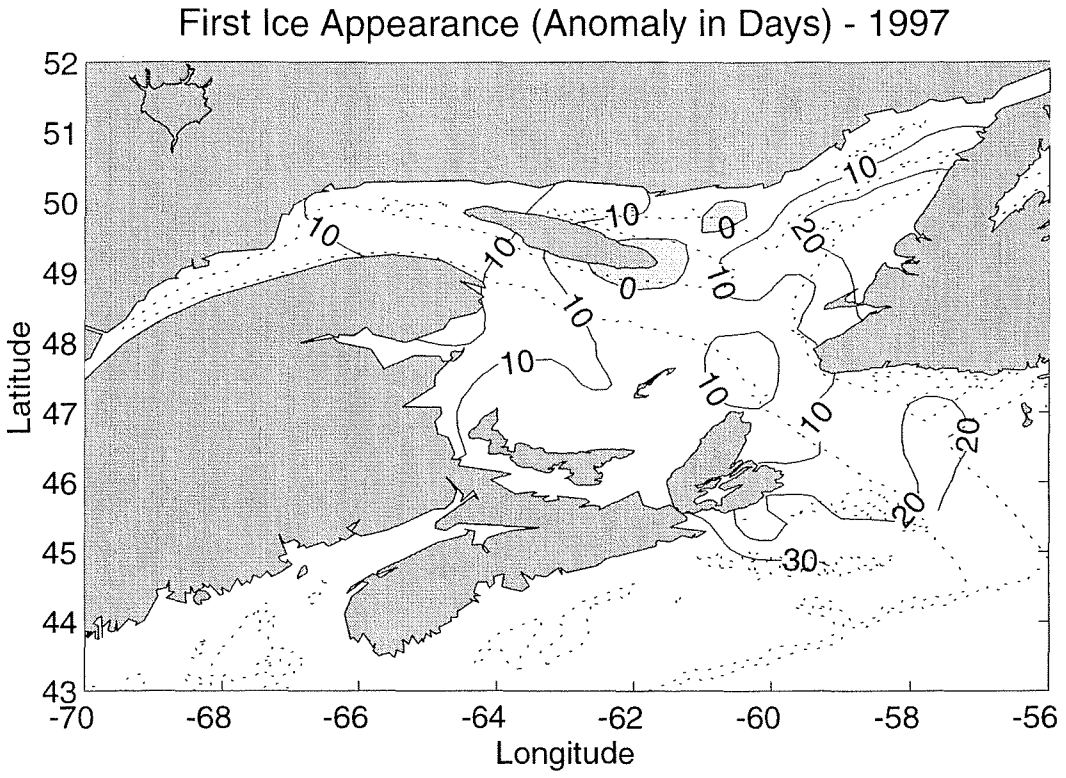
First Ice Appearance (Anomaly in Days) - 1997
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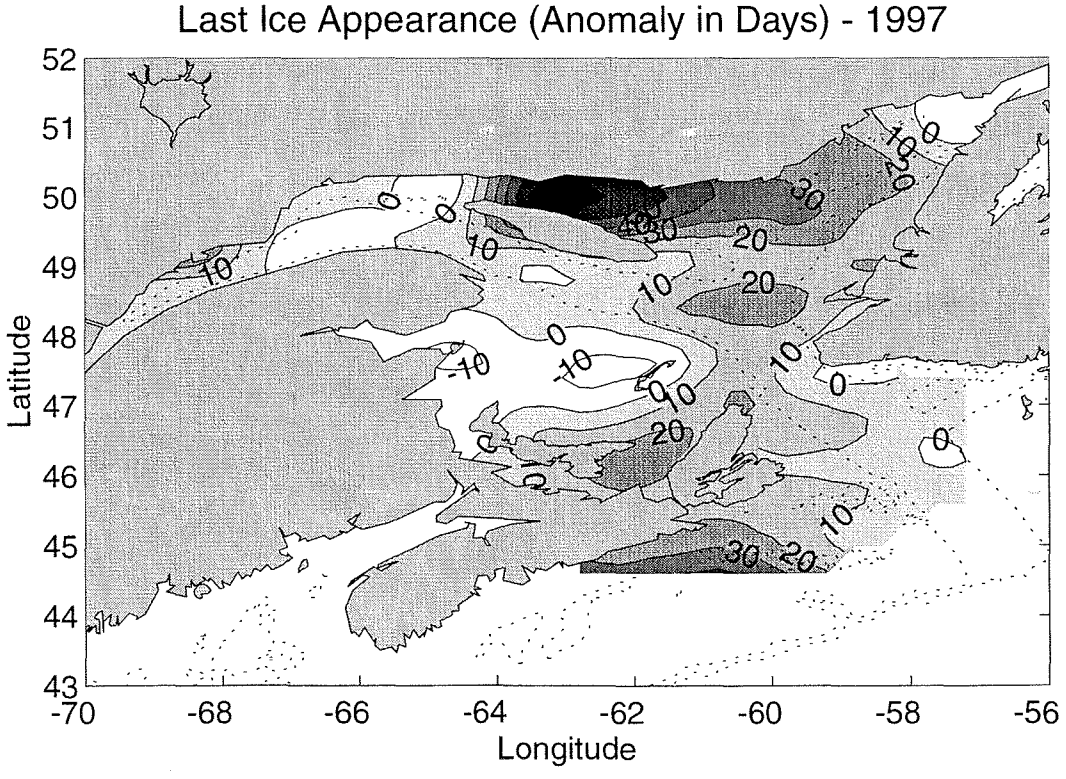
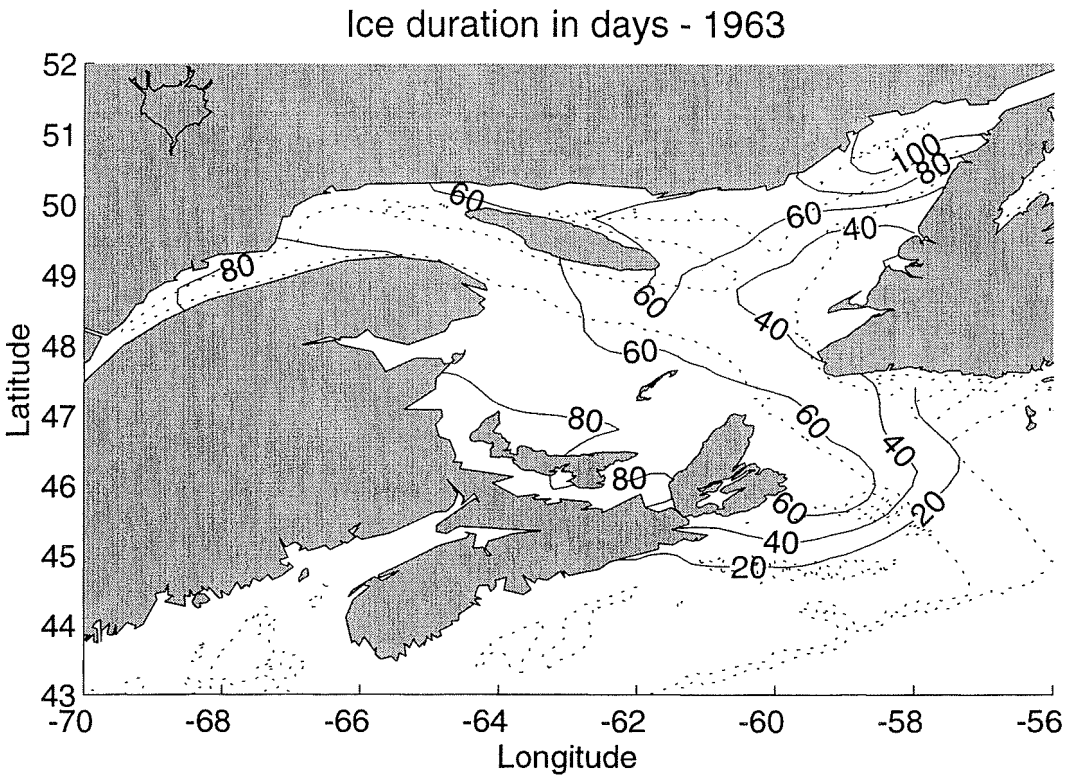

Last Ice Appearance (Anomaly in Days) - 1997
Latitude
Longitude
52
51
50
49
48
47
46
45
44
43
-70
-68
-66
-64
-62
-60
-58
-56

Appendix III. Duration of sea ice.

For 1963 to 1997, plots are provided on the duration of sea ice and their anomalies in days relative to the 1964-1993 means. Positive anomalies are shaded and represent a longer-than-normal duration of sea ice which is generally associated with colder conditions.


Ice duration in days - 1963
Latitude
Longitude
52
51
50
49
48
47
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-64
-62
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-58
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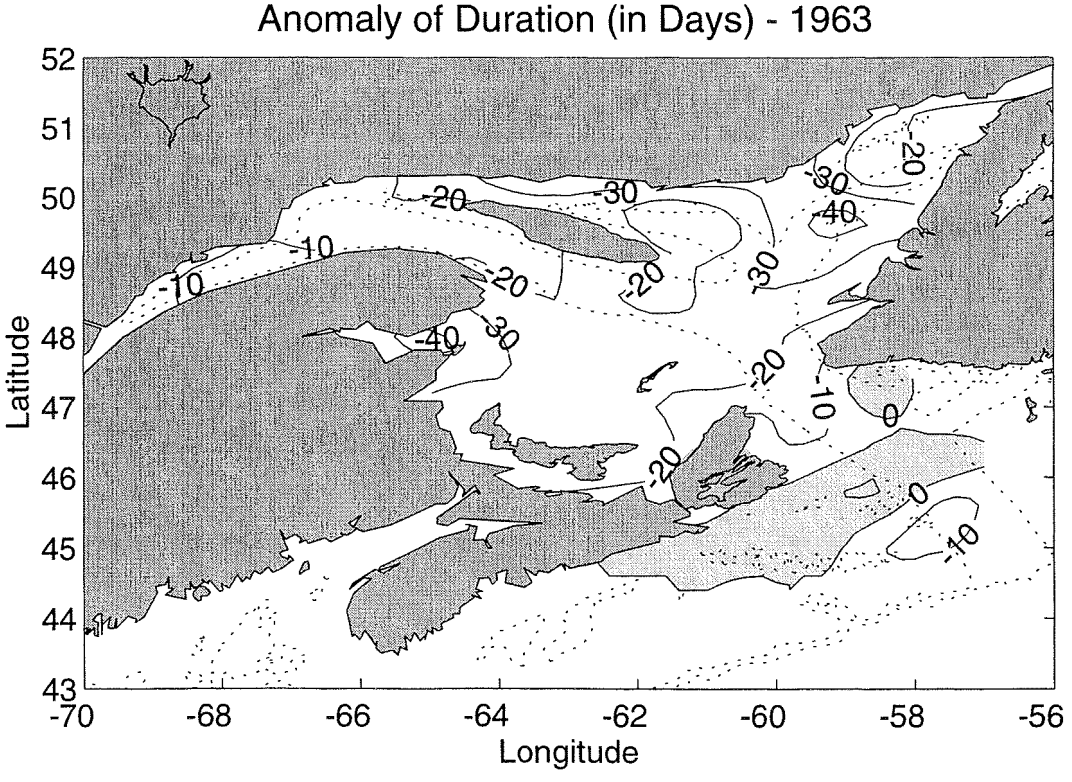
Anomaly of Duration (in Days) - 1963
Latitude
Longitude
52
51
50
49
48
47
46
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44
43
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-68
-66
-64
-62
-60
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-56
-10
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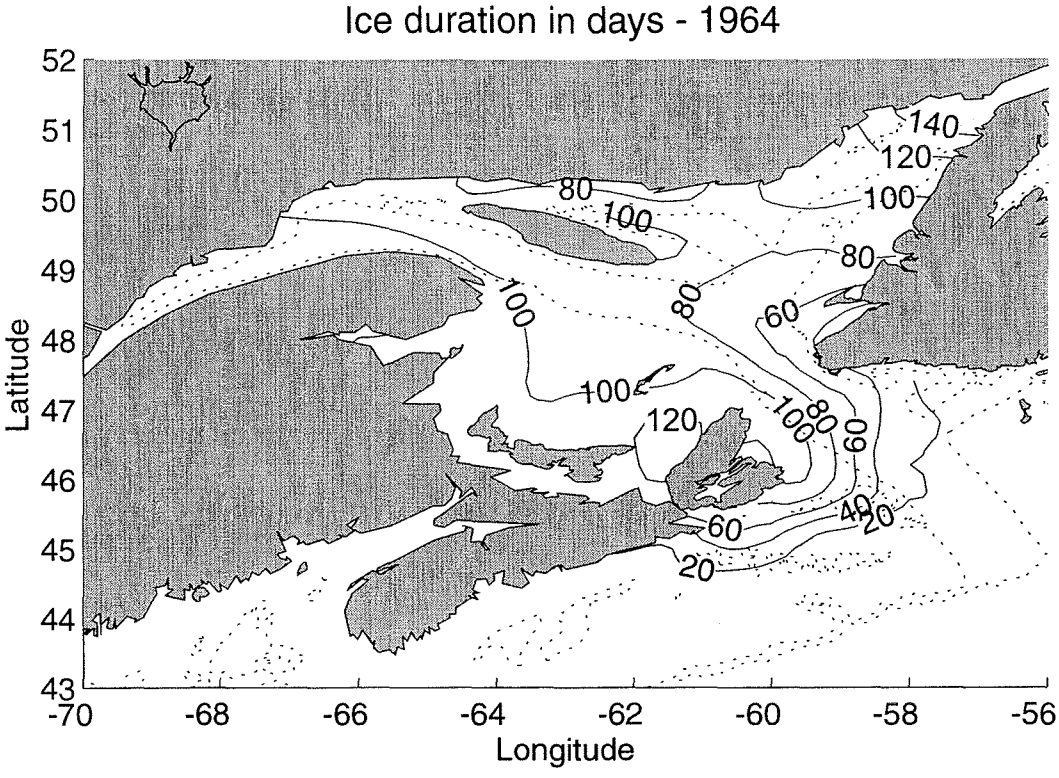
Ice duration in days - 1964
Latitude
Longitude
52
51
50
49
48
47
46
45
44
43
-70
-68
-66
-64
-62
-60
-58
-56
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80
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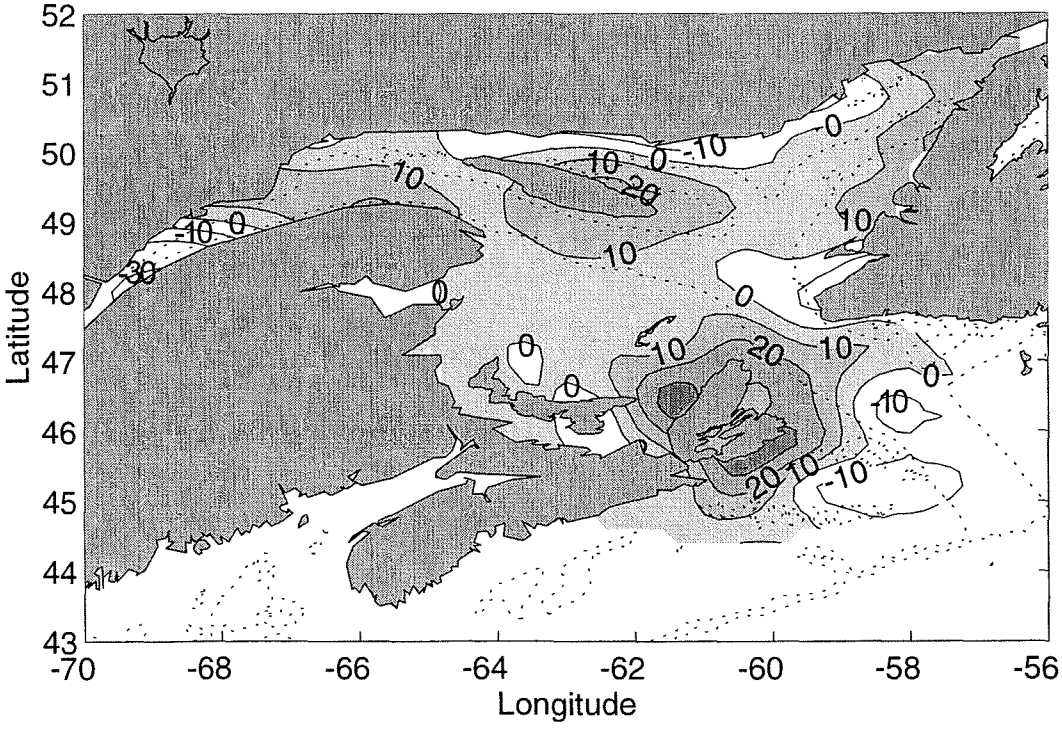
Anomaly of Duration (in Days) - 1964
Latitude
Longitude
52
51
50
49
48
47
46
45
44
43
-70
-68
-66
-64
-62
-60
-58
-56
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10
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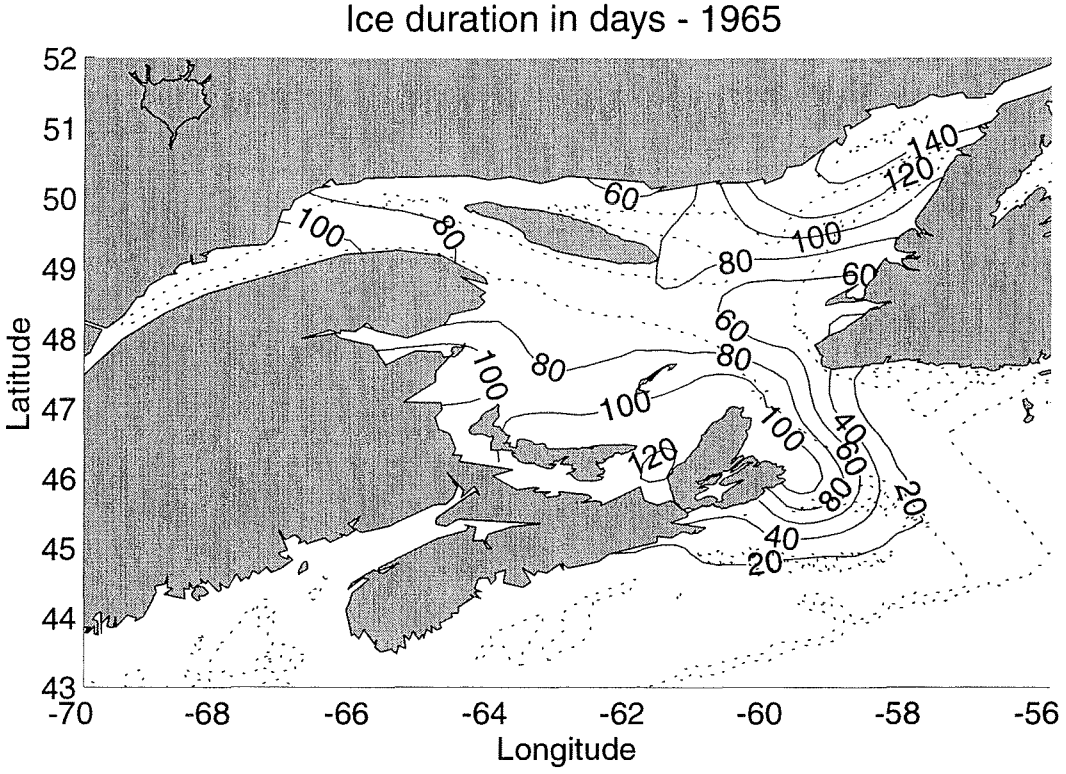
Ice duration in days - 1965
Latitude
Longitude
52
51
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47
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-64
-62
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-56
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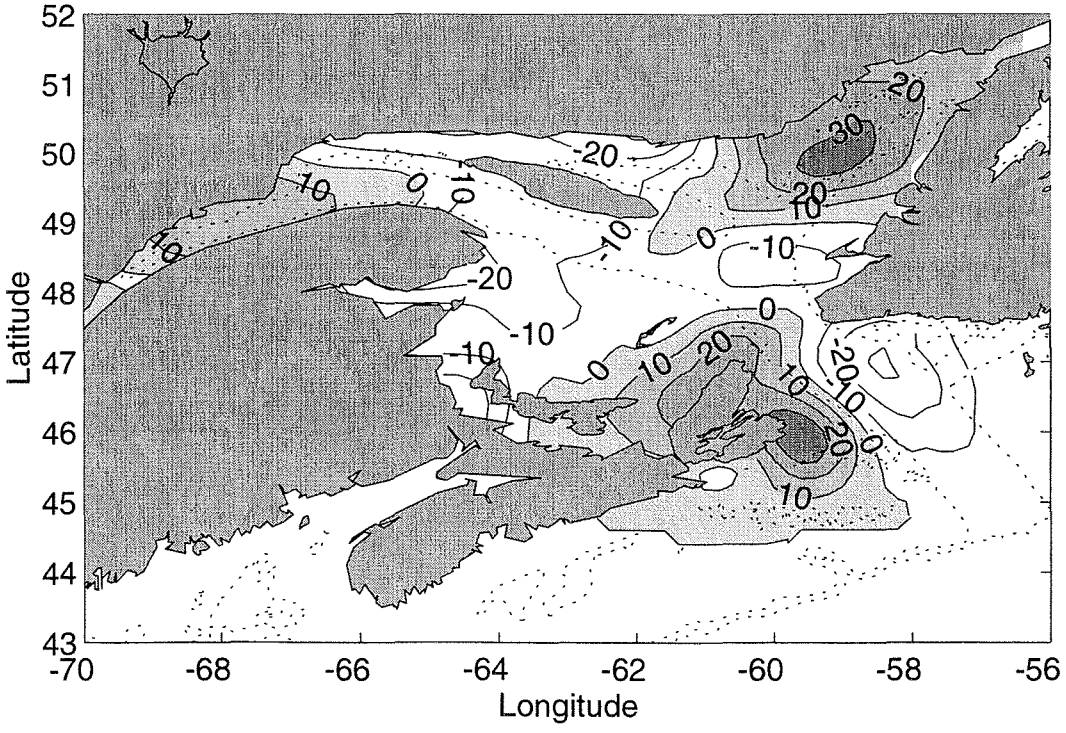
Anomaly of Duration (in Days) - 1965
Latitude
Longitude
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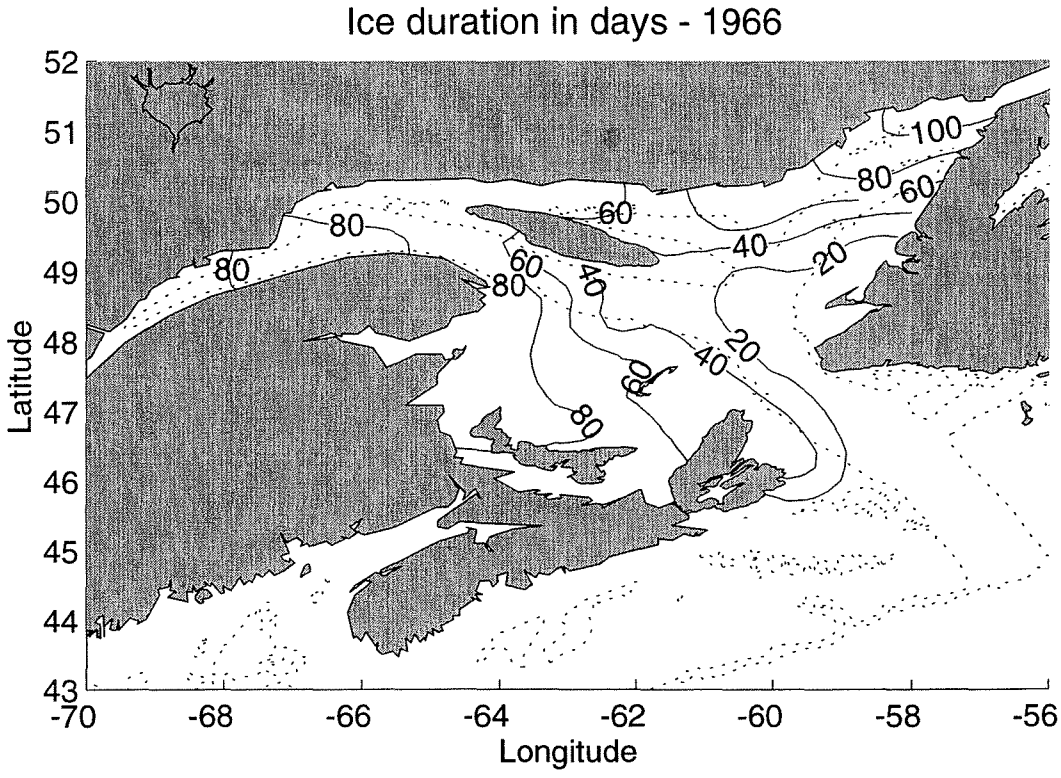
Ice duration in days - 1966
Latitude
Longitude
52
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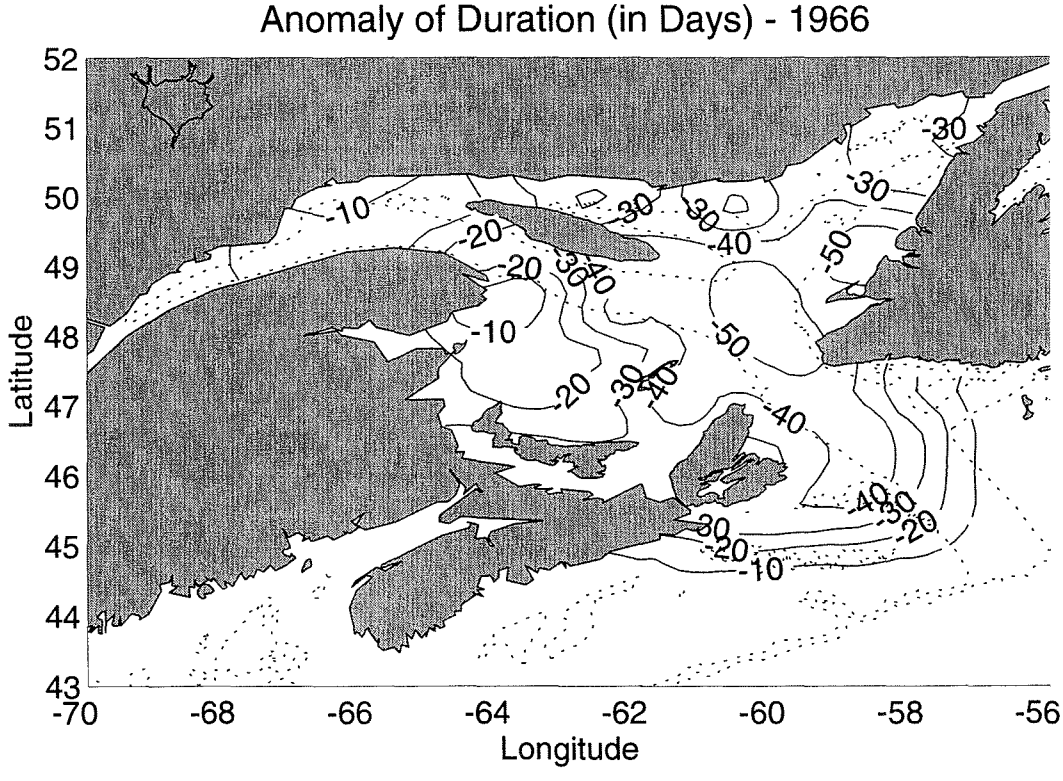
Anomaly of Duration (in Days) - 1966
Latitude
Longitude
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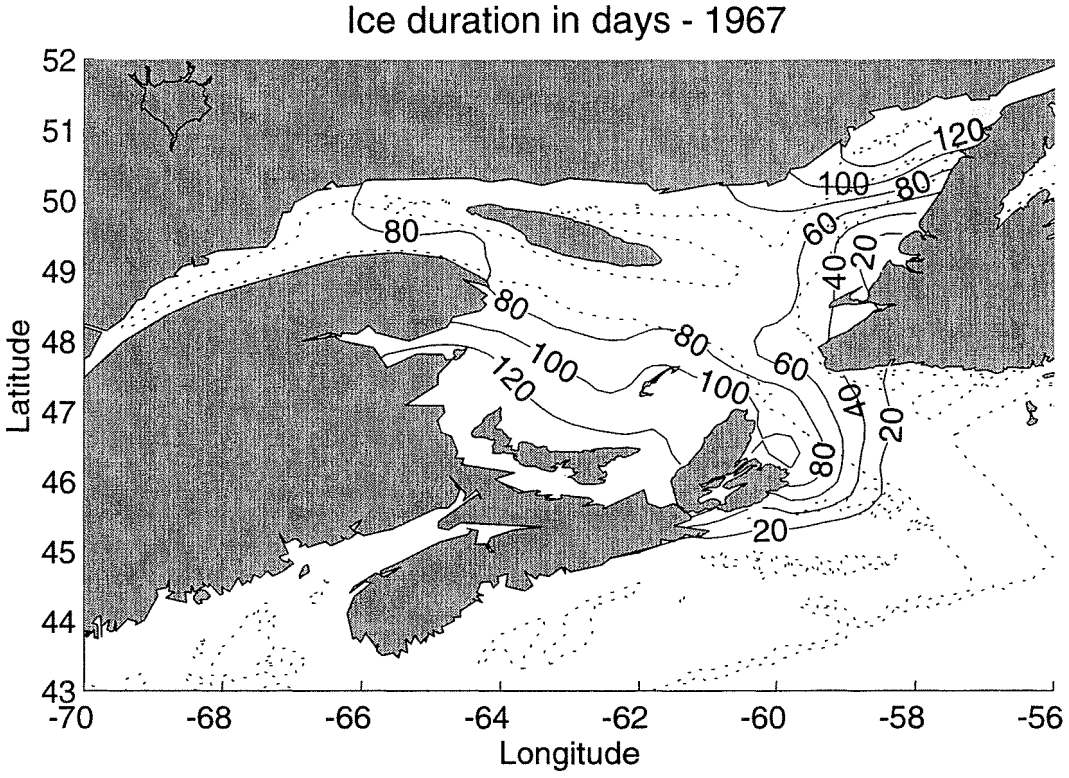
Ice duration in days - 1967
Latitude
Longitude
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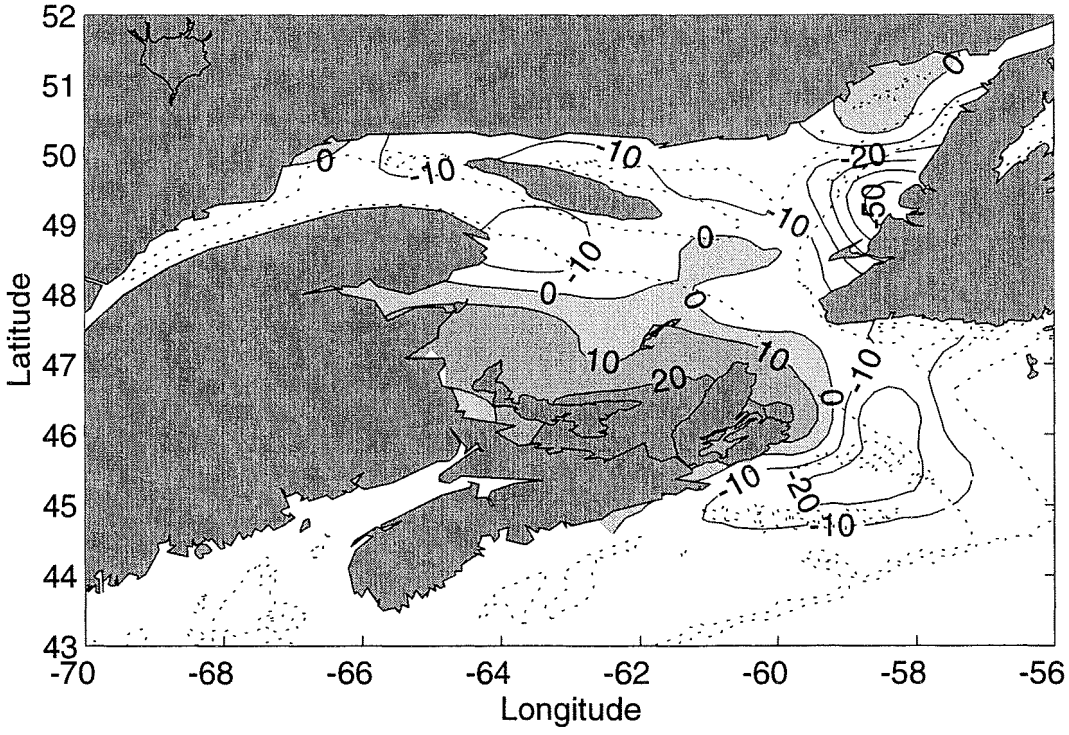
Anomaly of Duration (in Days) - 1967
Latitude
Longitude
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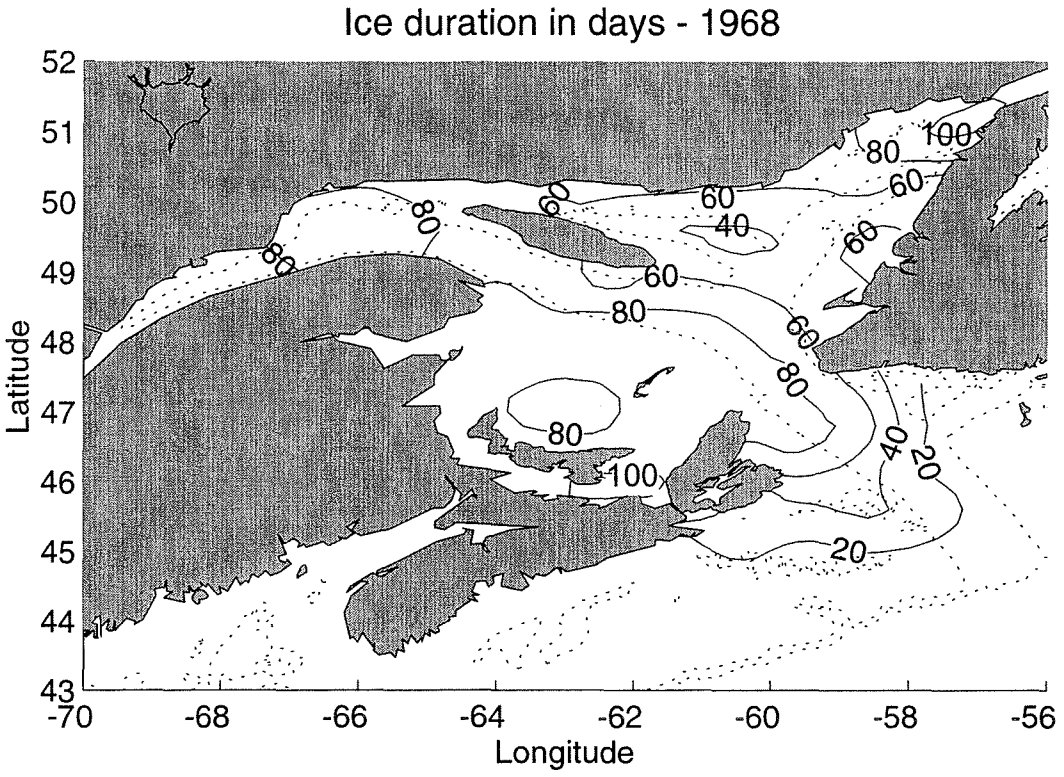
Ice duration in days - 1968
Latitude
Longitude
52
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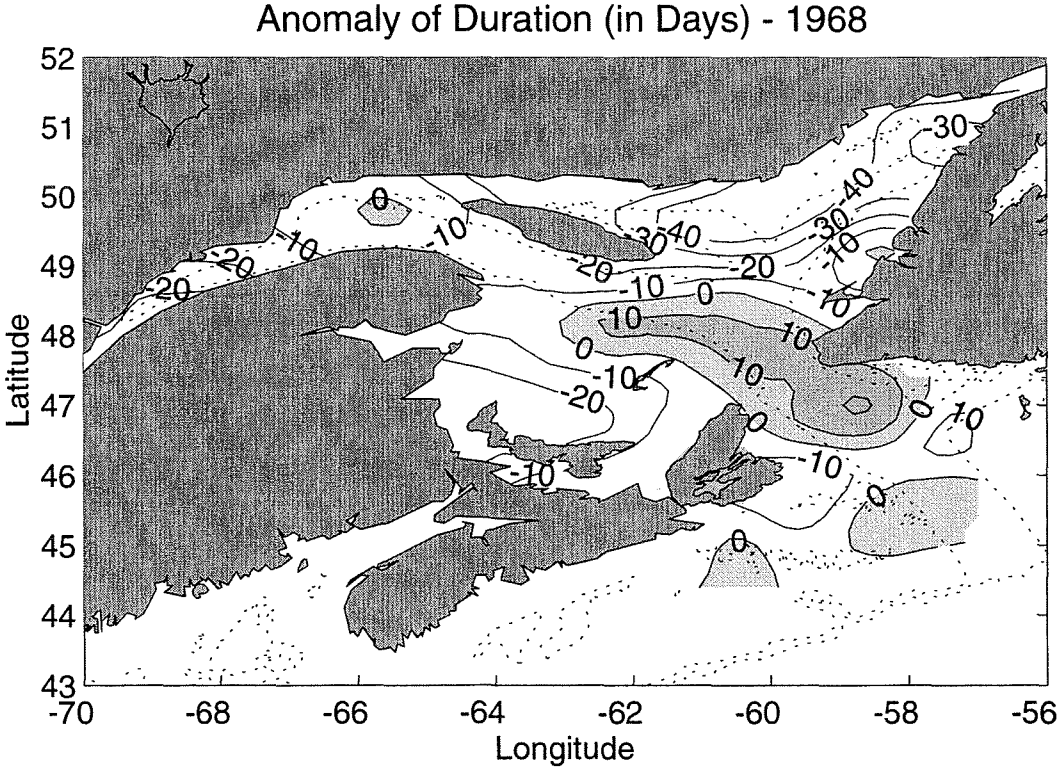
Anomaly of Duration (in Days) - 1968
Latitude
Longitude
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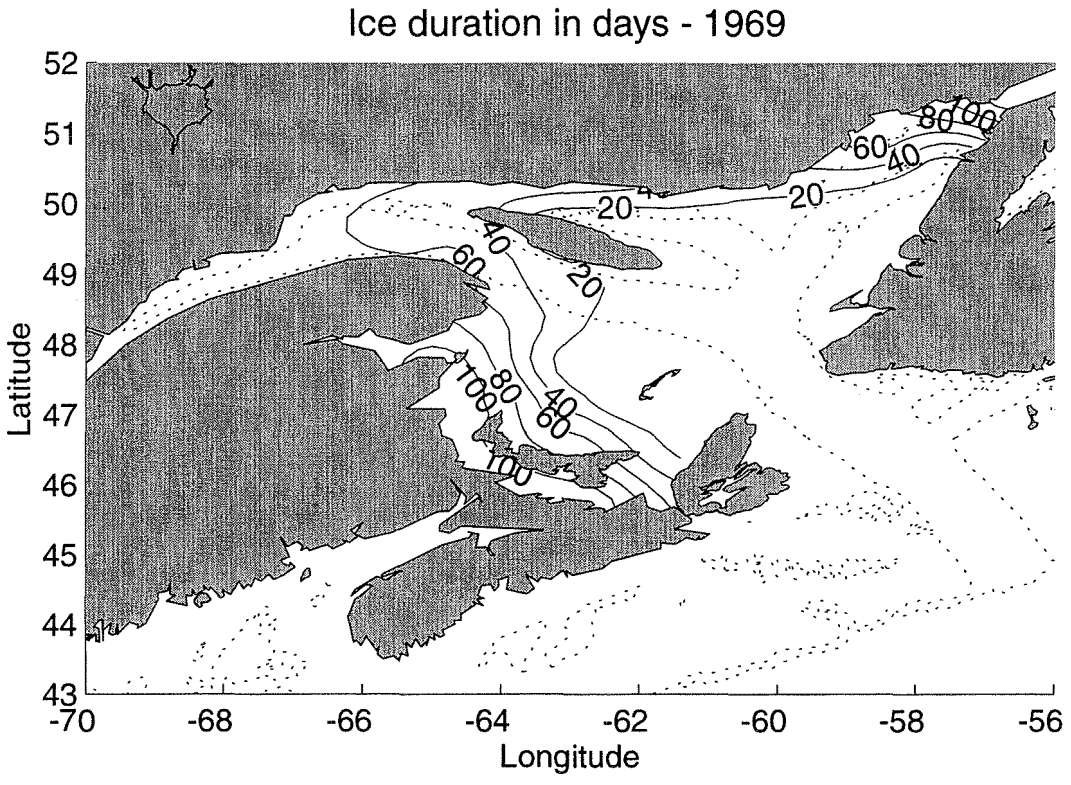
Ice duration in days - 1969
Latitude
Longitude
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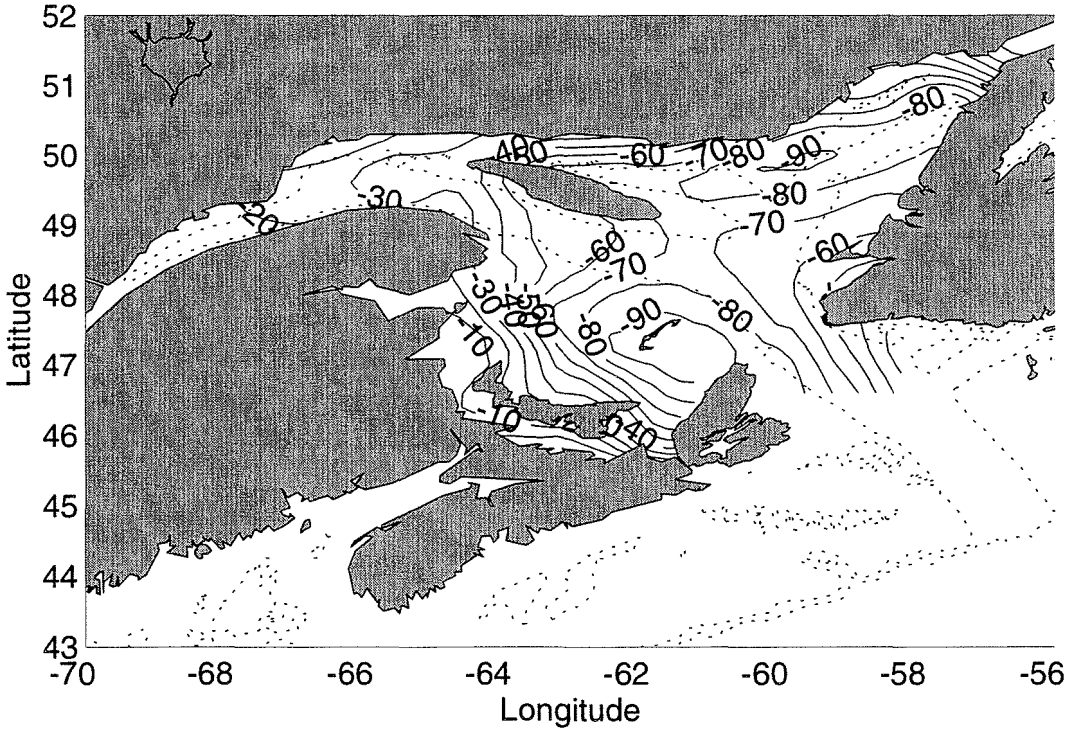
Anomaly of Duration (in Days) - 1969
Latitude
Longitude
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-64
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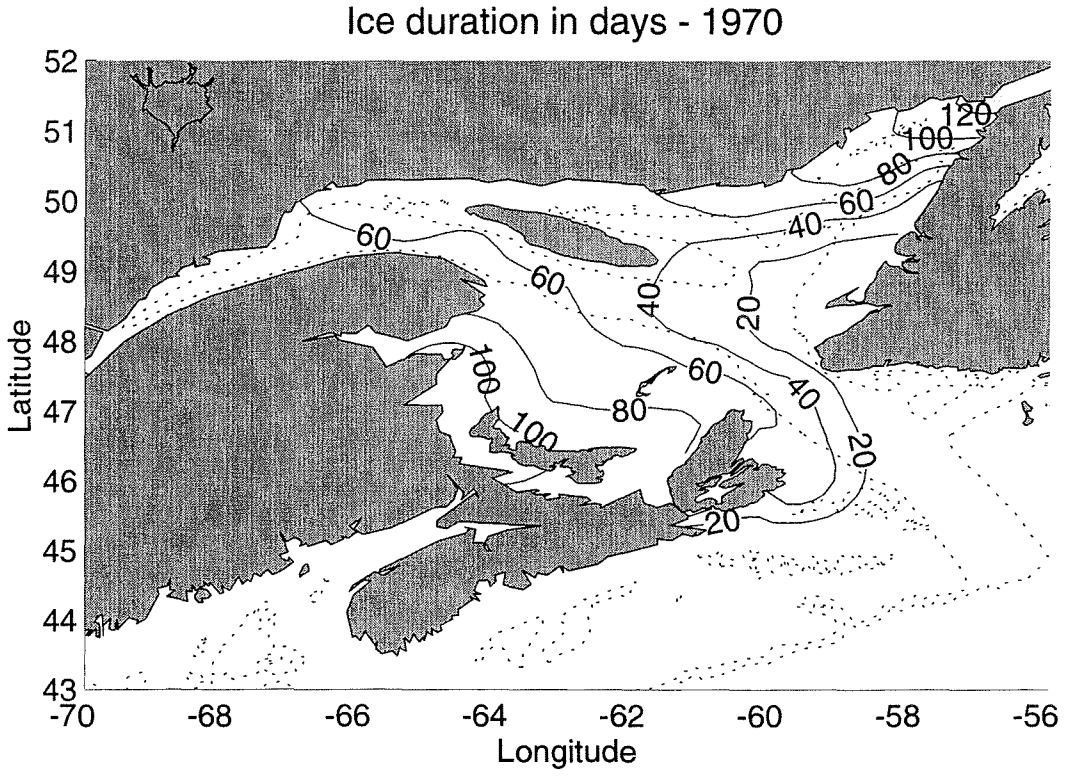
Ice duration in days - 1970
Latitude
Longitude
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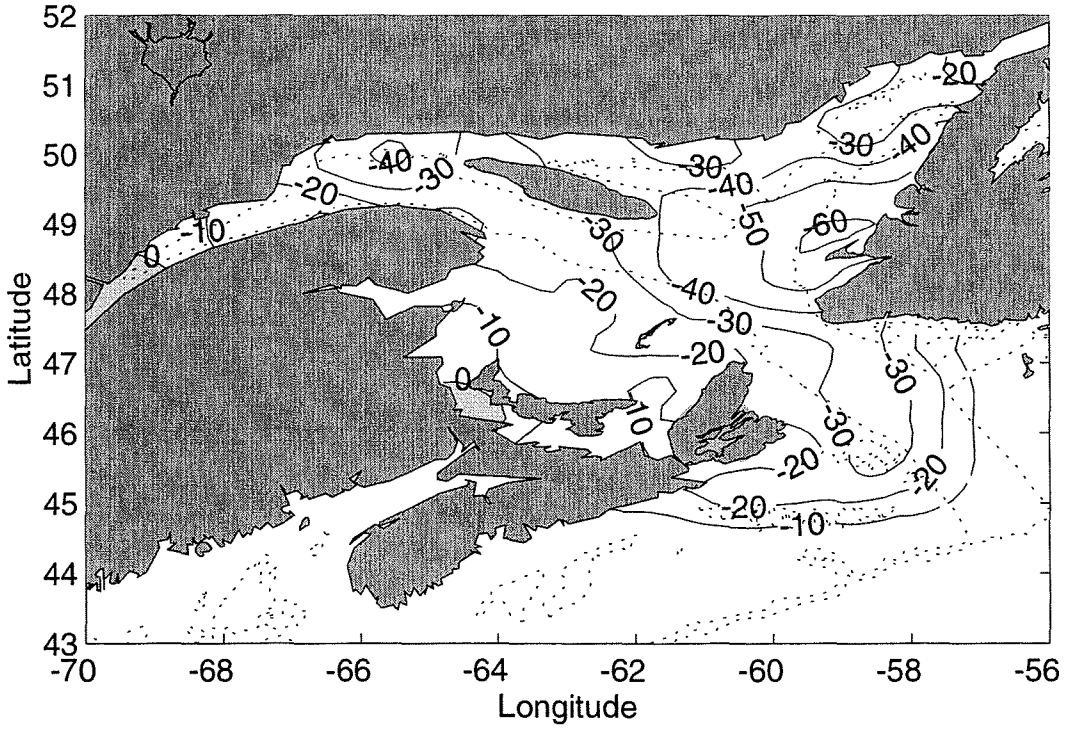
Anomaly of Duration (in Days) - 1970
Latitude
Longitude
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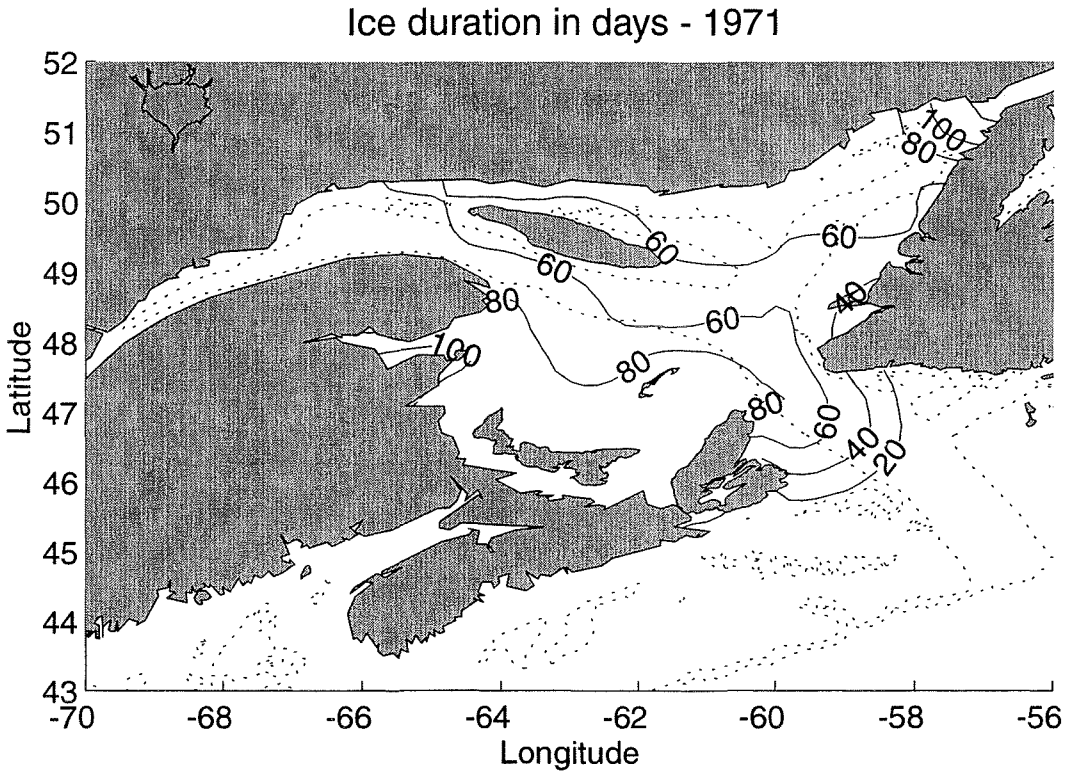
Ice duration in days - 1971
Latitude
Longitude
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-64
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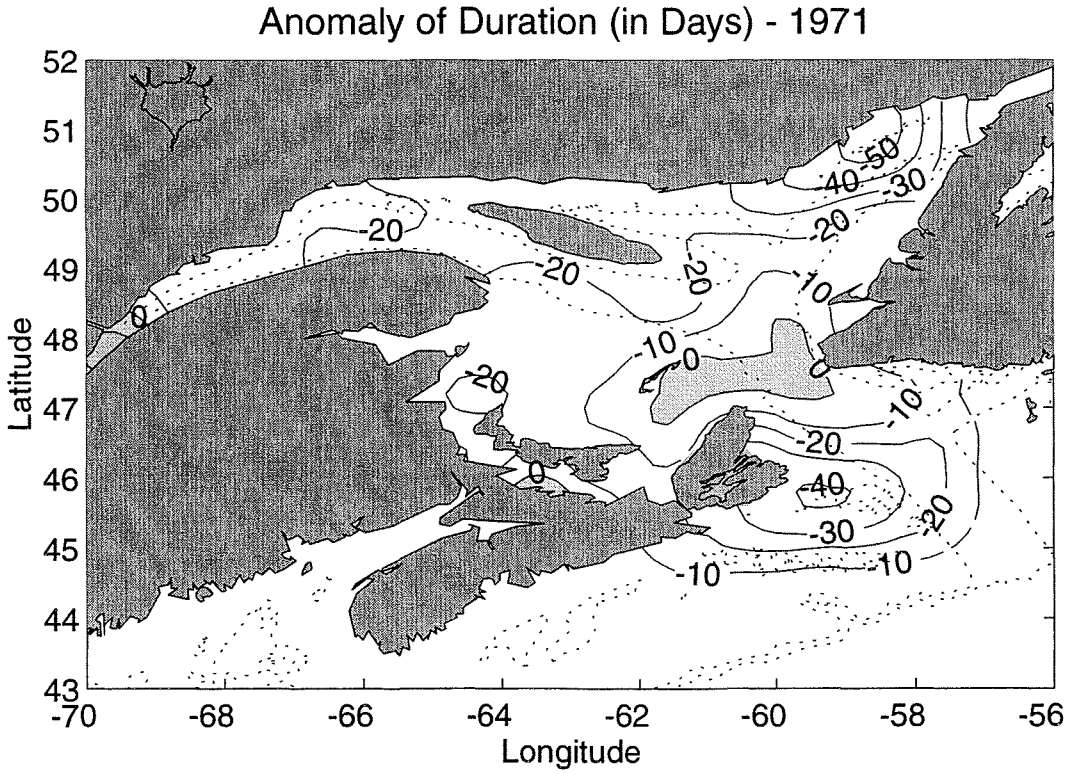
Anomaly of Duration (in Days) - 1971
Latitude
Longitude
52
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-64
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-50
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-10
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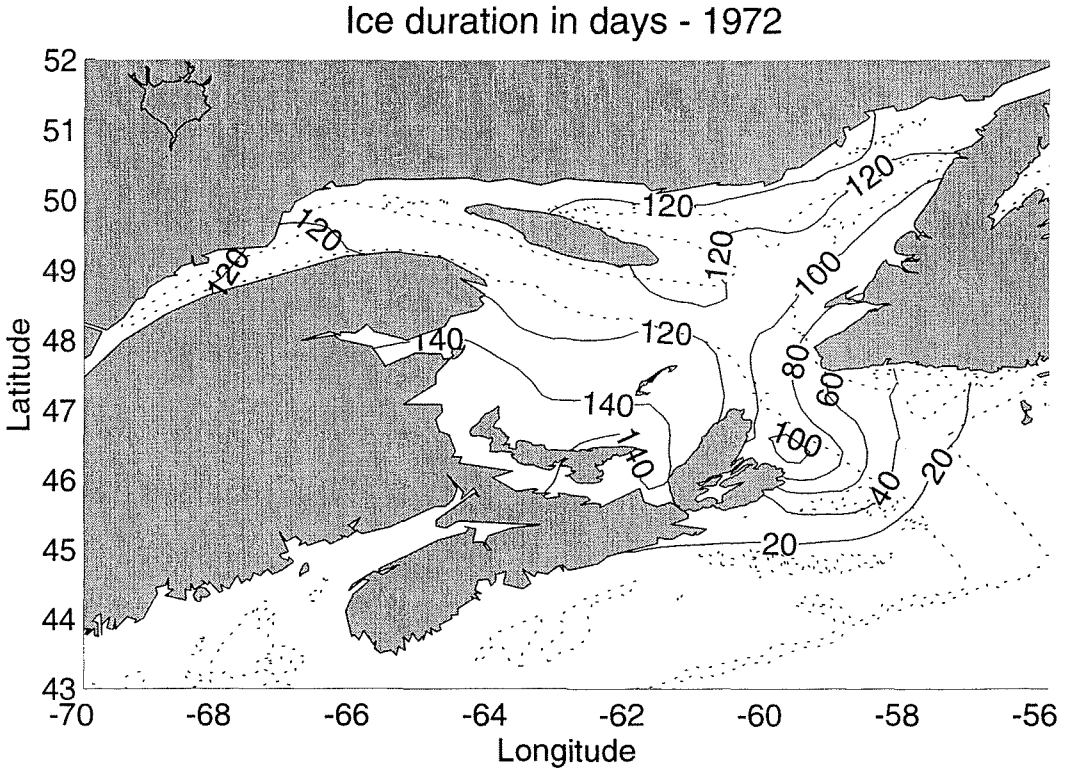
Ice duration in days - 1972
Latitude
Longitude
52
51
50
49
48
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-70
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-66
-64
-62
-60
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-56
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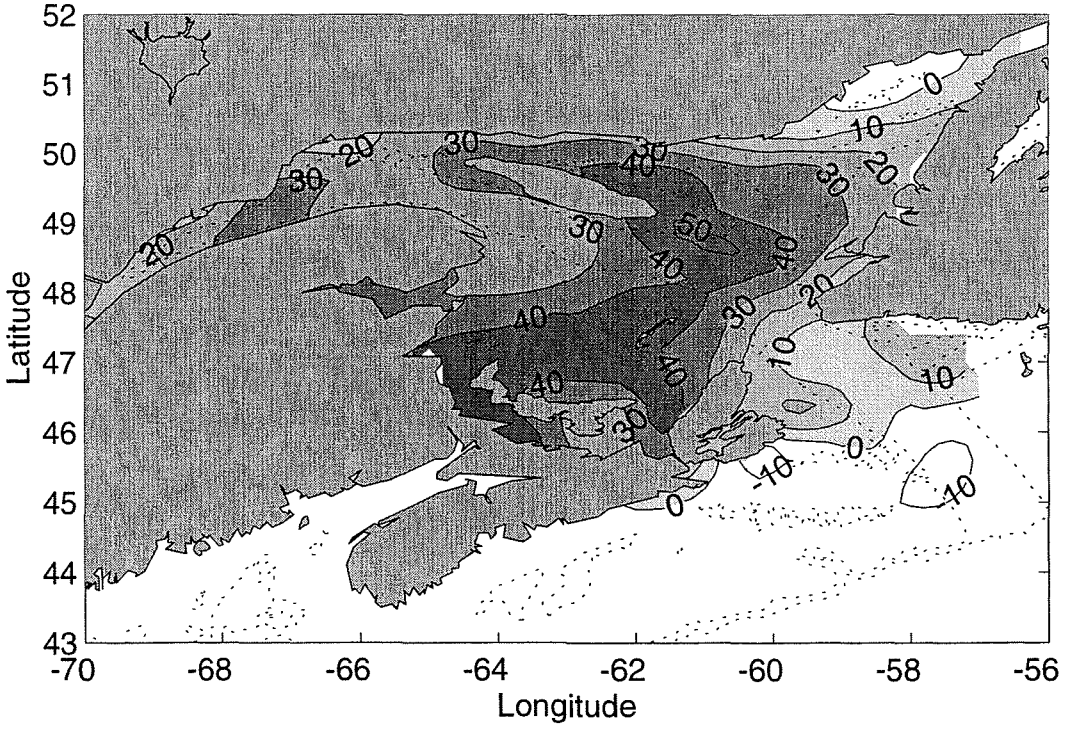
Anomaly of Duration (in Days) - 1972
Latitude
Longitude
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48
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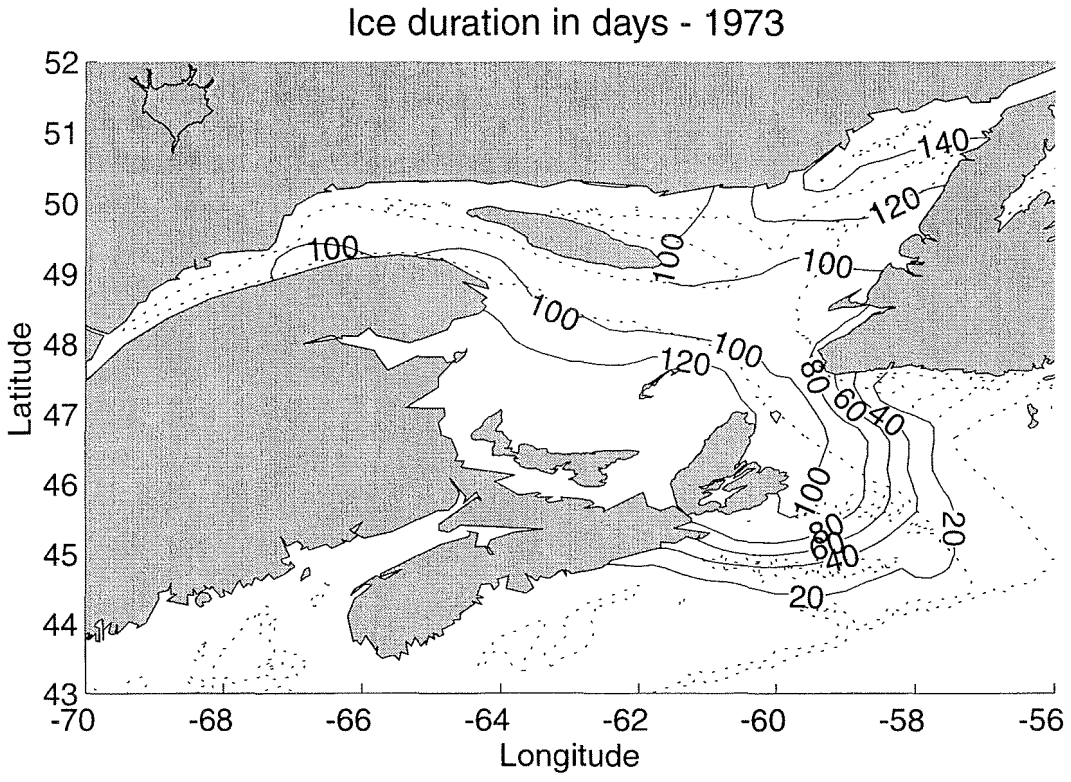
Ice duration in days - 1973
Latitude
Longitude
52
51
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49
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47
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44
43
-70
-68
-66
-64
-62
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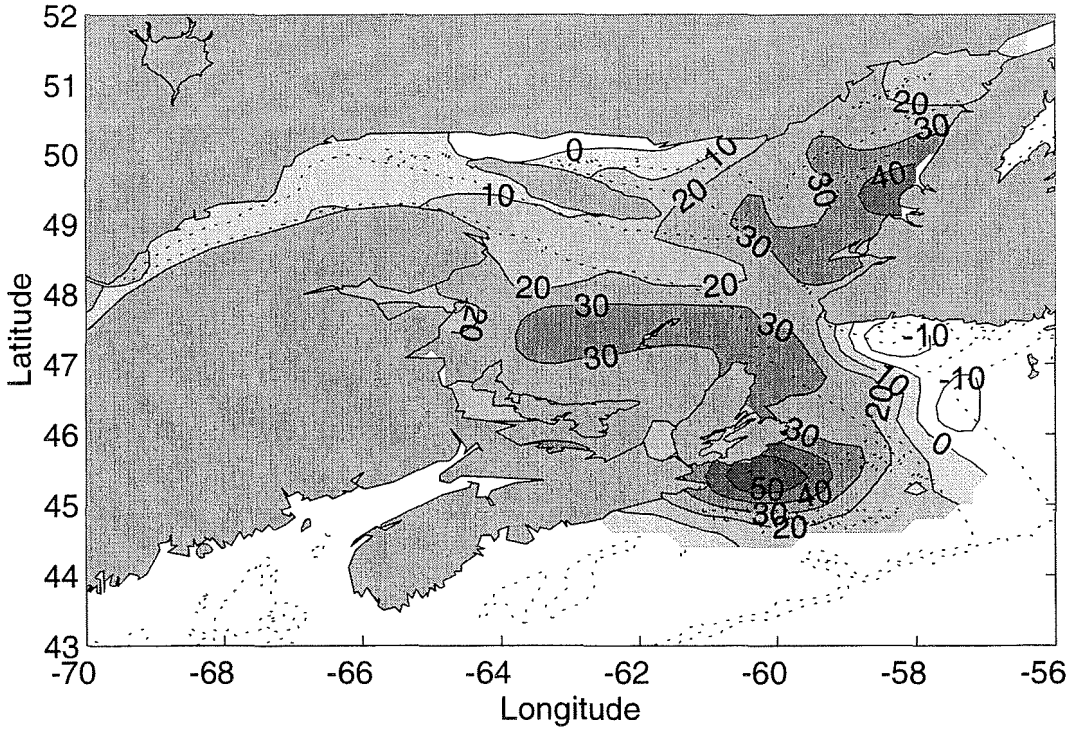
Anomaly of Duration (in Days) - 1973
Latitude
Longitude
52
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-64
-62
-60
-58
-56
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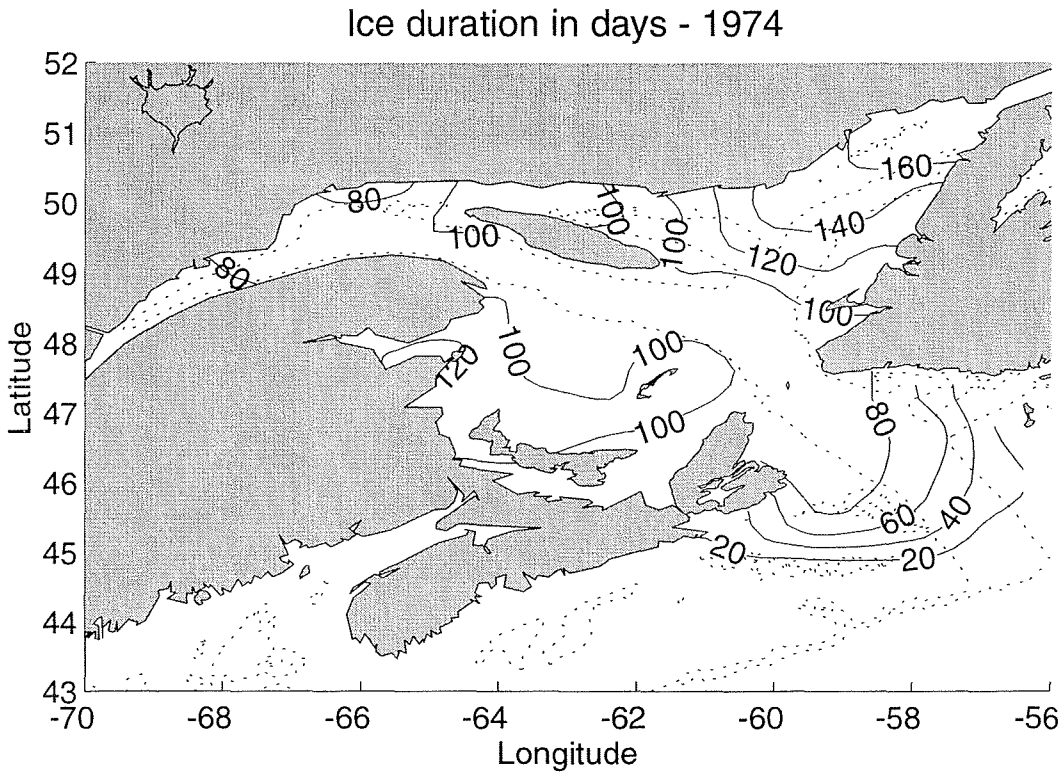
Ice duration in days - 1974
Latitude
Longitude
52
51
50
49
48
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-64
-62
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80
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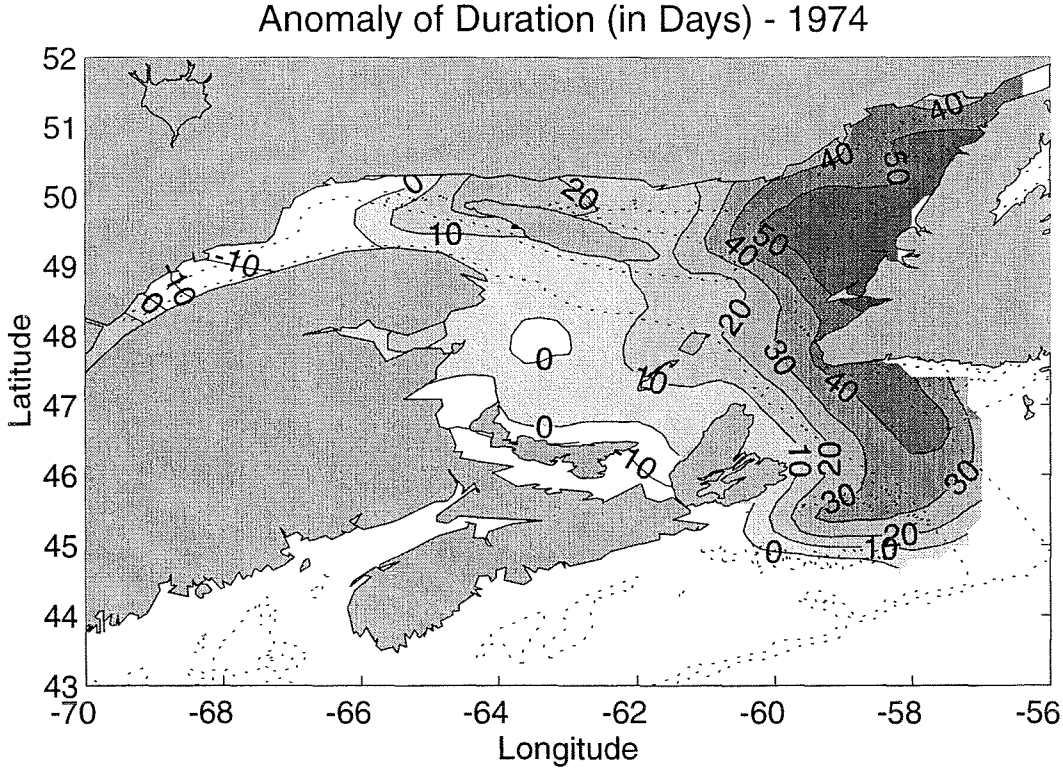
Anomaly of Duration (in Days) - 1974
Latitude
Longitude
52
51
50
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48
47
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44
43
-70
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-64
-62
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-10
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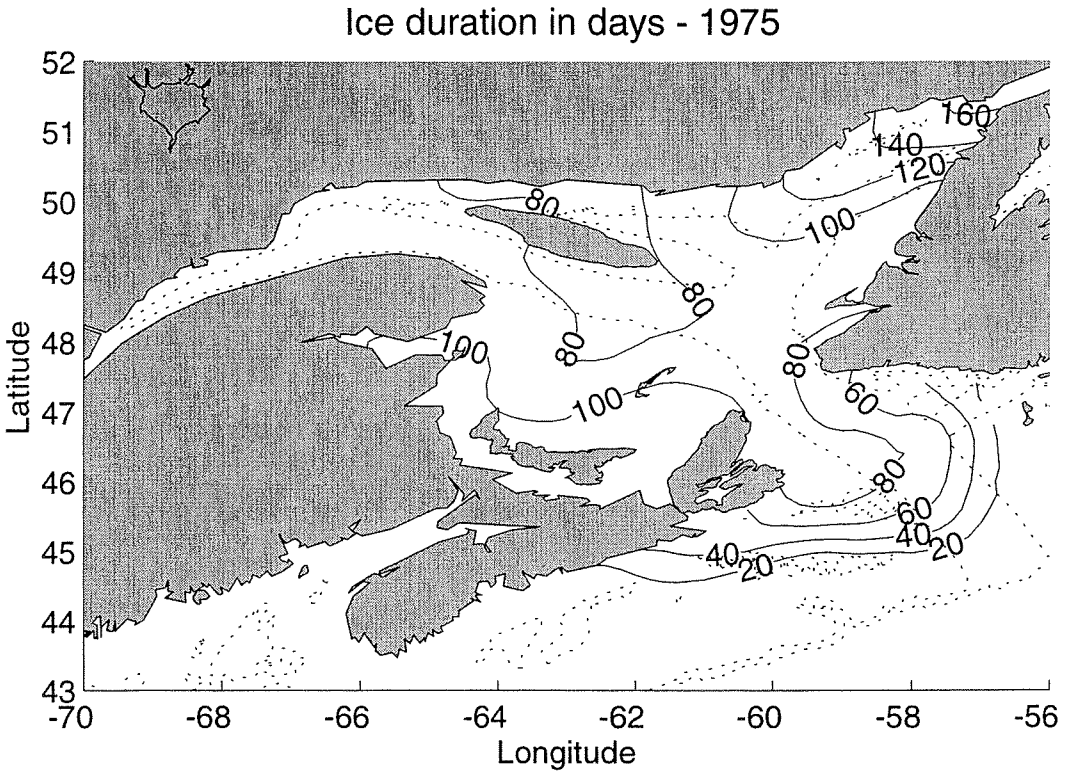
Ice duration in days - 1975
Latitude
Longitude
52
51
50
49
48
47
46
45
44
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-70
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-64
-62
-60
-58
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160
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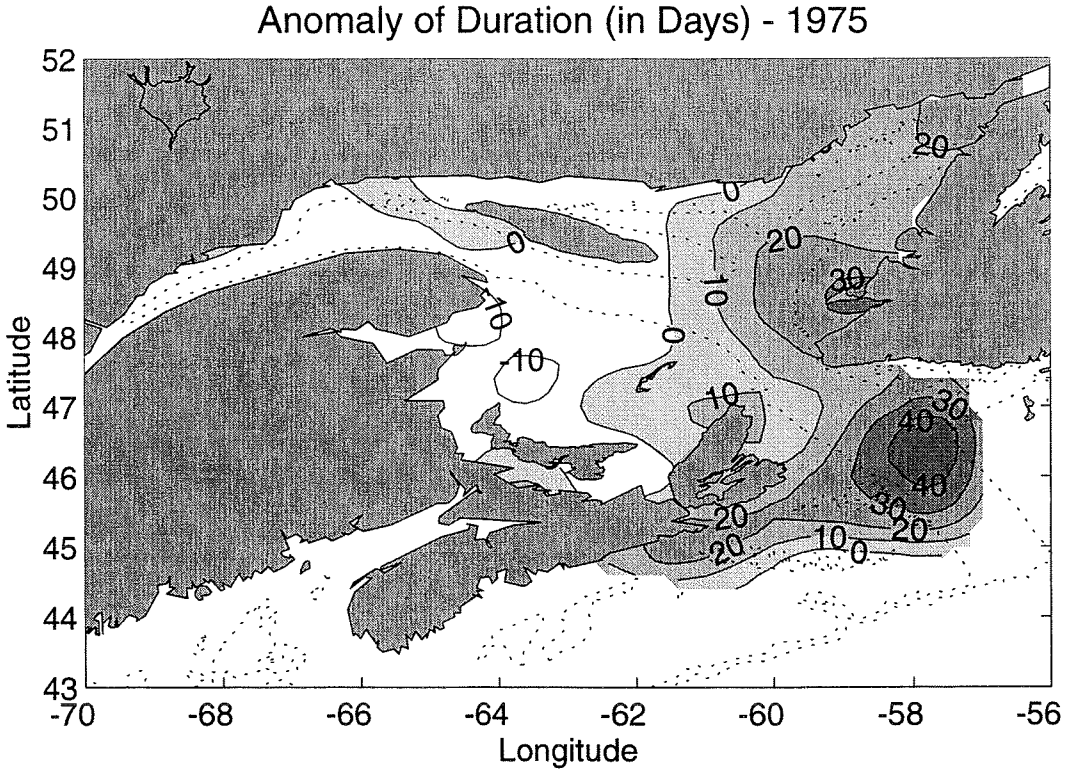
Anomaly of Duration (in Days) - 1975
Latitude
Longitude
52
51
50
49
48
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44
43
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-68
-66
-64
-62
-60
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-56
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-10
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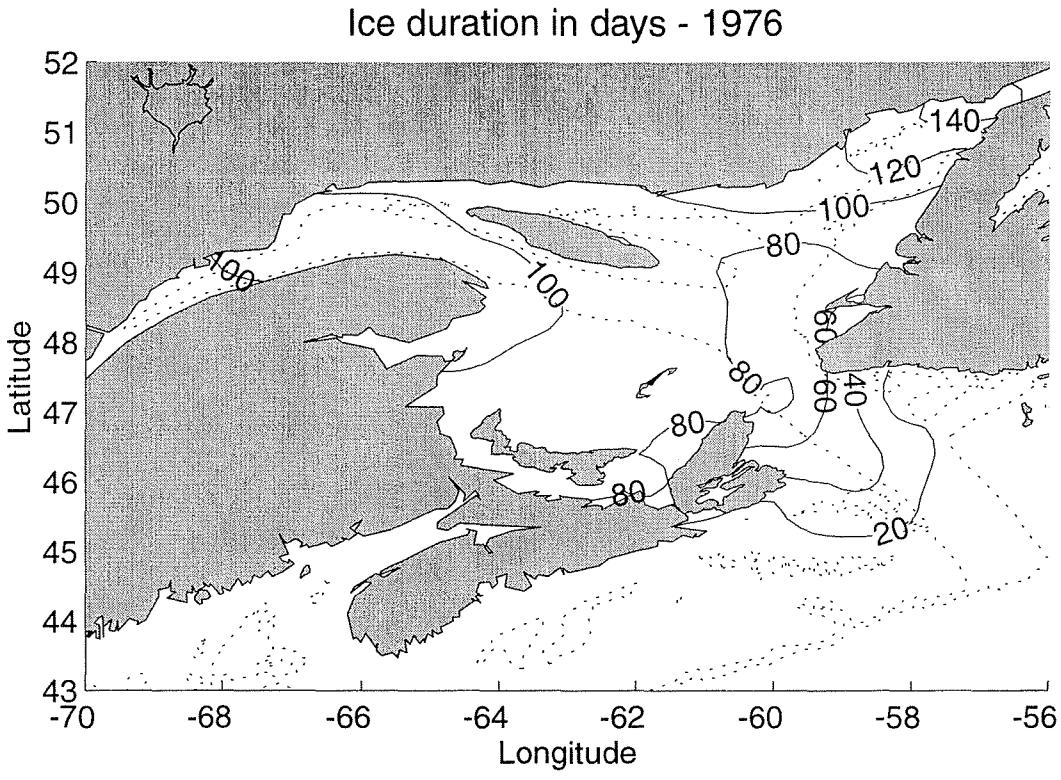
Ice duration in days - 1976
Latitude
Longitude
52
51
50
49
48
47
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-66
-64
-62
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-56
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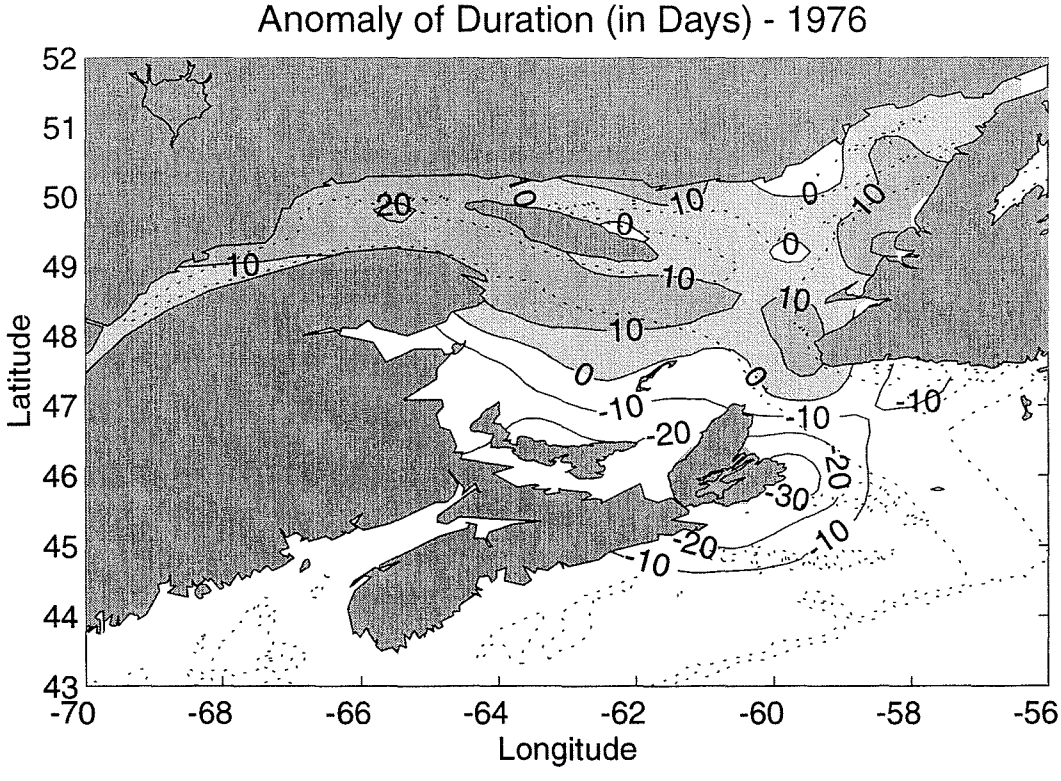
Anomaly of Duration (in Days) - 1976
Latitude
Longitude
52
51
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48
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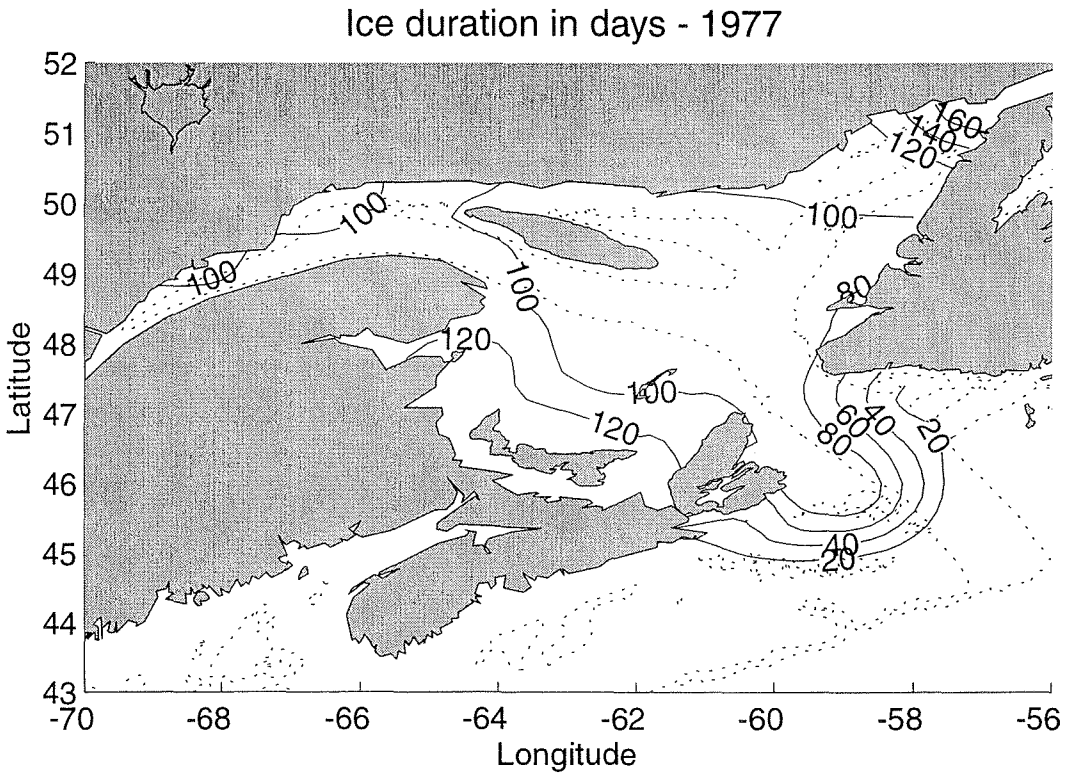
Ice duration in days - 1977
Latitude
Longitude
52
51
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-64
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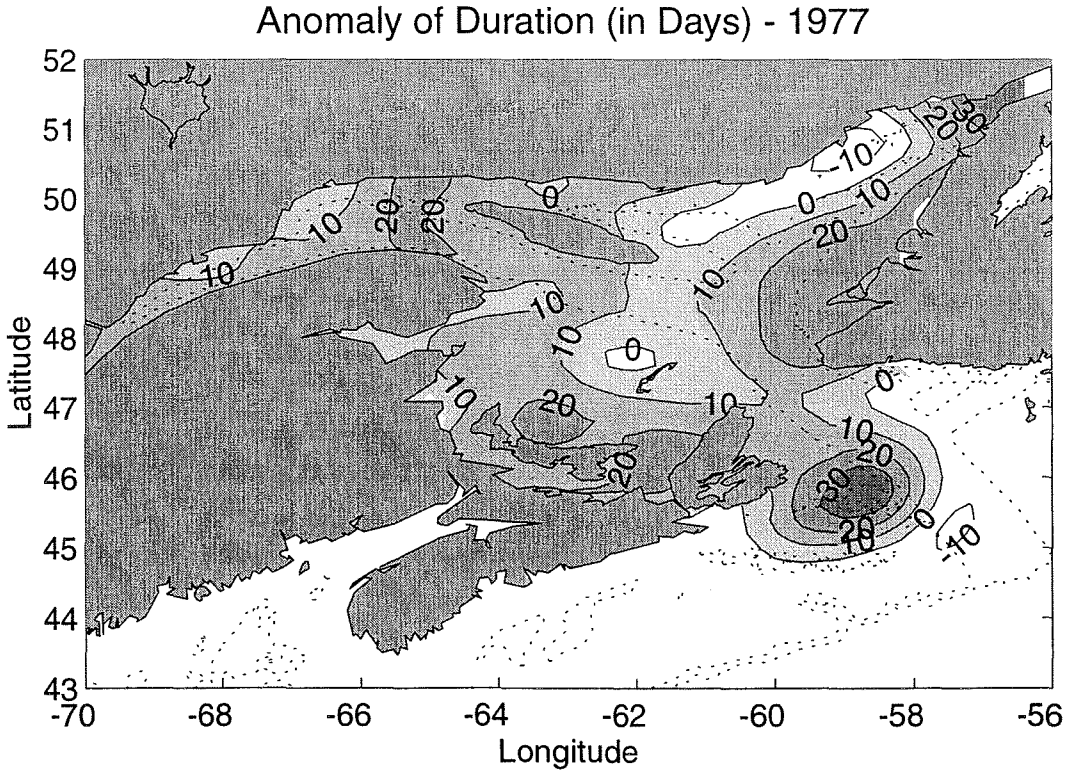
Anomaly of Duration (in Days) - 1977
Latitude
Longitude
52
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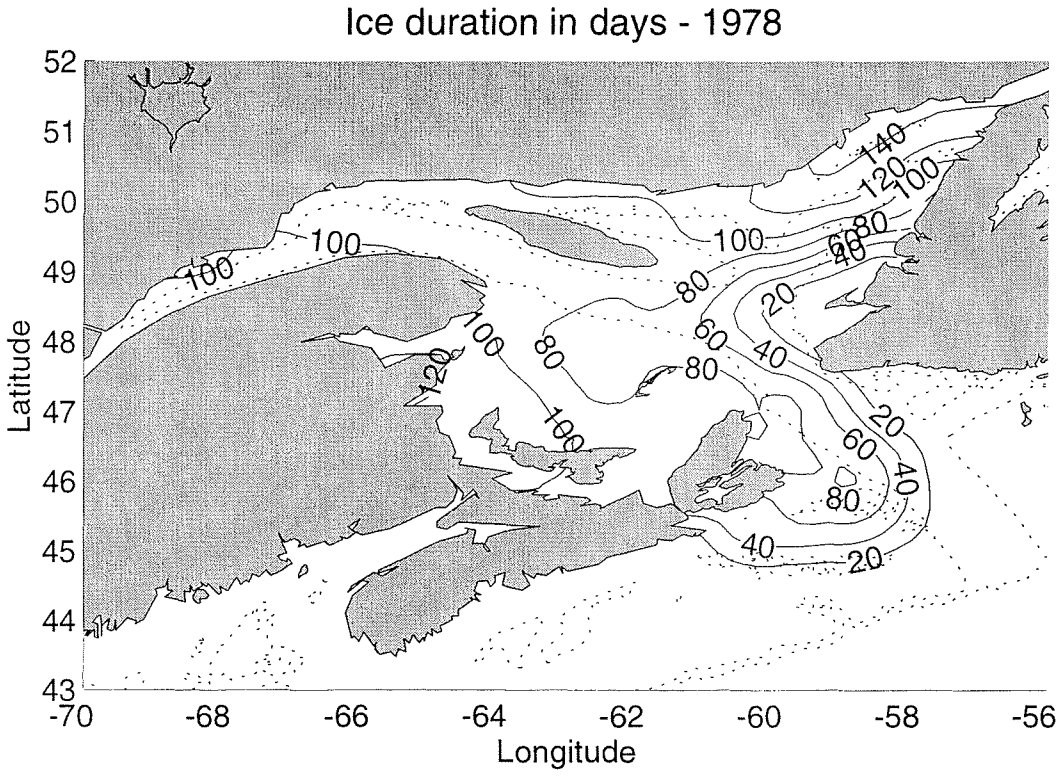
Ice duration in days - 1978
Latitude
Longitude
52
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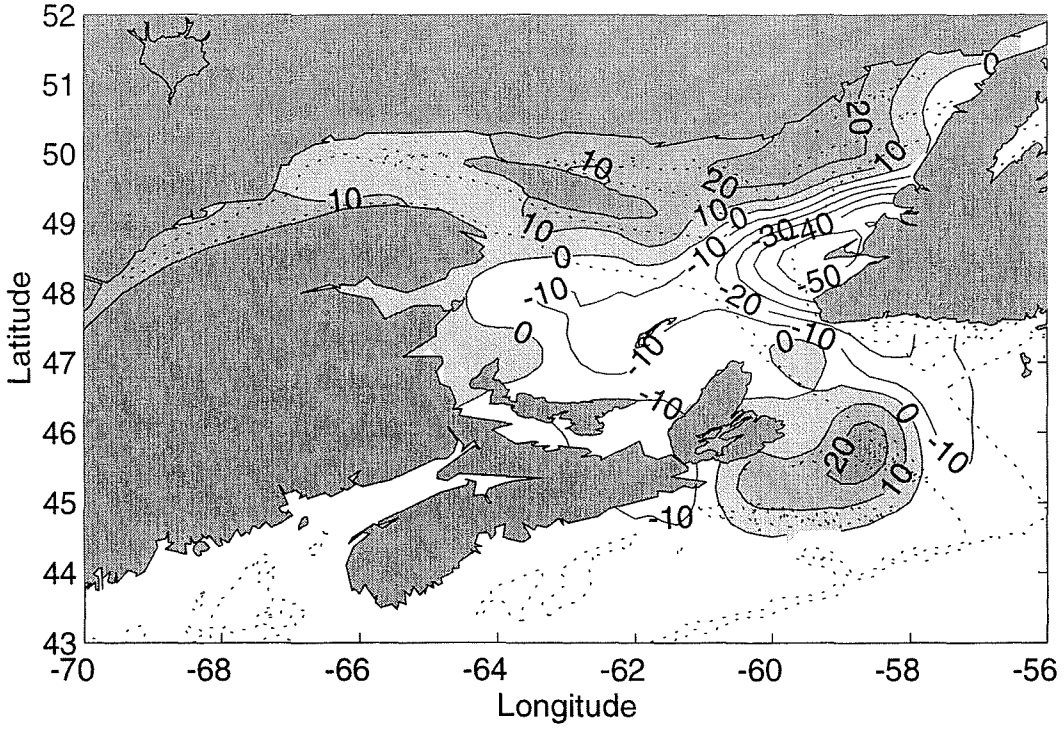
Anomaly of Duration (in Days) - 1978
Latitude
Longitude
52
51
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43
-70
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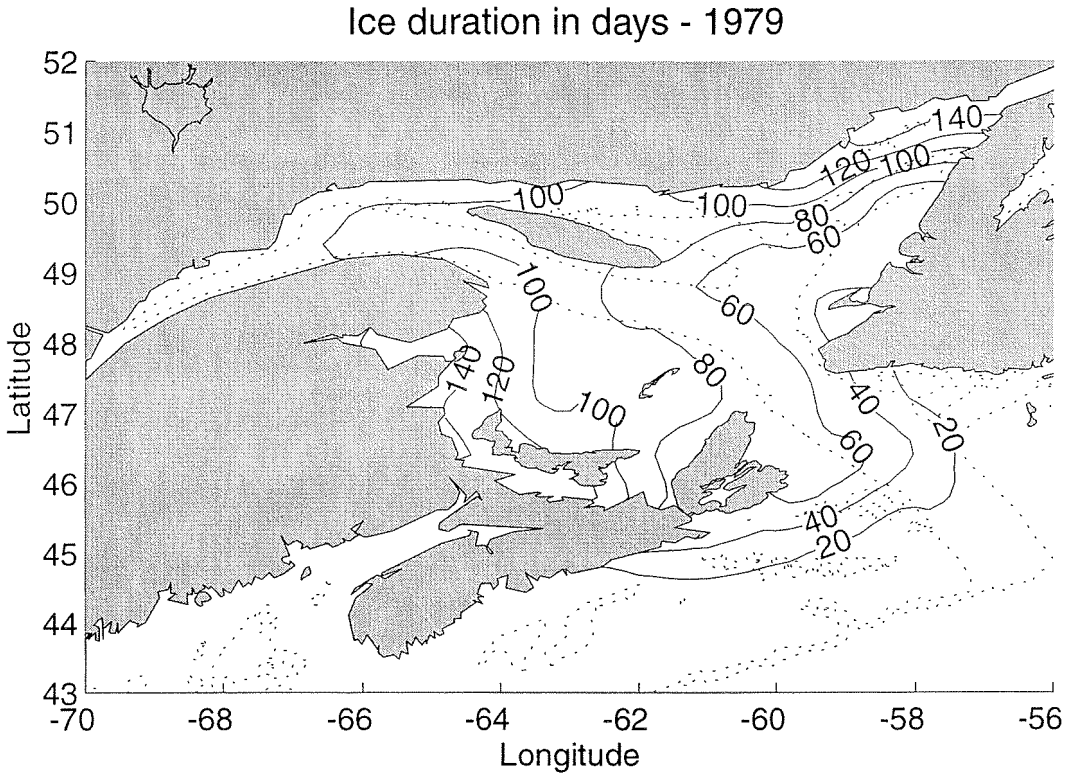
Ice duration in days - 1979
Latitude
Longitude
52
51
50
49
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-70
-68
-66
-64
-62
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-58
-56
140
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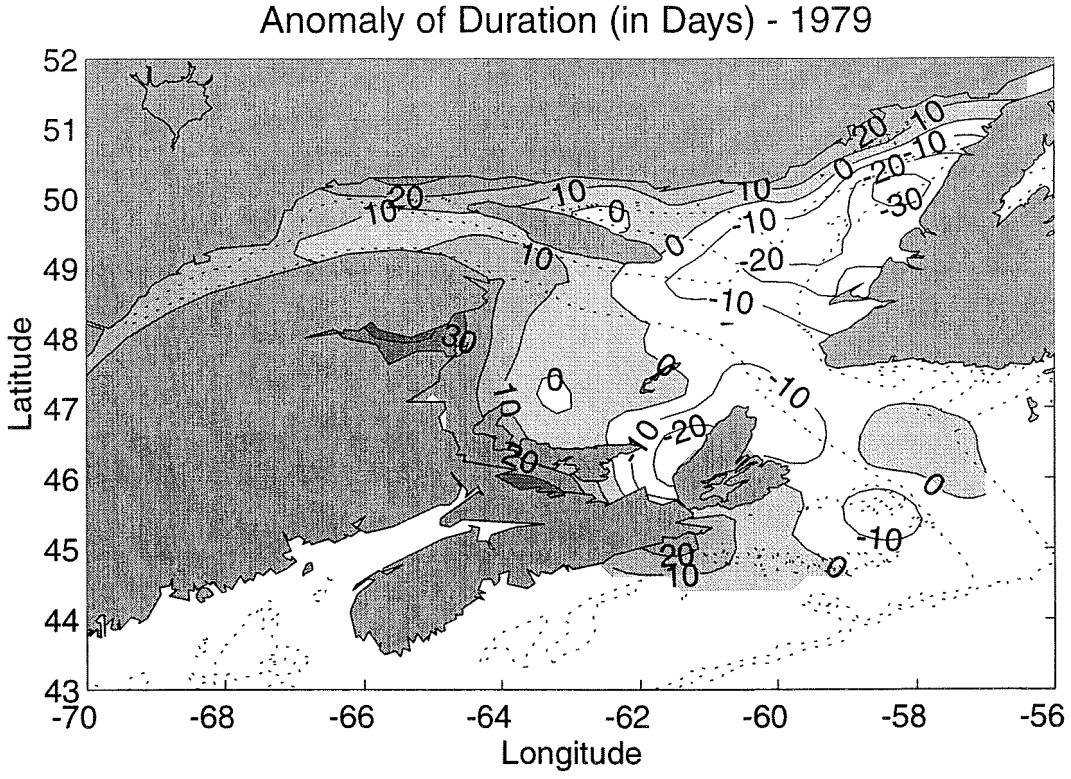
Anomaly of Duration (in Days) - 1979
Latitude
Longitude
52
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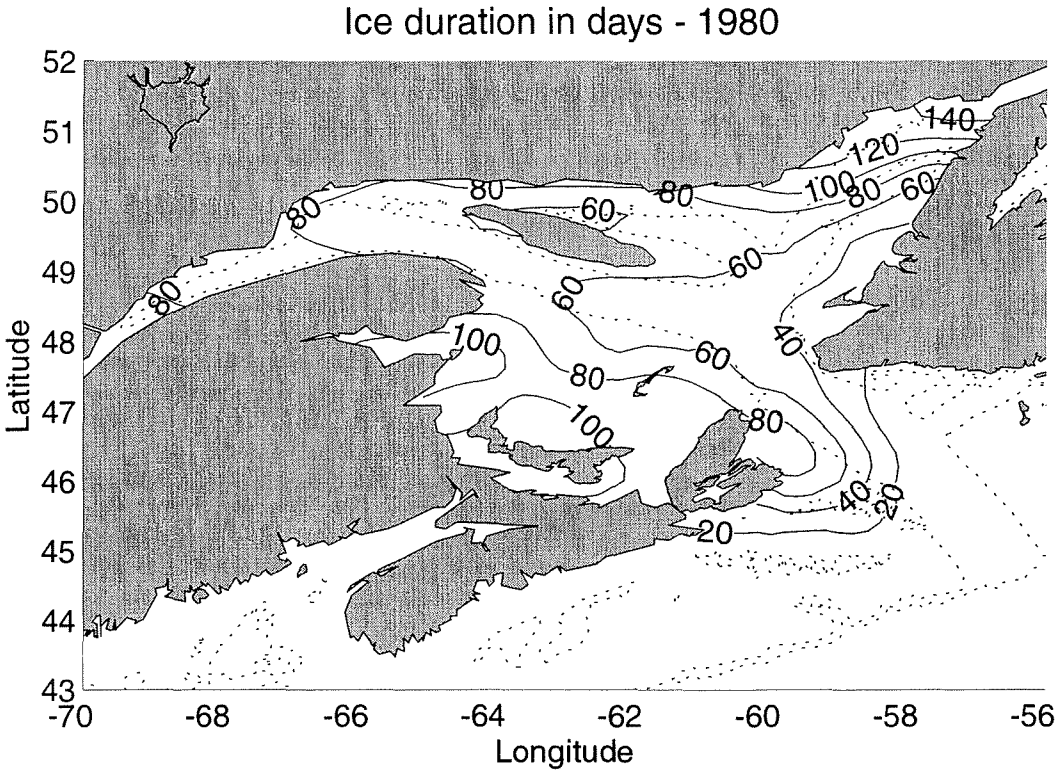
Ice duration in days - 1980
Latitude
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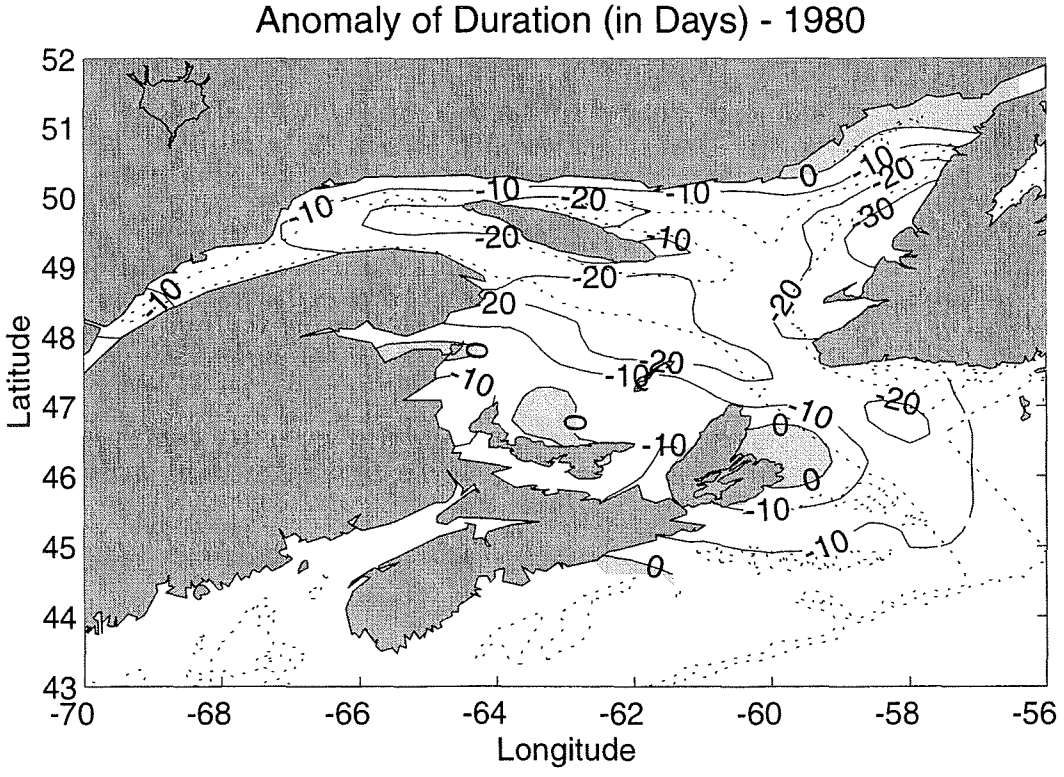
Anomaly of Duration (in Days) - 1980
Latitude
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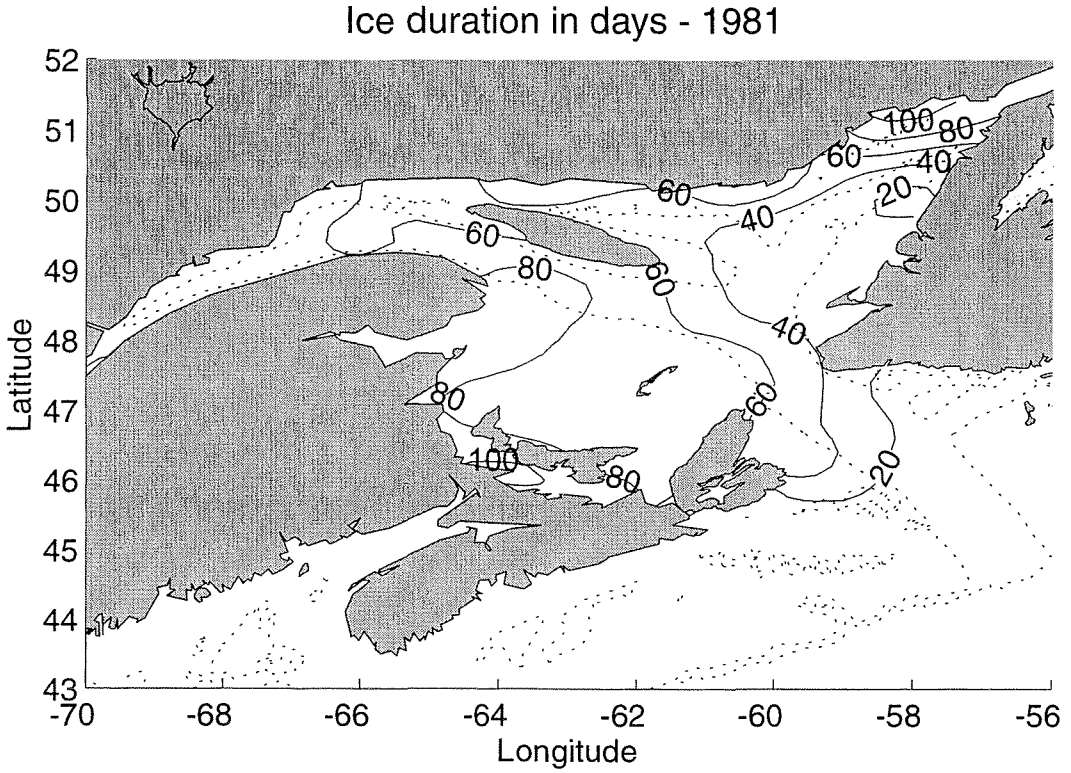
Ice duration in days - 1981
Latitude
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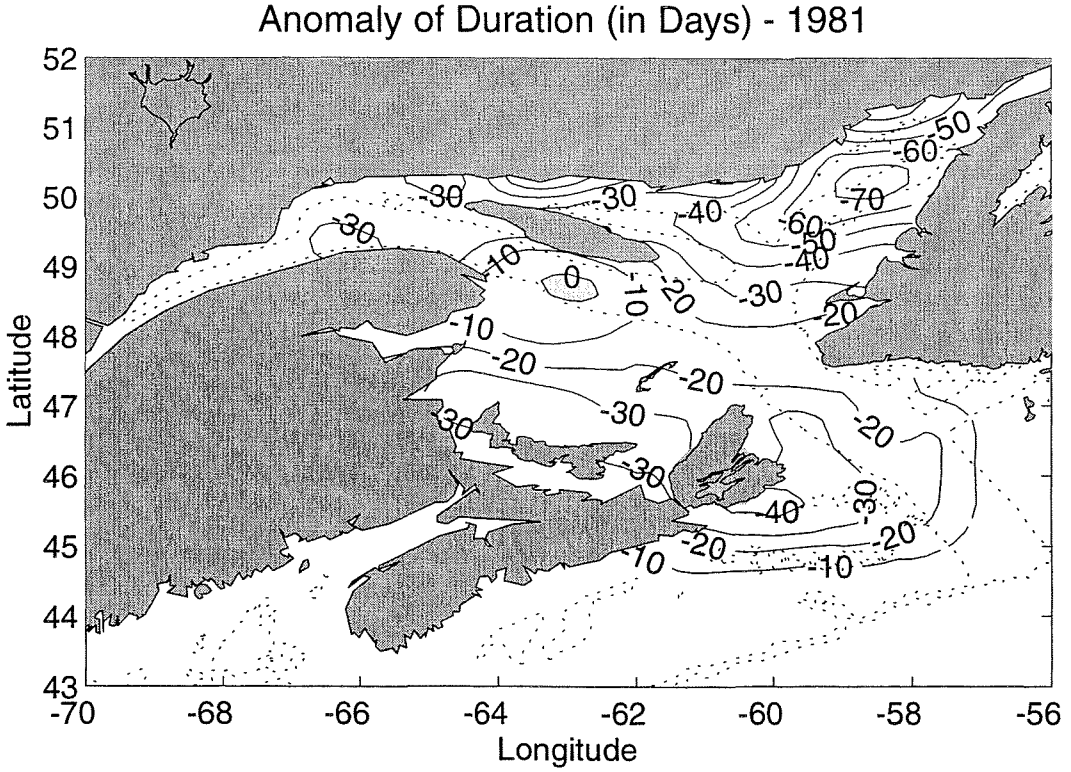
Anomaly of Duration (in Days) - 1981
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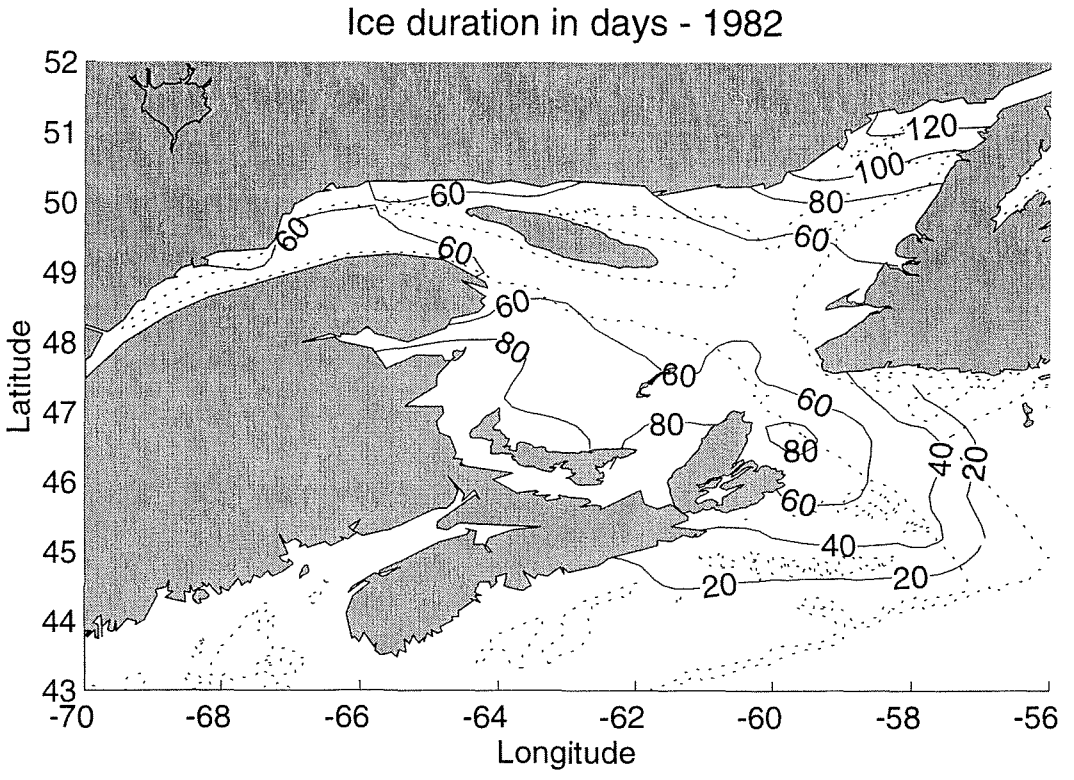
Ice duration in days - 1982
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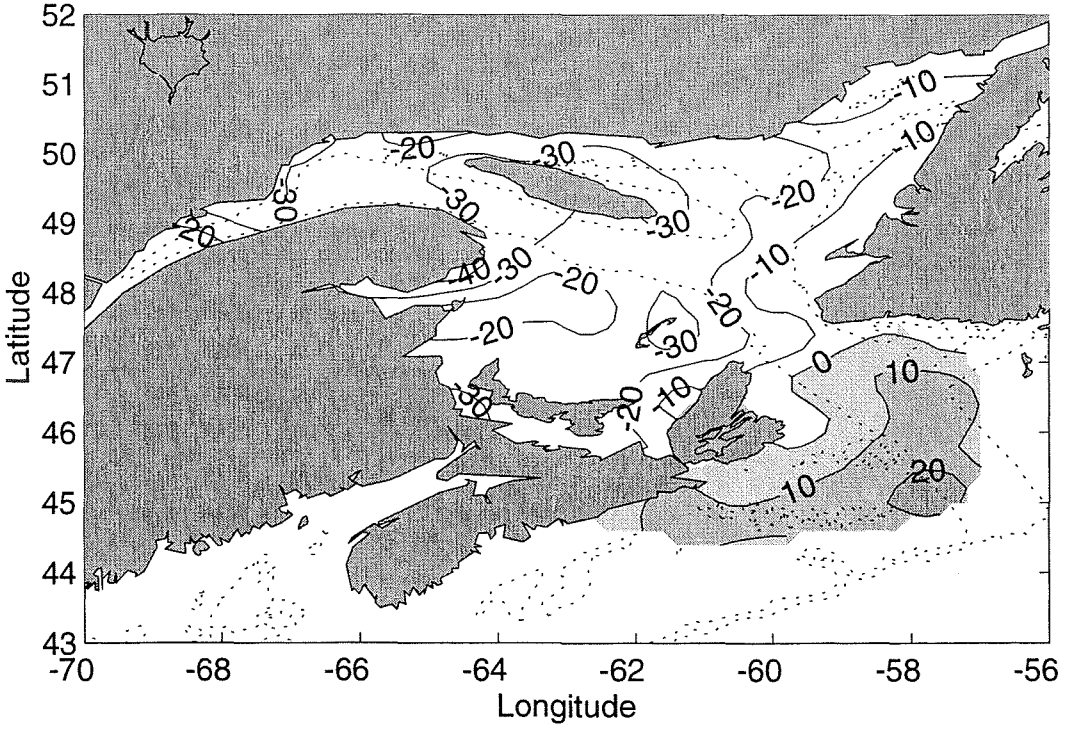
Anomaly of Duration (in Days) - 1982
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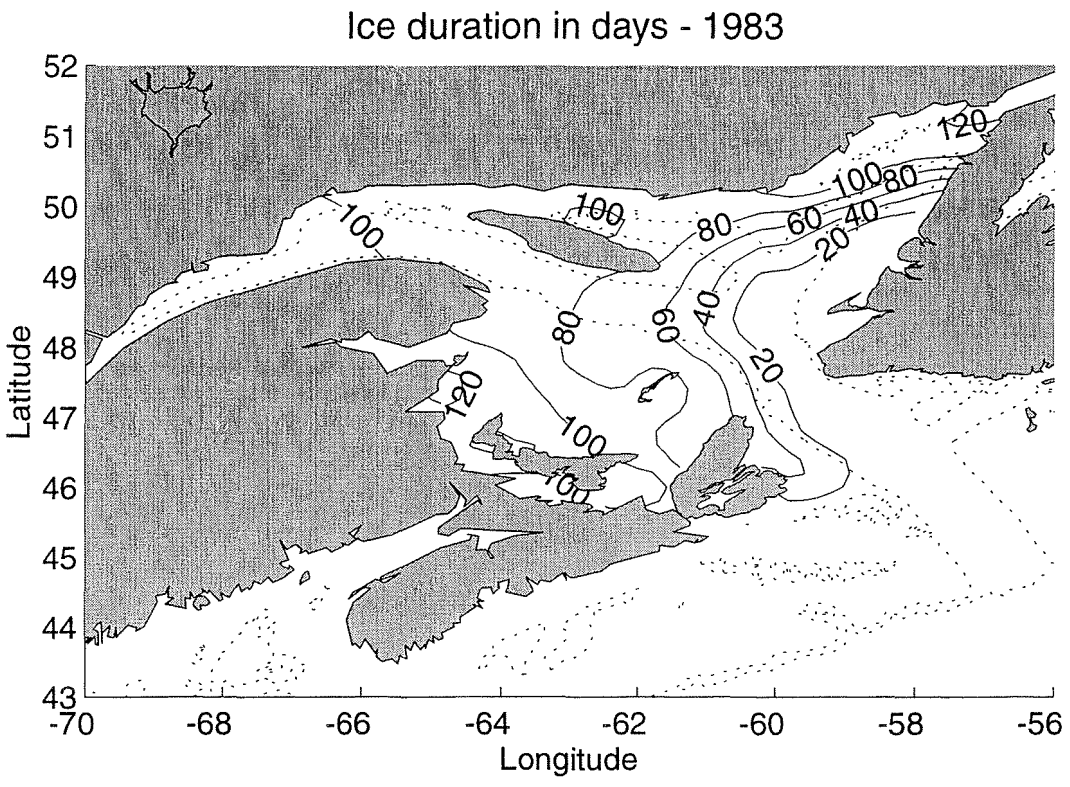
Ice duration in days - 1983
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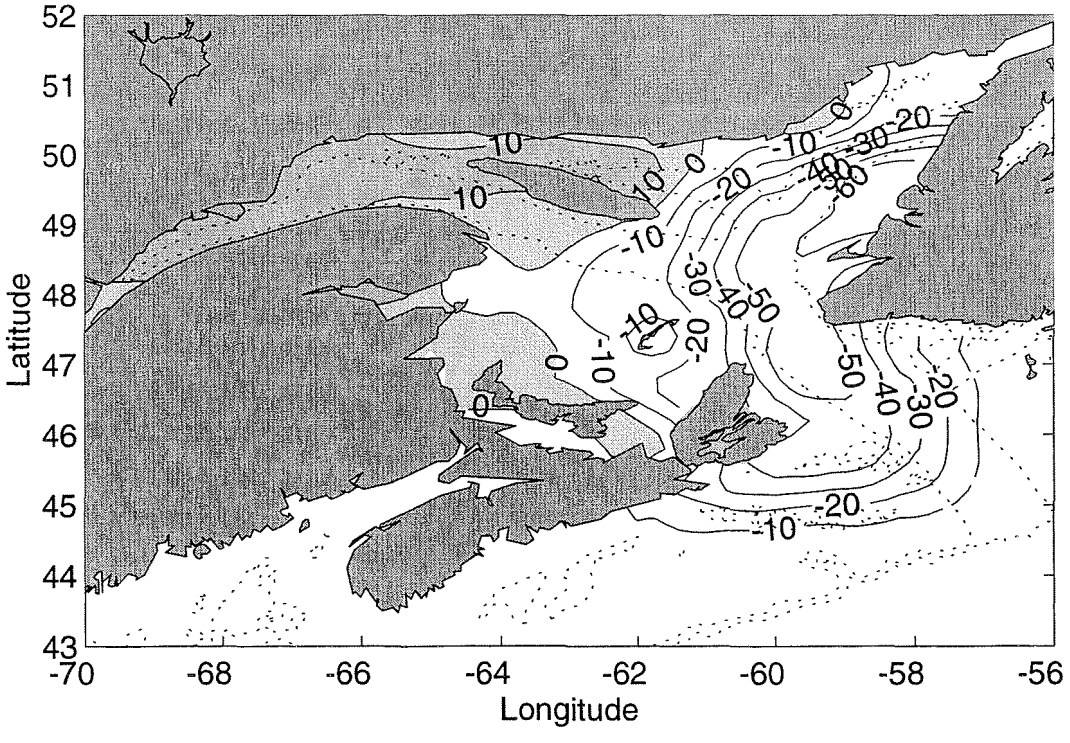
Anomaly of Duration (in Days) - 1983
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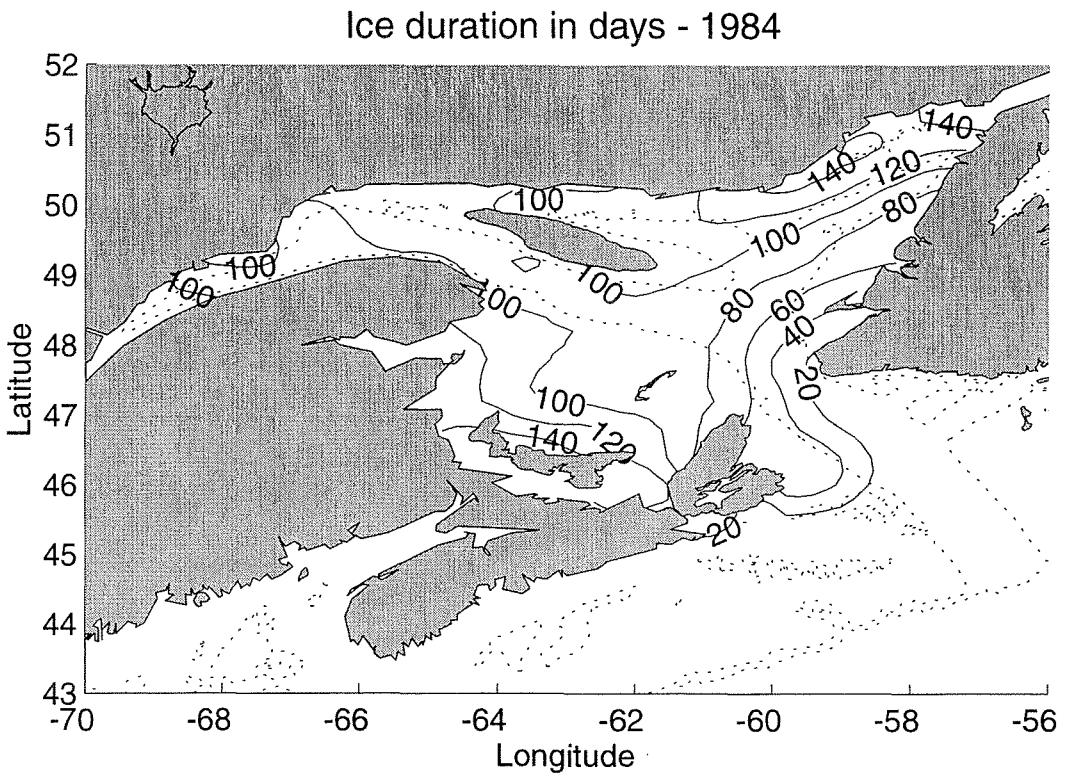
Ice duration in days - 1984
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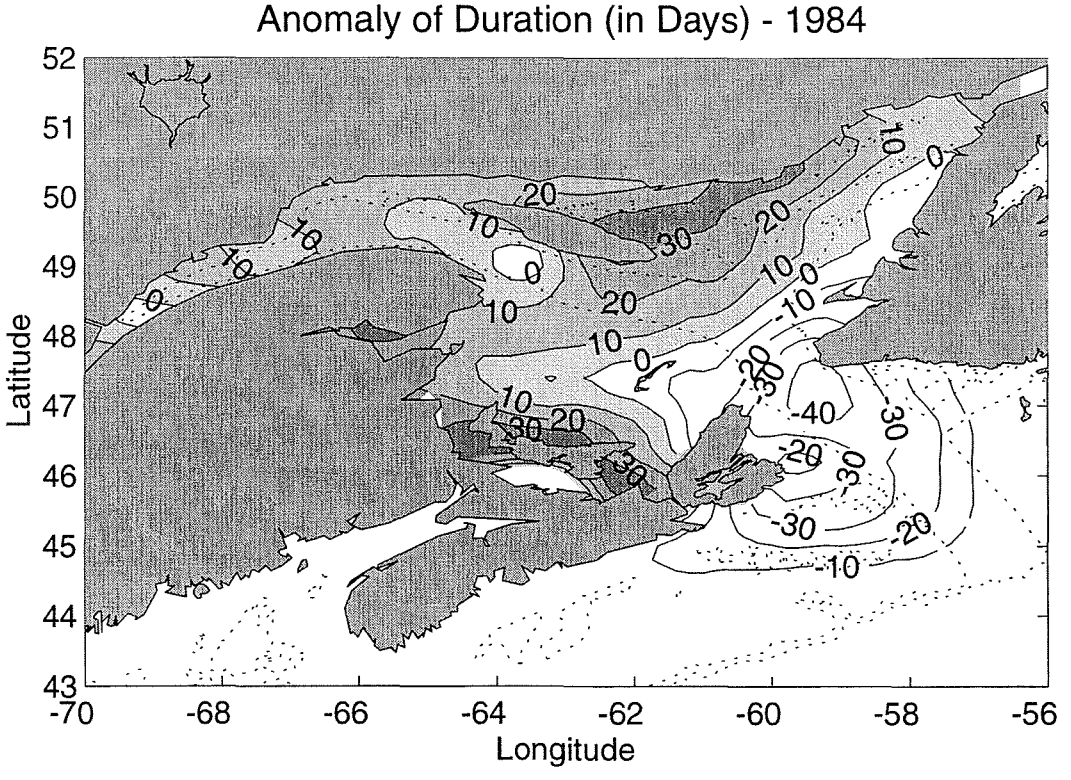
Anomaly of Duration (in Days) - 1984
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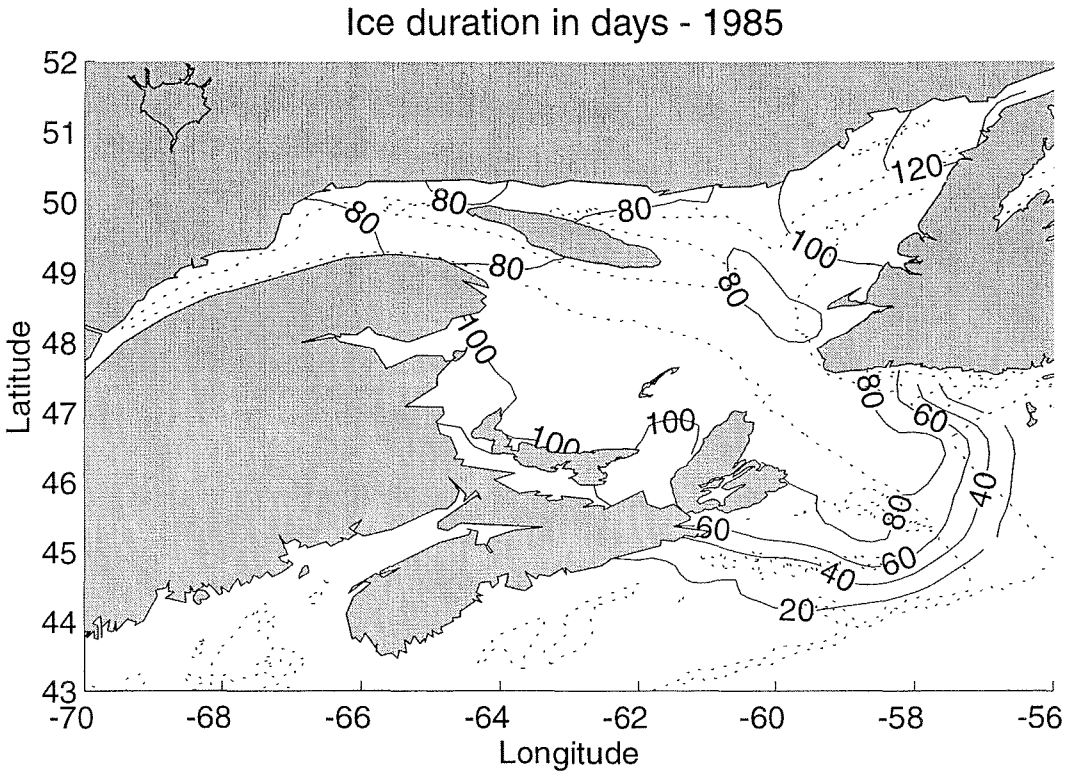
Ice duration in days - 1985
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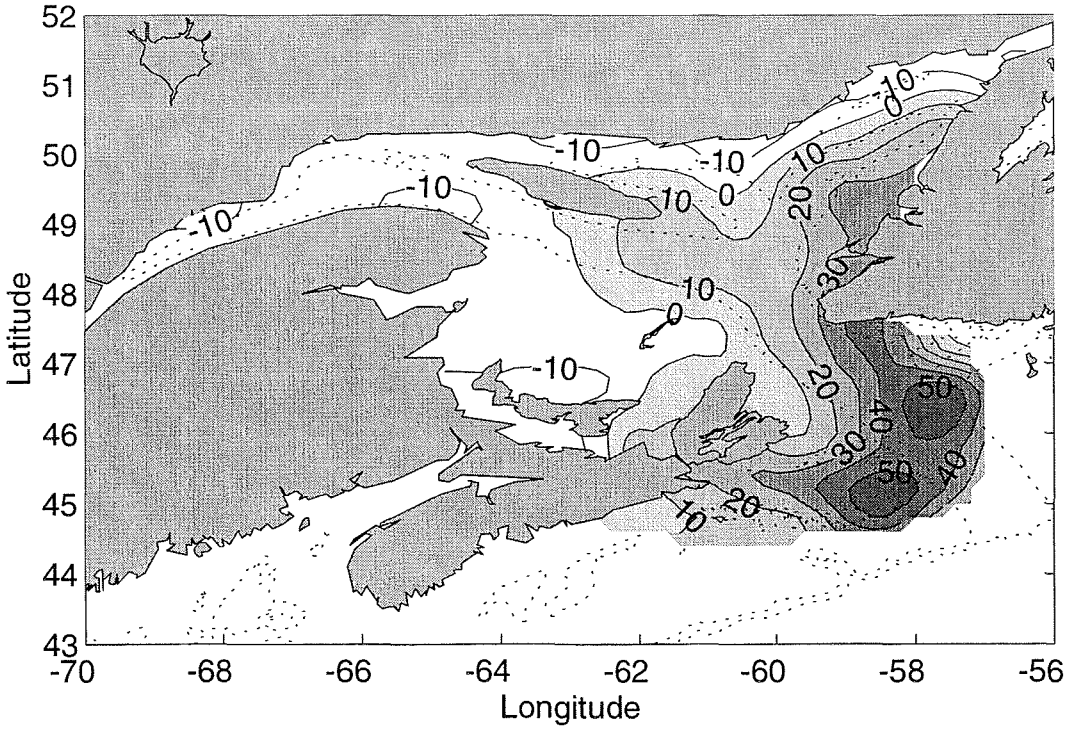
Anomaly of Duration (in Days) - 1985
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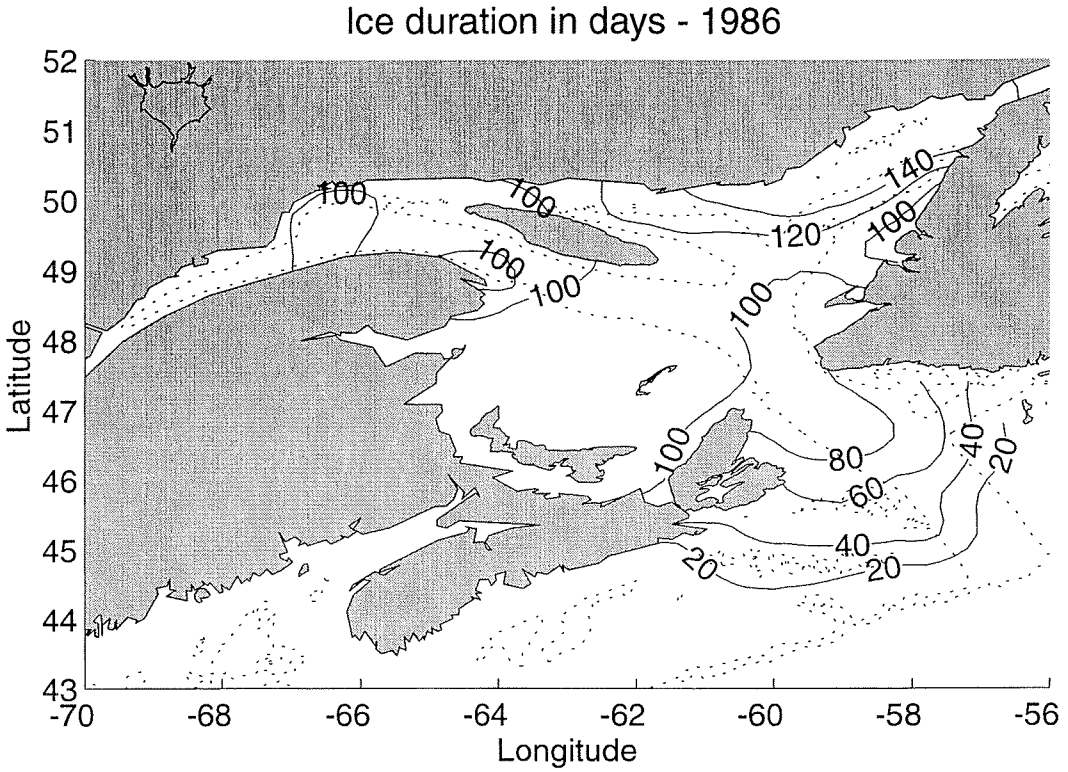
Ice duration in days - 1986
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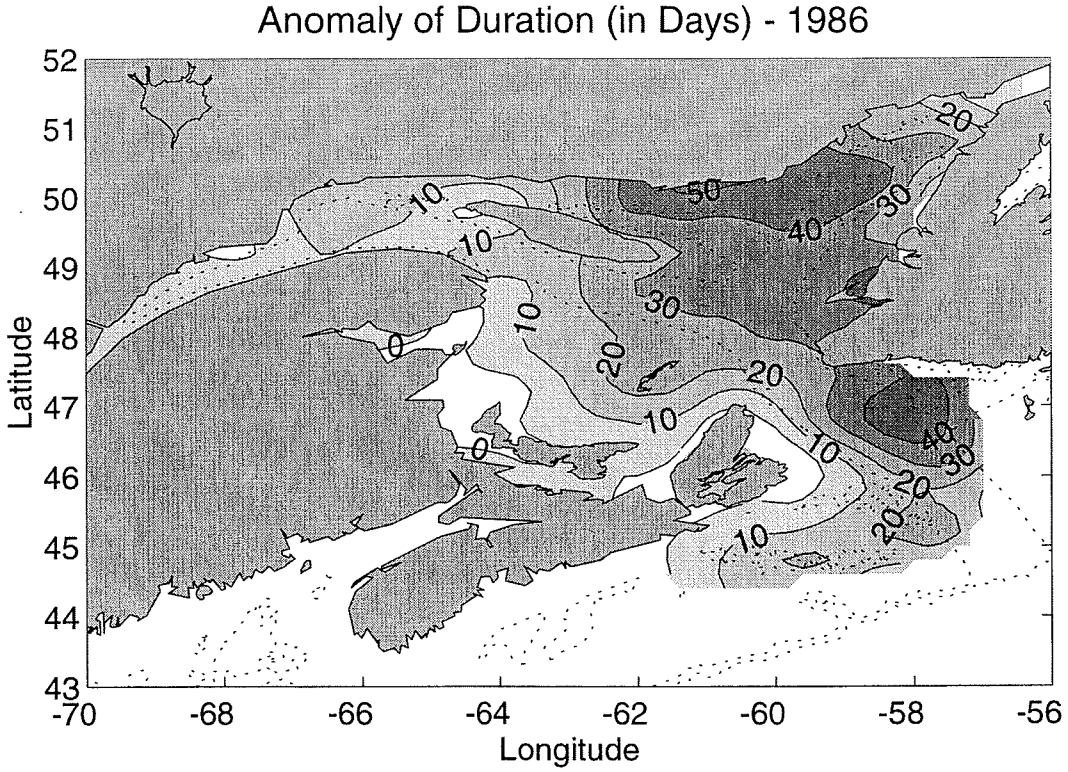
Anomaly of Duration (in Days) - 1986
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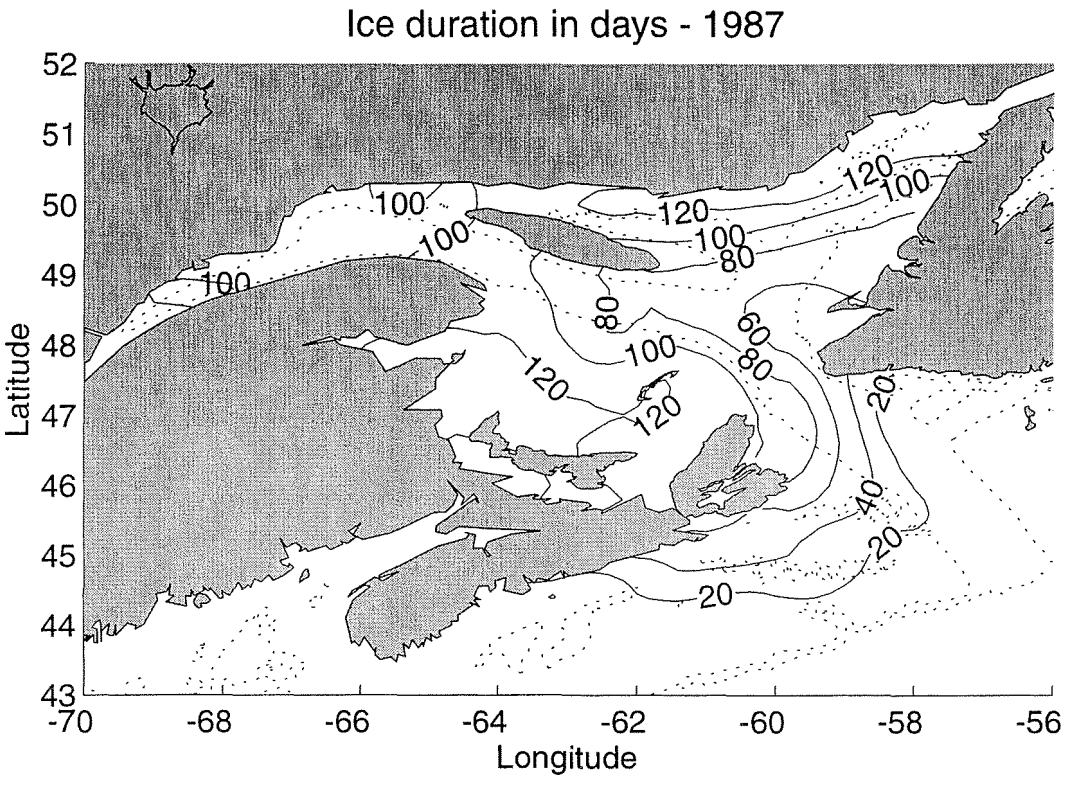
Ice duration in days - 1987
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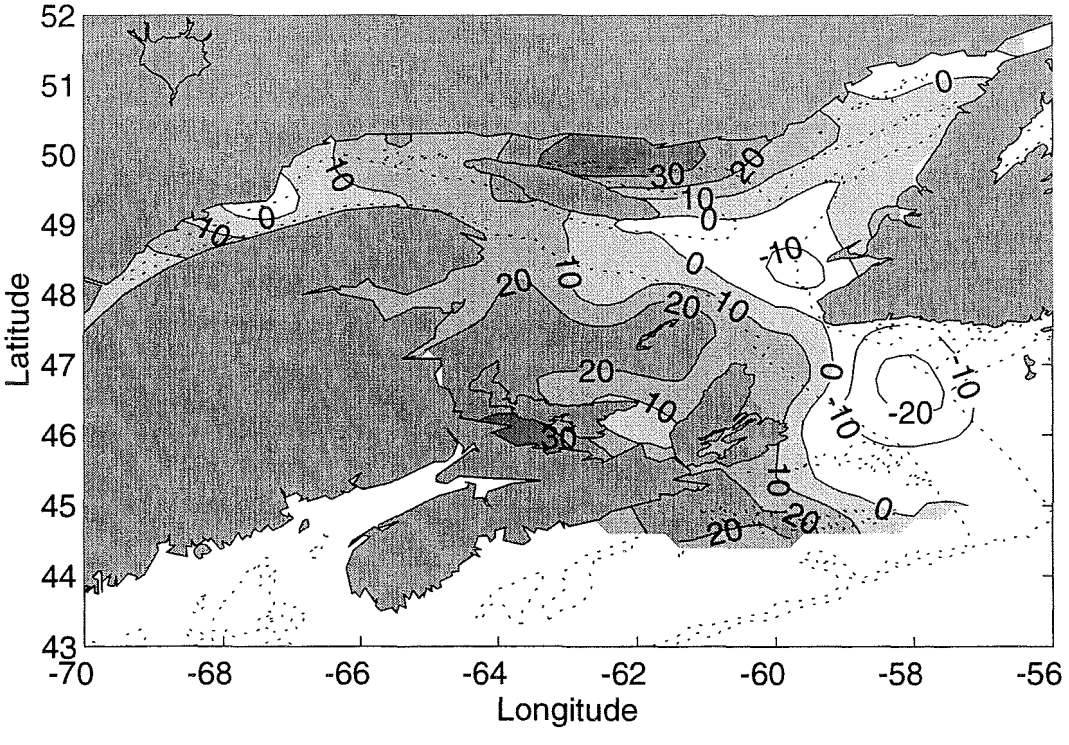
Anomaly of Duration (in Days) - 1987
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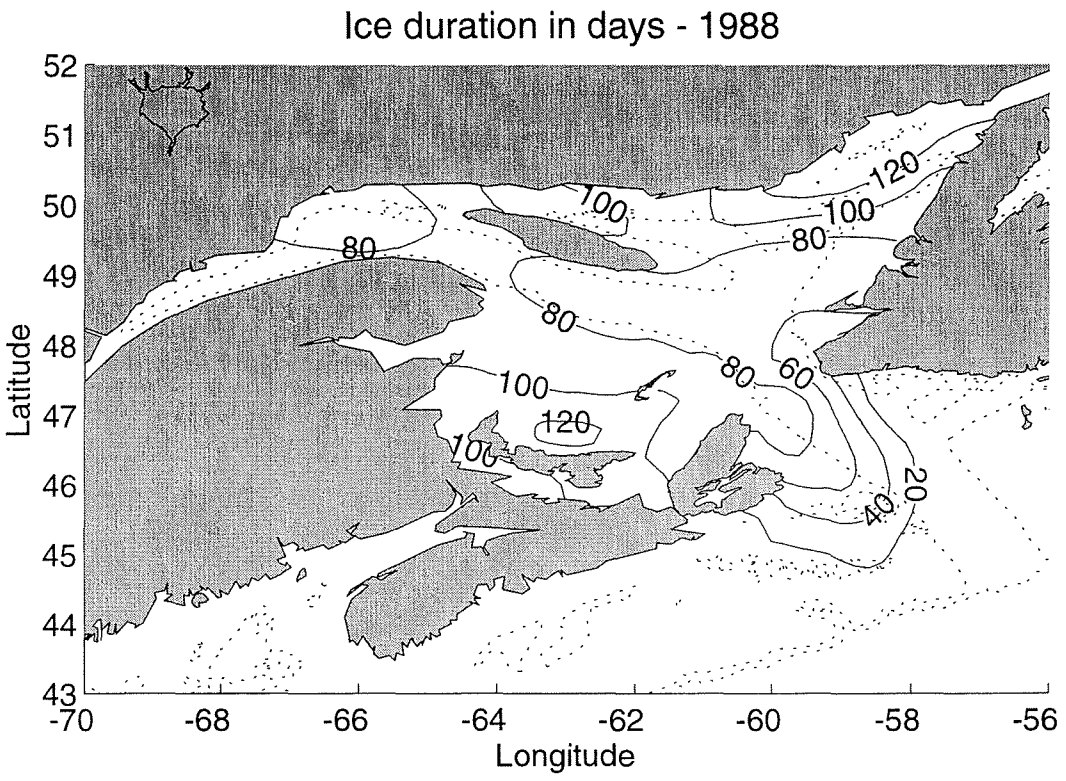
Ice duration in days - 1988
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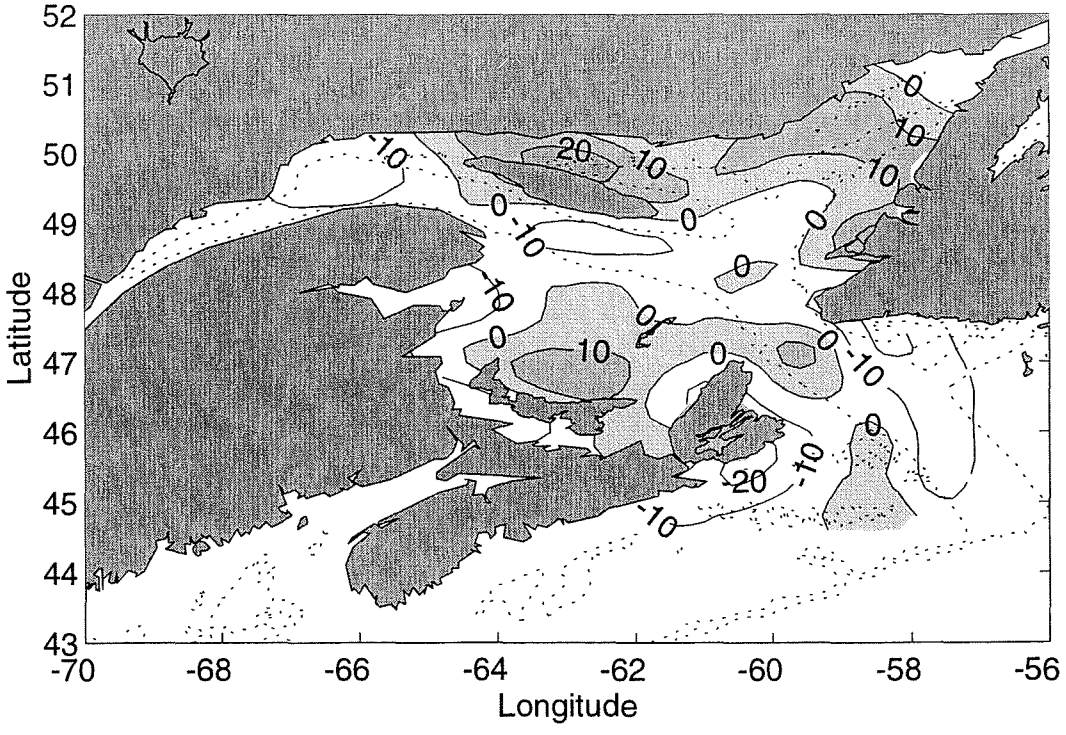
Anomaly of Duration (in Days) - 1988
Latitude
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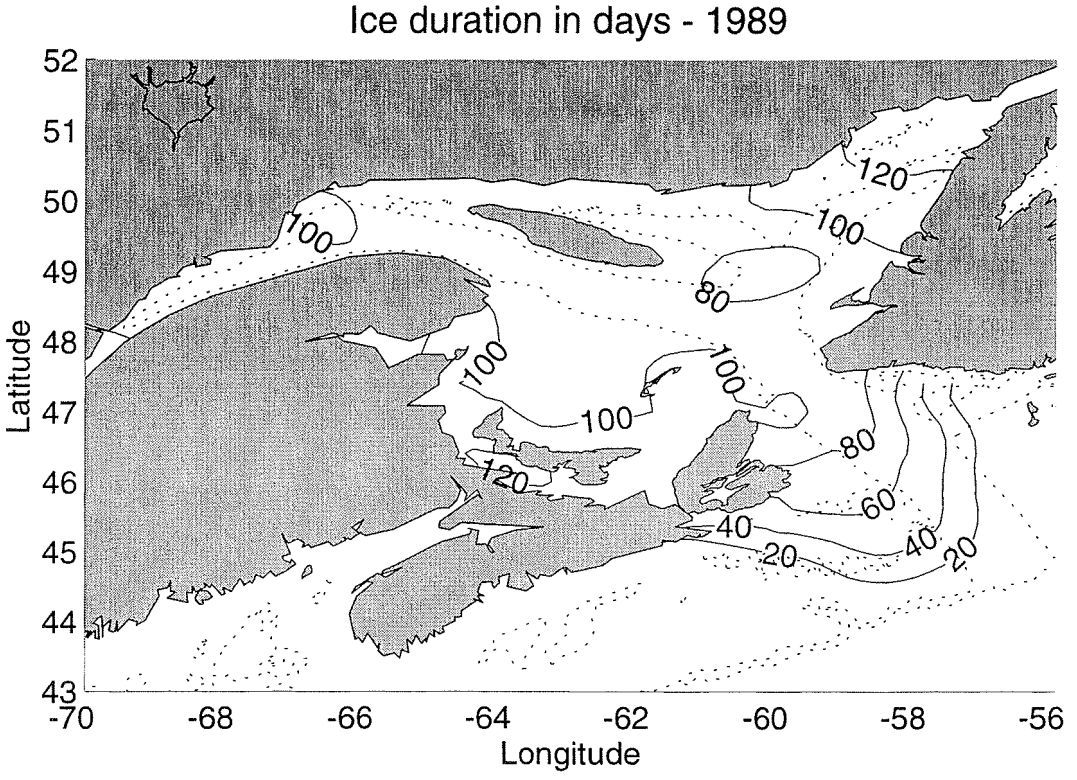
Ice duration in days - 1989
Latitude
Longitude
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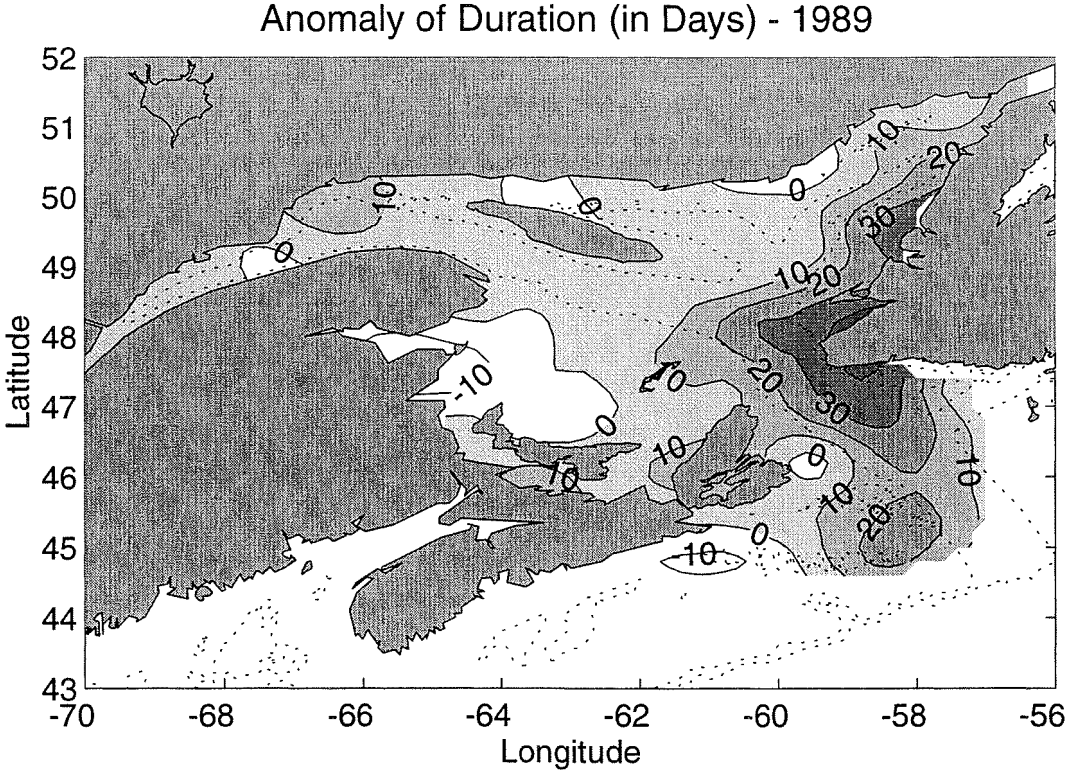
Anomaly of Duration (in Days) - 1989
Latitude
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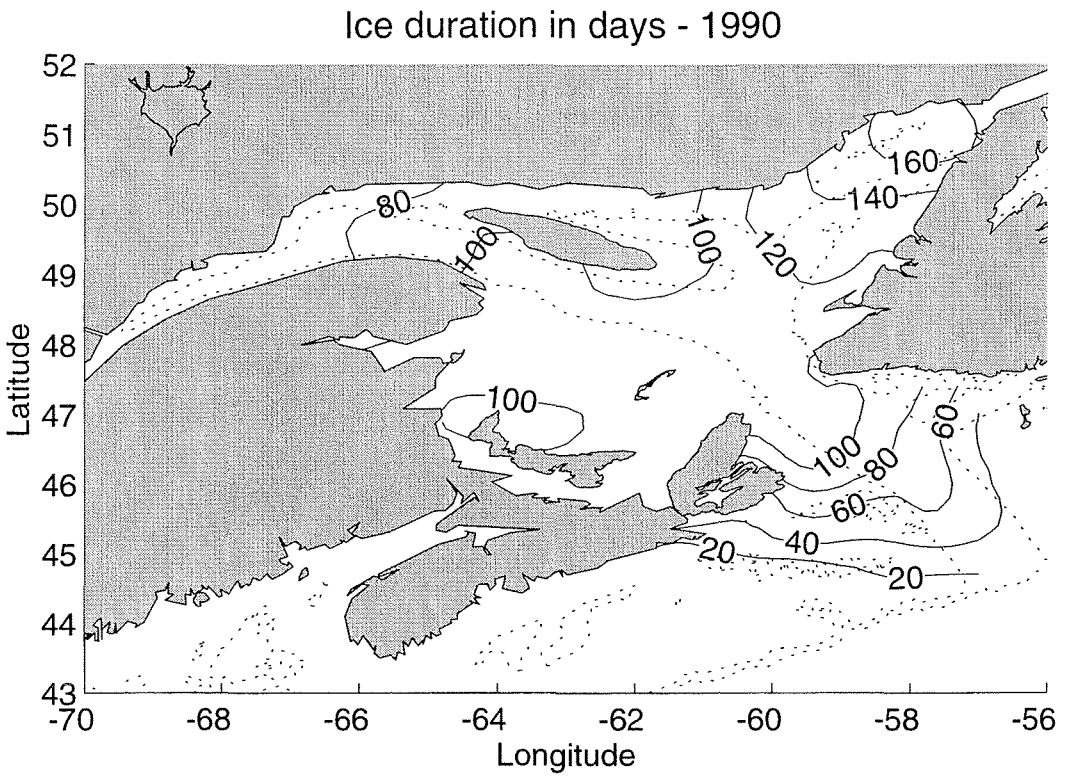
Ice duration in days - 1990
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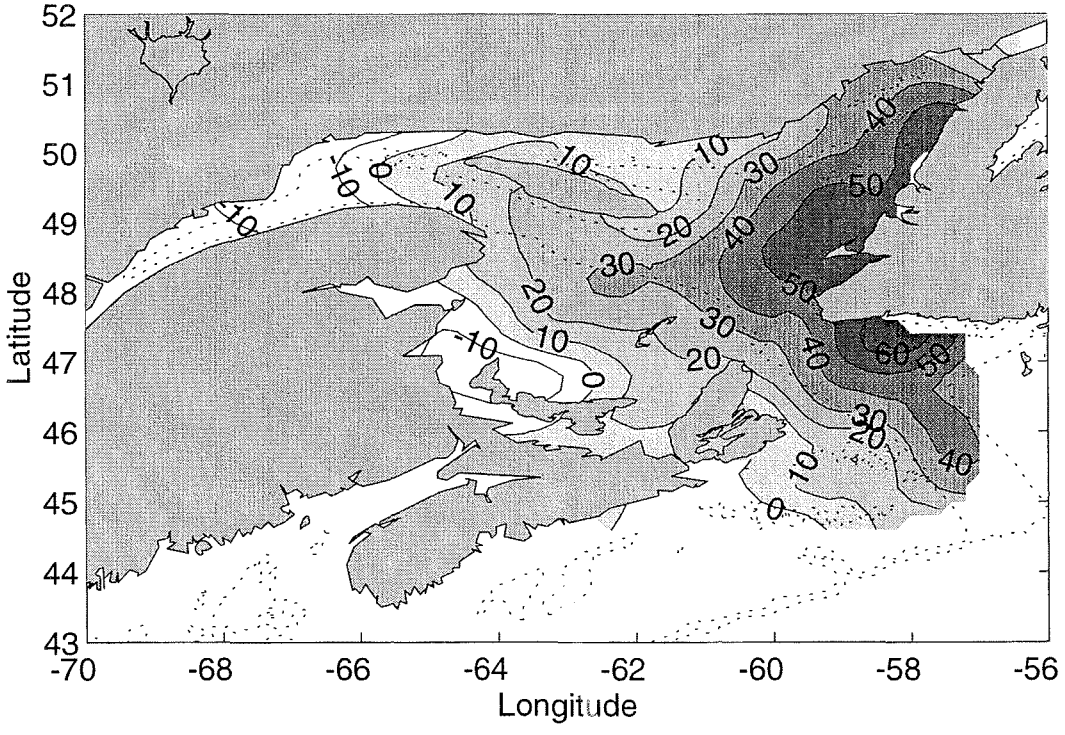
Anomaly of Duration (in Days) - 1990
Latitude
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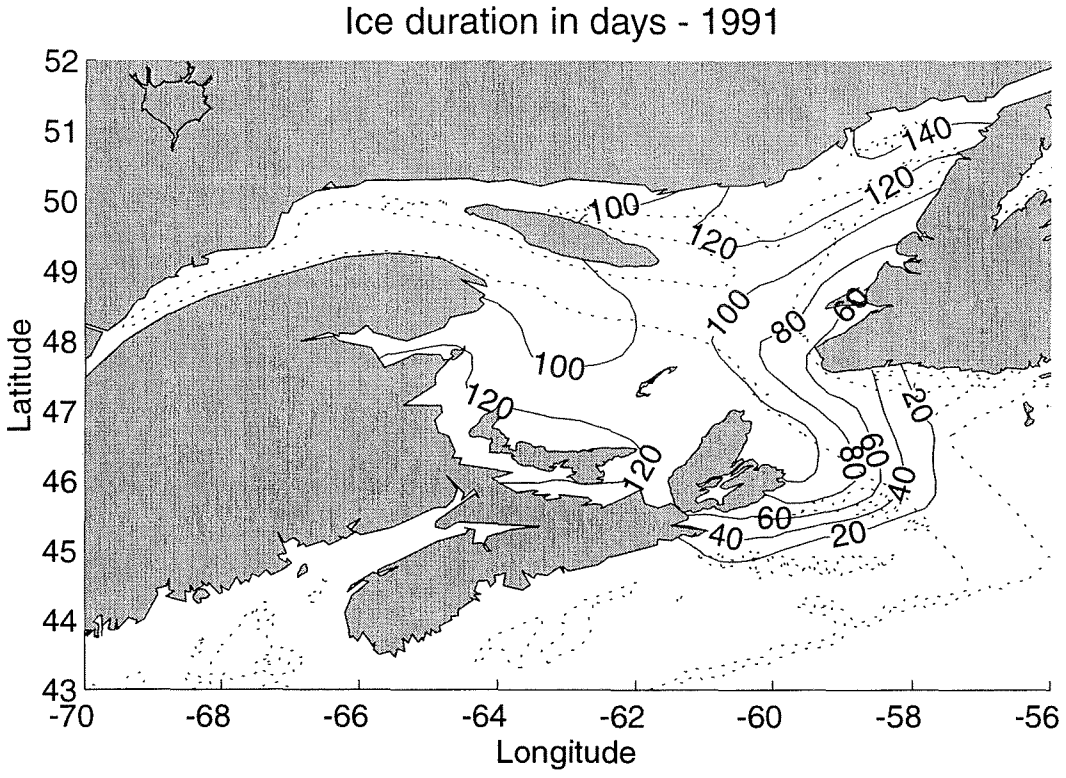
Ice duration in days - 1991
Latitude
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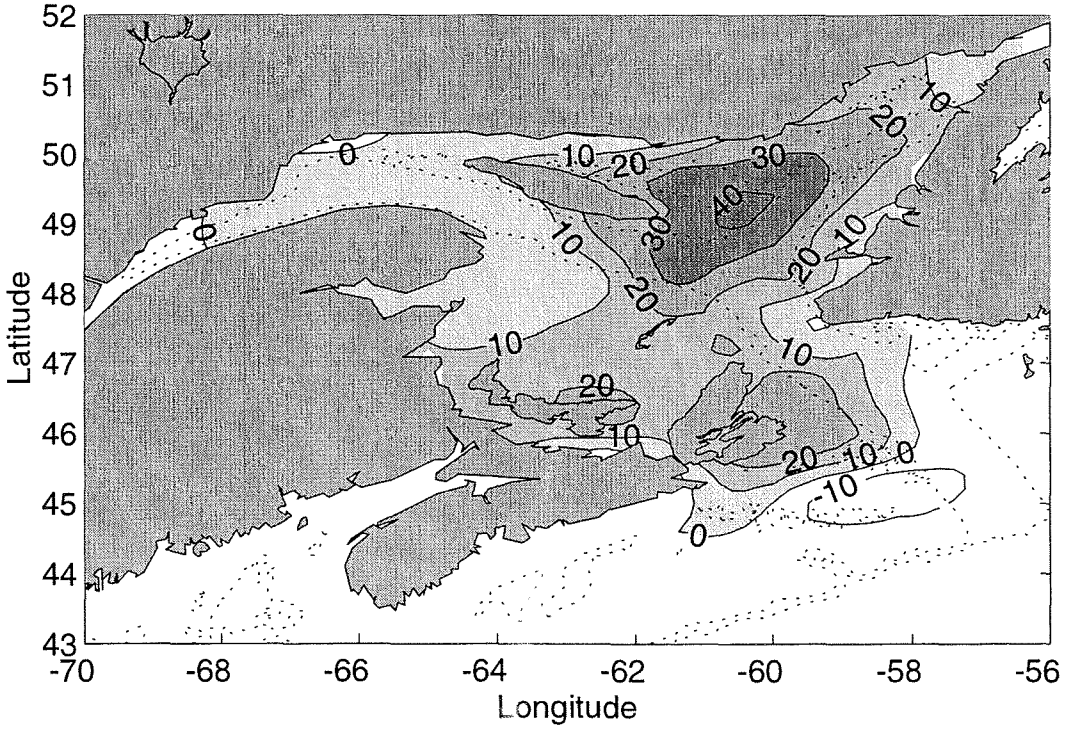
Anomaly of Duration (in Days) - 1991
Latitude
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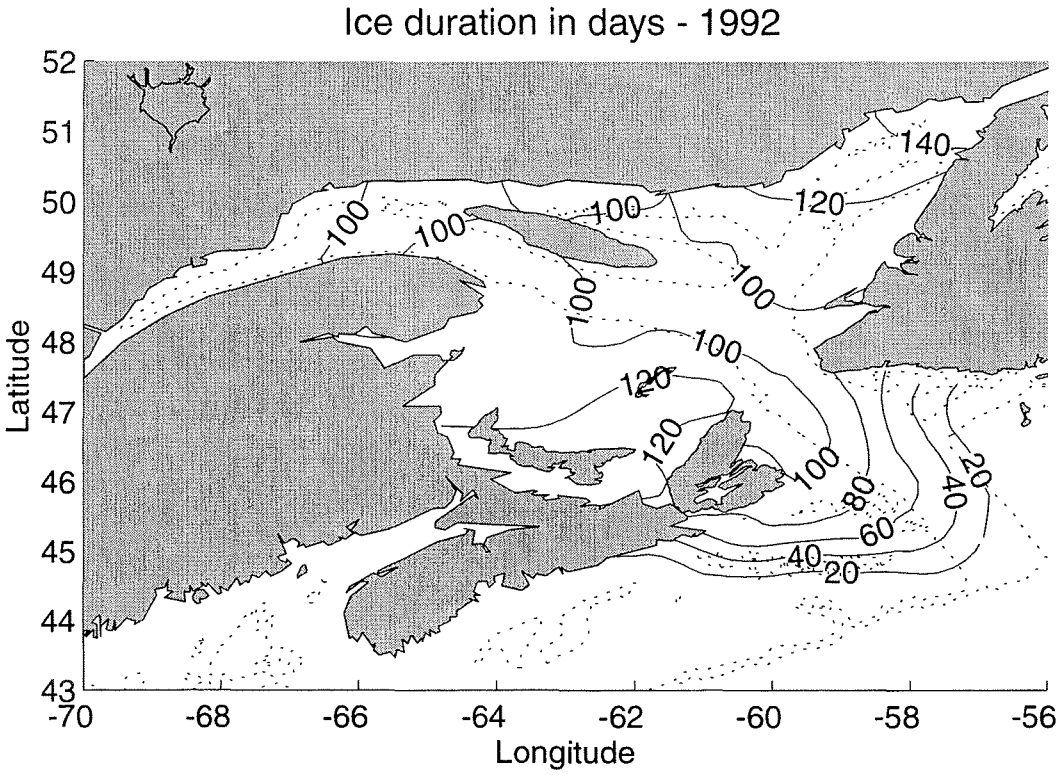
Ice duration in days - 1992
Latitude
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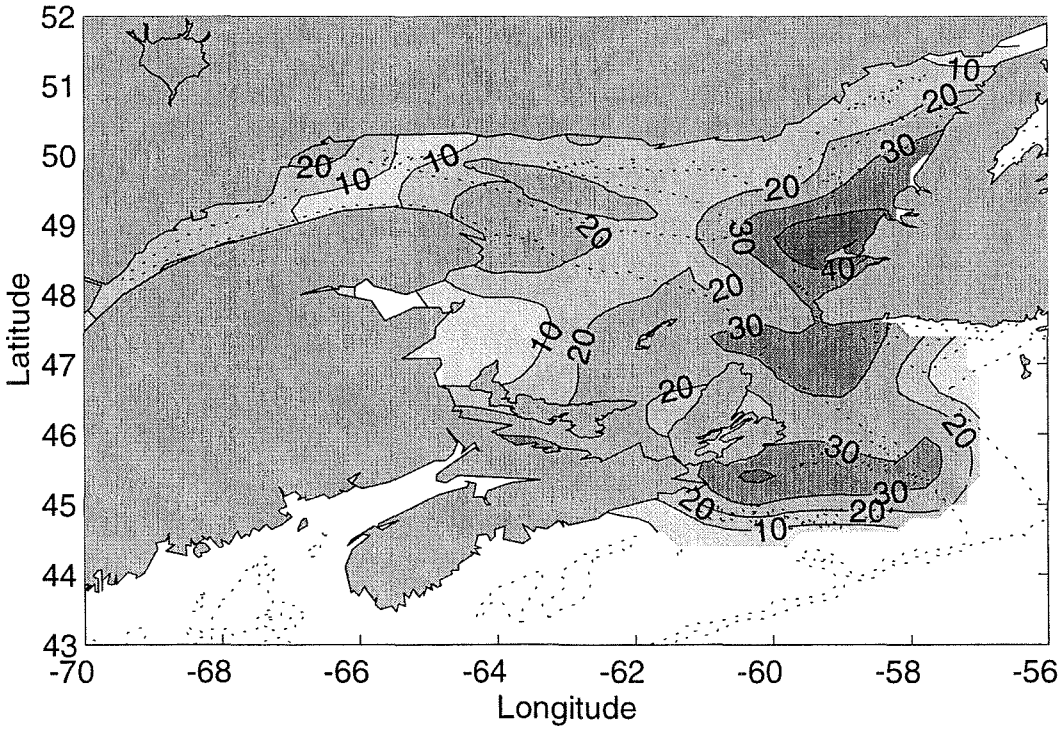
Anomaly of Duration (in Days) - 1992
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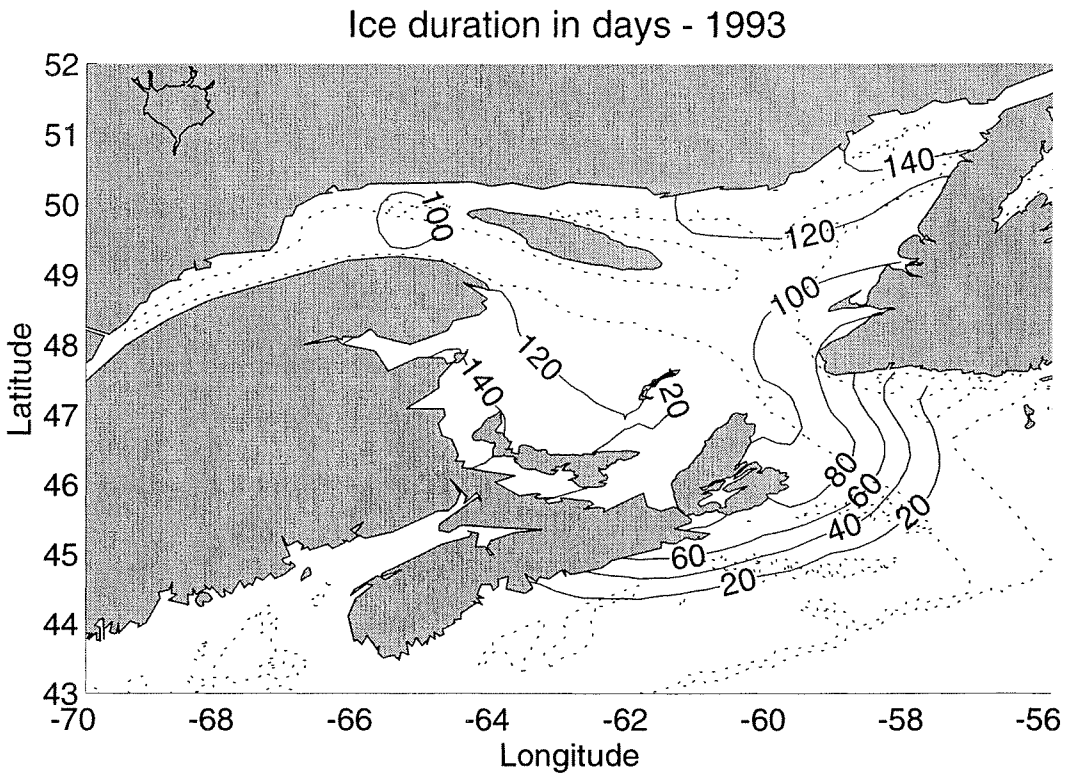
Ice duration in days - 1993
Latitude
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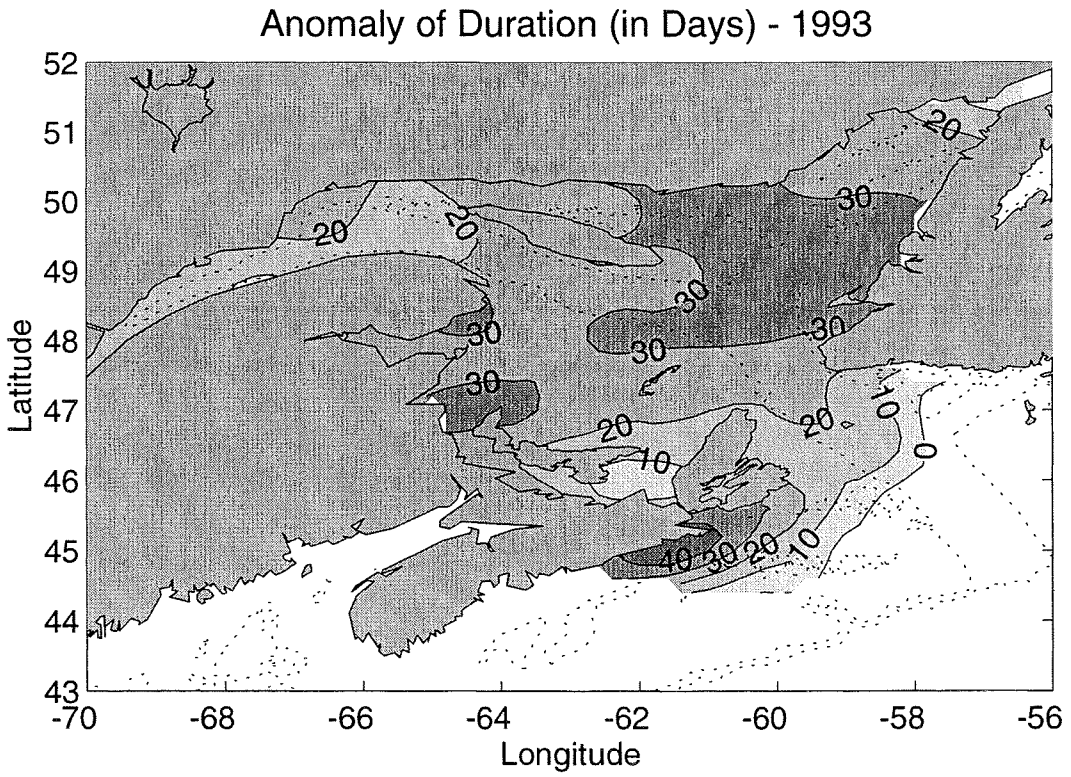
Anomaly of Duration (in Days) - 1993
Latitude
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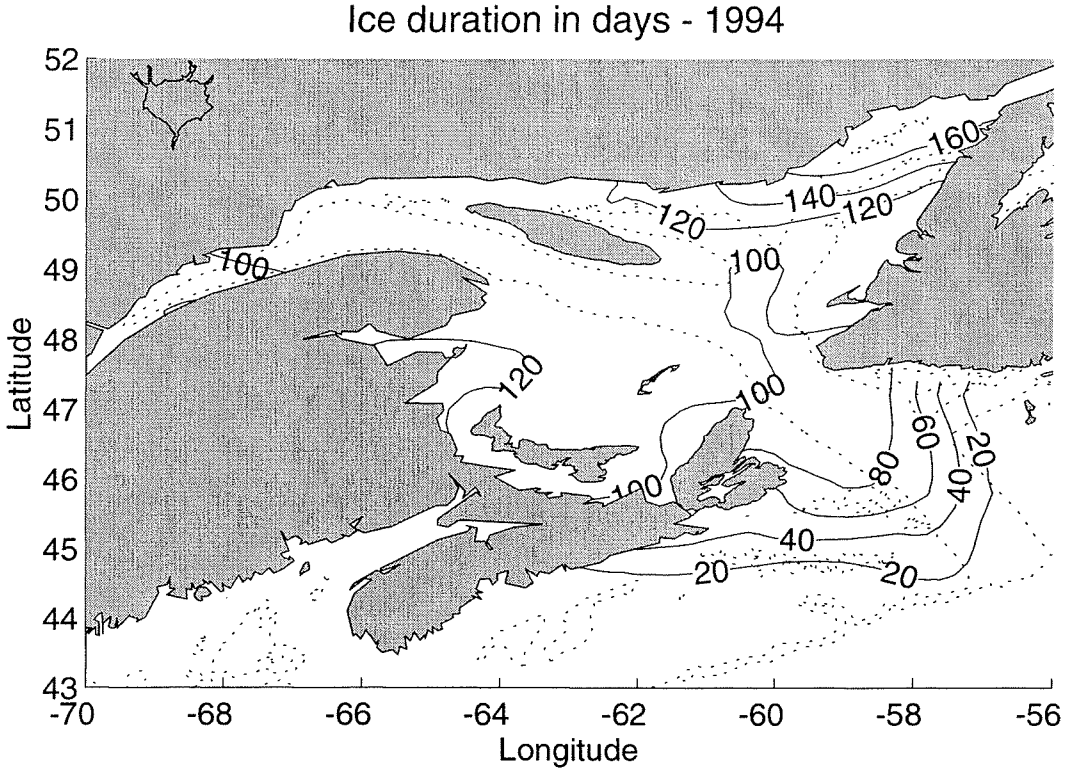
Ice duration in days - 1994
Latitude
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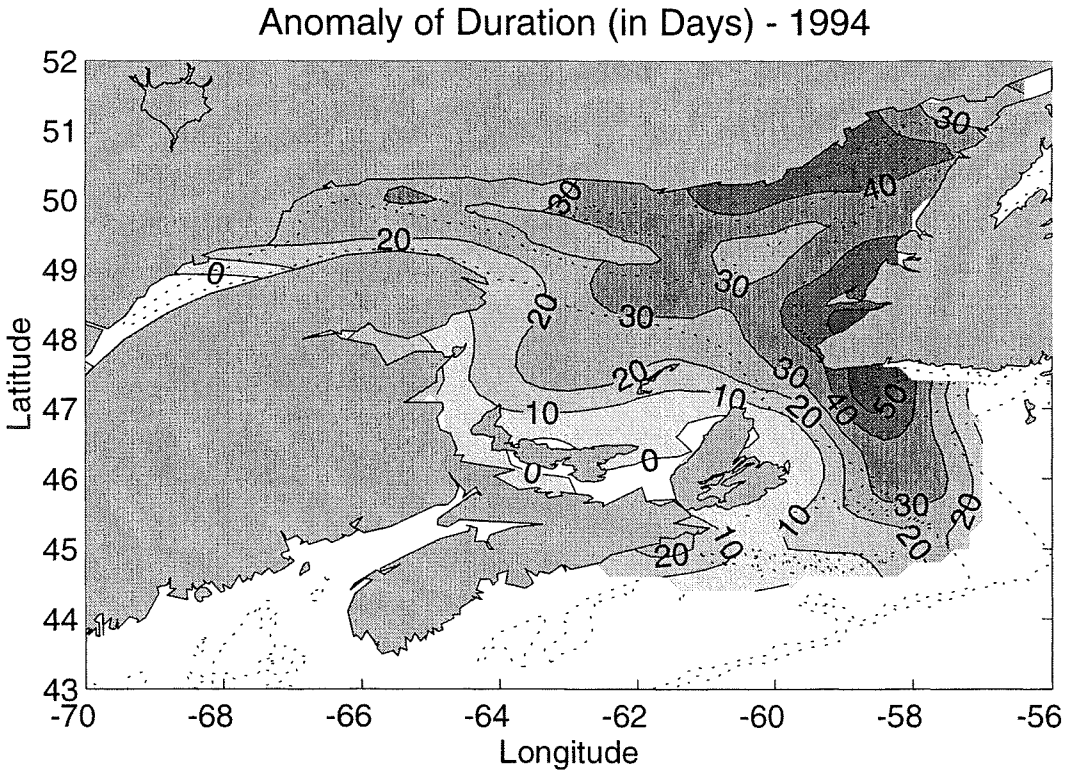
Anomaly of Duration (in Days) - 1994
Latitude
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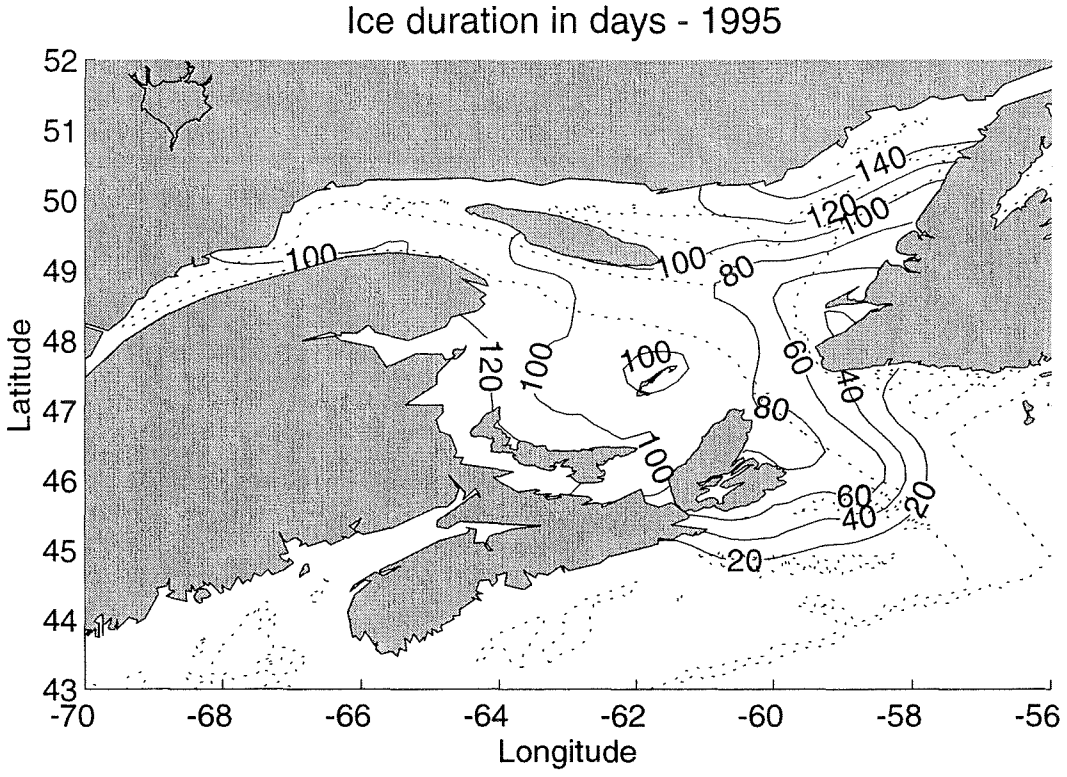
Ice duration in days - 1995
Latitude
Longitude
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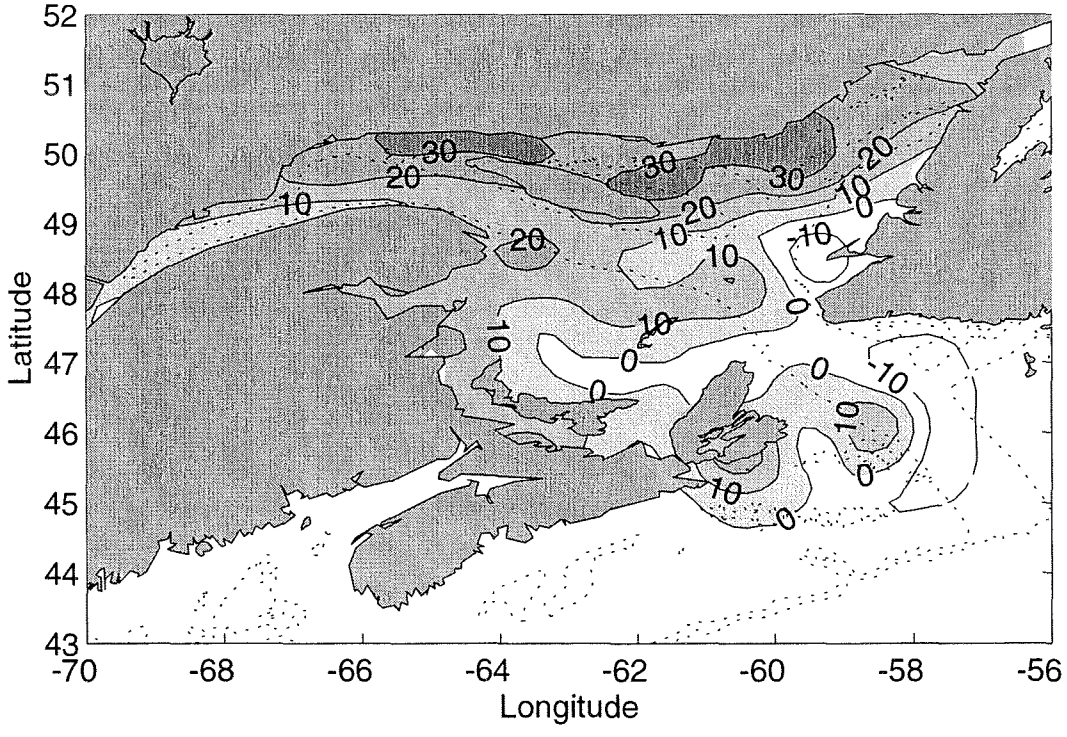
Anomaly of Duration (in Days) - 1995
Latitude
Longitude
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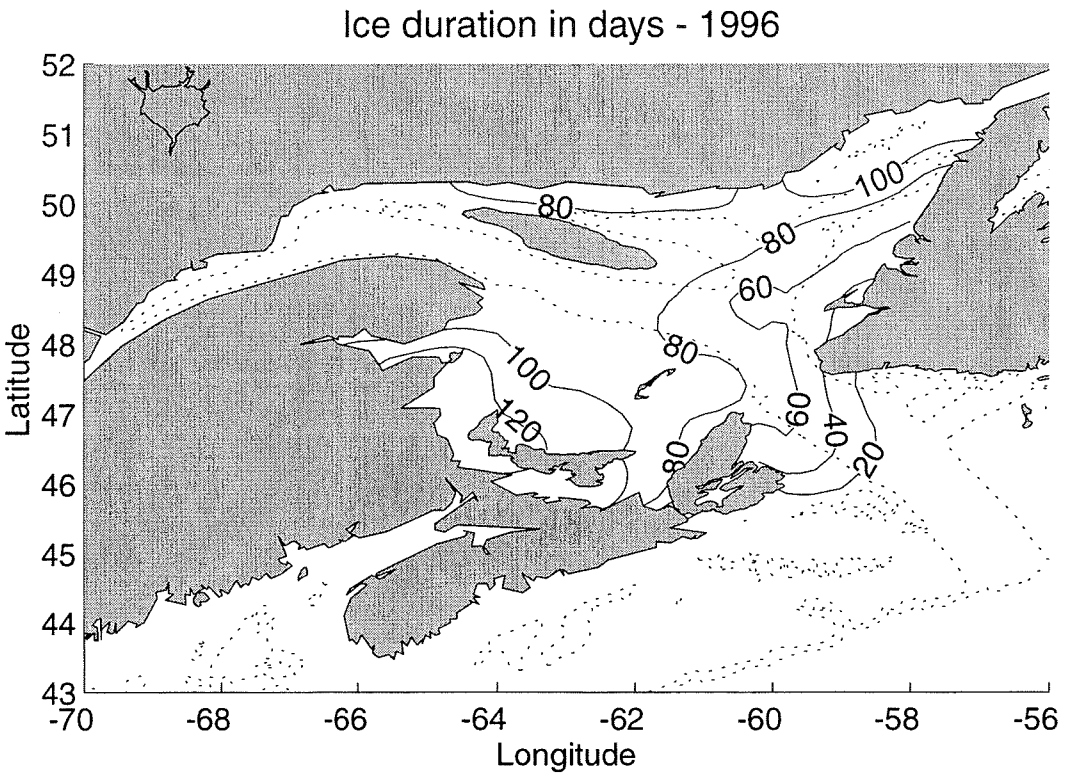
Ice duration in days - 1996
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Longitude
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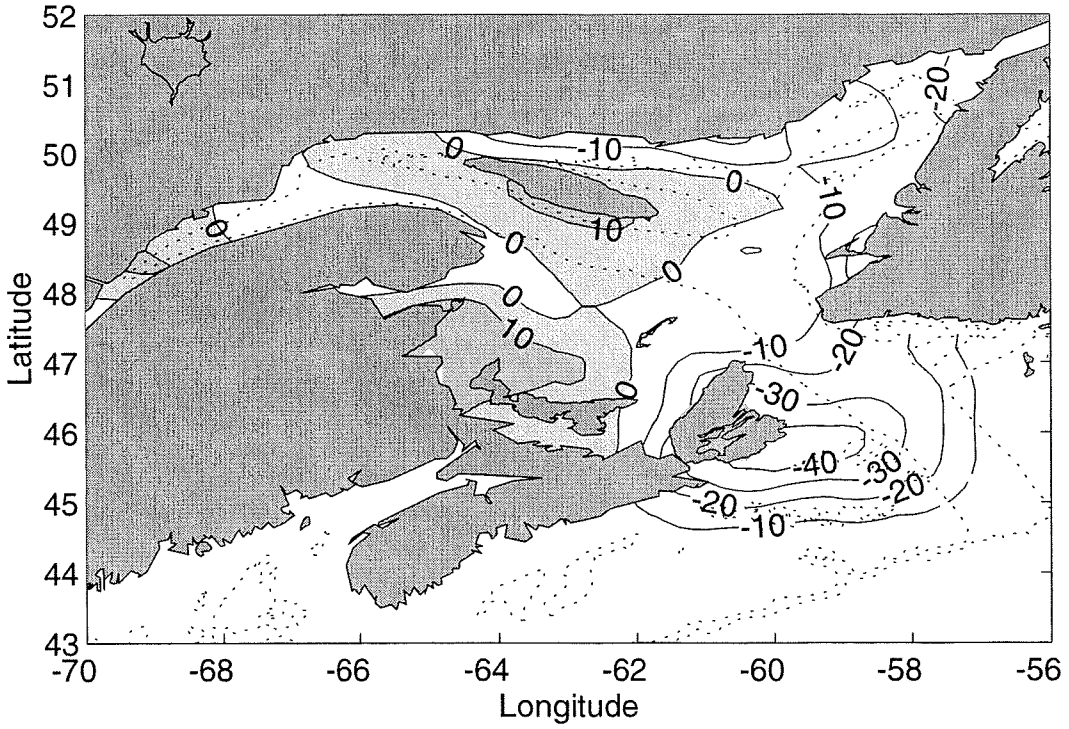
Anomaly of Duration (in Days) - 1996
Latitude
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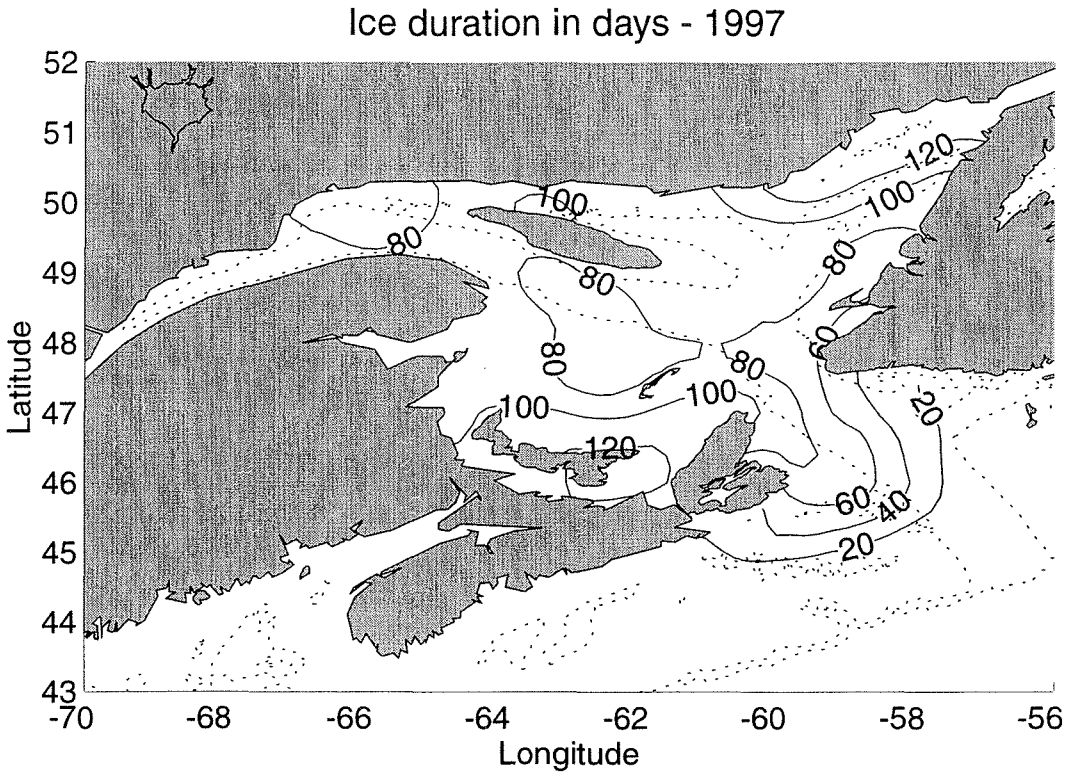
Ice duration in days - 1997
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Longitude
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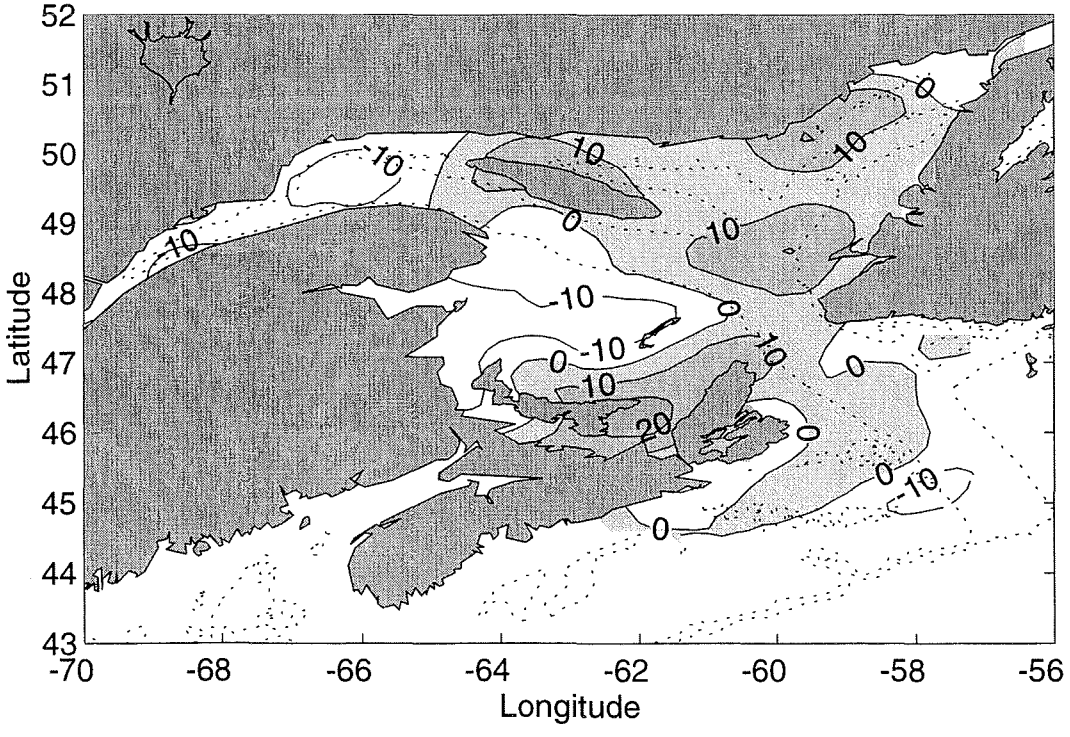
-56
120
100
80
60
40
20


Anomaly of Duration (in Days) - 1997
Latitude
Longitude
52
51
50
49
48
47
46
45
44
43
-70
-68
-66
-64
-62
-60
-58
-56
20
10
0
-10