Fisheries and Oceans Canada | Pêches et Océans Canada

C S A S

Canadian Stock Assessment Secretariat

S C É S

Secrétariat canadien pour l'évaluation des stocks

Research Document 2000/061

Document de recherche 2000/061

Not to be cited without permission of the authors[1]

Ne pas citer sans autorisation des auteurs[1]

Satellite Measurements of Sea Surface Temperature: an Application to Regional Ocean Climate

B. Petrie and C. S. Mason

Department of Fisheries and Oceans, Maritimes Region
Ocean Sciences Division, Bedford Institute of Oceanography
Box 1006, Dartmouth, N.S. B2Y 4A2

[1] This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

[1] La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Research documents are produced in the official language in which they are provided to the Secretariat.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at:

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1480-4883
Ottawa, 2000

Canada

ABSTRACT

We have constructed the monthly sea surface temperature and temperature anomaly maps for four Canadian Atlantic coast regions: the Scotian Shelf, Gulf of St. Lawrence, Newfoundland Shelf and the Canadian World Ocean Circulation Experiment (WOCE) region (35-67^{o}N, 35-77^{o}W). The dataset covers the period January, 1998 to November, 1999 and is derived from satellite infrared radiometry. Throughout most of the region, but particularly over the Grand Banks and the Scotian Shelf, sea surface temperature anomalies have been at or near their highest values since 1981. Twenty sub-areas from Hudson Strait to Georges Bank have been examined in greater detail for the period 1983 to 1999. Overall, 70% of the annual temperature anomalies can be accounted for by two empirical orthogonal modes. The first mode accounts for 52% of the temperature variance with the major contributions from the Newfoundland Shelf, Cabot Strait, most of the Gulf of St. Lawrence and the Scotian Shelf. The second mode, accounting for 18% of the overall variance, is dominated by contributions from the Labrador Sea and Shelf and the northern Newfoundland Shelf.

RÉSUMÉ

Nous avons établi des cartes de la température de surface mensuelle de la mer et des cartes des anomalies de température pour quatre régions côtières de l’Atlantique canadien : le plateau néo-écossais, le golfe du Saint-Laurent, la plate-forme de Terre-Neuve et la région canadienne de l’Expérience sur la circulation océanique mondiale du («WOCE» 35-67ºN, 35-77ºW). Les données couvrent la période qui s’étend de janvier 1998 à novembre 1999, et ont été obtenues par radiométrie infra-rouges par satellite. Dans l’ensemble de la région, mais particulièrement au-dessus des Grands Bancs et du plateau néo-écossais, les anomalies de température de surface de la mer se trouvaient près ou au-dessus des valeurs les plus élevées notées depuis 1981. Vingt sous-zones, du détroit d’Hudson au banc Georges, ont été examinées en détail pour la période de 1983 à 1999. Dans l’ensemble, 70 % des anomalies de température annuelle peuvent être expliquées par deux modes empiriques orthogonaux. Le premier mode représente 52 % des écarts de température avec des apports principaux de la plate-forme de Terre-Neuve, du détroit de Cabot, de la plus grande partie du golfe du Saint-Laurent et du plateau néo-écossais. Le second mode, qui représente 18 % de la variance totale, est dominé par des apports de la mer et de la plate-forme du Labrador et du nord de la plate-forme de Terre-Neuve.

INTRODUCTION

We examine monthly time series of sea surface temperatures (SST) estimated from satellite observations for the period January 1998 to November 1999. This period corresponds to the first 2 years of the Atlantic Zonal Monitoring Program. Specifically, we have prepared monthly sea surface temperature and temperature anomaly maps for the 3 Atlantic zone sub-regions: the Gulf of St. Lawrence, the Newfoundland Shelf and the Scotian Shelf-Gulf of Maine area. In addition, we have prepared an additional set of monthly maps for the entire east coast area from Davis Strait in the northern Labrador Sea to the Middle Atlantic Bight off the United States coast. Twenty sub-areas within the Atlantic zone were chosen for more detailed analysis, similar to Petrie et al. (1999). These sub-areas range from Hudson Strait to Georges Bank and were selected in consultation with the other DFO labs. The long-term monthly means are derived for each sub-area and are subsequently used to derive temperature anomalies. These long-term means and anomalies are compared to in situ data for 3 sub-areas. An empirical orthogonal analysis of the 20 time series of the annual anomalies indicates that only 2 modes are required to account for 70% of the sea surface temperature variability. The modes divide the temperature variation in the overall region into 2 distinct parts.

SST DATABASE DESCRIPTION

Satellite measurements of sea-surface temperature (SST) were obtained from the Physical Oceanography Archive Centre of the Jet Propulsion Laboratory (JPL). This study used the JPL product of weekly global (2048x1024 pixels) 18 kilometre gridded multichannel sea-surface temperature (MCSST) derived from the daytime NOAA Advance Very High Resolution Radiometer (AVHRR). The data cover the period from October 1981 through November 1999. The database is updated irregularly. In the past year, times between updates have been as short as 2 weeks and as long as 3 months; the average interval for the year is 1.5 months. Additional details about the dataset, data processing and accessibility, local calibrations as well as a monthly image catalogue are provided by Mason et al. (1998). For 3 sites, Sta. 27 off St. John's, Emerald Basin on the Scotian Shelf, and Prince 5 at the mouth of the Bay of Fundy, Mason et al. (1998) found good agreement between the ship and MCSST measurements with linear regression slopes of 1.03 to 1.05 (±0.03) and intercepts with a standard error of about 0.3°C. The standard deviations of temperature differences between the MCSST and in situ datasets was less than 1.5^{o} C. They concluded that the dataset was useful in examining long-term changes of ocean sea surface temperature in the region.

MONTHLY SST AND SST ANOMALIES

False colour images of the monthly SST and SST anomalies are available from the authors for the Scotian Shelf-Gulf of Maine, the Newfoundland Shelf, the Gulf of St. Lawrence and the entire Canadian east coast region for the period January 1998 to November 1999. In the interest of cost , we present only 4 selected images of SST and SST anomalies for the Canadian east coast: April and September 1998, March and June of 1999.

Sea surface temperatures were within the normal range for the Scotian Shelf-Gulf of Maine region during the winter of 1998. In April, above normal temperatures developed on the eastern Scotian Shelf and the adjacent slope area. This anomaly persisted until September when average conditions returned. October and November featured an extensive cold anomaly over much of the region. The scattered SST data in early 1999 indicate the development of a 3-5^{o}C above normal temperature anomaly in the slope water. This initial manifestation of the anomaly may have been a northward movement of the shelf-slope front. By March, this anomaly is quite evident and extends from the Tail of Grand Bank to south of Georges Bank; in addition, most of the Scotian Shelf is 1-3^{o}C above normal. By June the temperature anomaly had reached its peak, with a large part of the area 3-5^{o}C above normal. Much of the Scotian Shelf had returned to near normal SSTs by November. A Gulf Stream eddy is evident off the western Scotian Shelf and Georges Bank throughout most of 1999 but particularly in September.

A warm anomaly developed over the southwest slope of the Newfoundland Shelf, St. Pierre and Green Banks by April of 1998, similar to the Scotian Shelf. The anomaly persisted and expanded over much of the region south of 48^{o}N. From the scattered data it appeared to extend eastward beyond Flemish Cap until September. Near or below normal temperatures occurred in September and October. However, warm conditions returned in November along with evidence of the inshore branch of the Labrador Current confined by Avalon Channel. In early 1999, a warm anomaly developed over the Grand Banks and was particularly strong over the southwest continental slope. The anomaly persisted throughout the summer and reached a peak in June when most of the Banks were 3-5^{o}C above normal. The warm anomaly abated slowly, lasting longest over the western Grand Banks until finally disappearing in November.

In the Gulf of St. Lawrence there was considerable data return during the winter months of 1998, implying that ice cover was low and SSTs were above normal. This was the case reported by Drinkwater et al. (1998), who showed the duration of ice cover in the Gulf as much as 45 days less than normal. Throughout most of 1998, SST in the Gulf was generally within the normal range, with occasional warm anomalies (May) followed by cold ones (June). The availability of data in the winter of 1999 also indicated that ice cover was low. A large patch of warm water developed in the eastern Gulf in May, and spread to the Magdalen

Shallows in June and July. Temperatures were also well above normal in September and October.

The data coverage for the Labrador Sea was very spotty but the indication is that above normal conditions, seen from May to August 1998 for Newfoundland waters in particular, also occurred in the Labrador Sea. However, in 1999 when the Scotian Shelf, the Gulf of St. Lawrence and the Newfoundland Shelf were experiencing anomalies up to 5^oC above normal, the Labrador Sea seemed to have near normal temperatures.

The outstanding feature of this 2 year period is the above normal temperature anomaly that began as early as February 1999 over the Scotian Shelf and Slope and the Newfoundland Shelf and Slope and lasted until October. This is consistent with the above normal air temperatures found throughout the region (Drinkwater et al., 2000).

In addition to the overall analysis of SST and its anomalies, we extracted temperatures for 20 sub-areas within the region (Fig. 1). The annual cycles of temperature were calculated and are displayed as the monthly means of temperature and their standard deviations (Fig. 2). For a given month, we required data from at least 7 years before we calculated a mean and standard deviation. The northern sub-areas of Bravo, Hudson Strait, Nain Bank and Hamilton Bank did not have sufficient data to calculate means for some months. This occurs for two reasons: the JPL data product archives a reduced dataset north and east of 50^o, and ice cover limits the data return during winter and spring in some areas. The histogram of the number of data points for each sub-area shows the broad range of data return, ranging from 524 points for Hudson Strait to 38,970 points for Southeast Shoal (Fig. 3). From the time series and the annual cycle, monthly SST anomalies were calculated (Fig. 4-7). The most northerly regions, grouped in Figure 4, show long-term trends in SST with below normal values in the early 80s, a relatively constant period from the mid-80s to the mid 90s, and above normal temperatures in the past few years. Some of this variability is indicated in the temperature records from the southern Labrador and Newfoundland Shelves. Hamilton Bank and St. Anthony Basin vary most like the northern sub-areas, but the SST over the rest of the Newfoundland Shelf diverges from this behaviour, e.g., the tendency for the early 80s to have above normal temperatures (Fig. 5). Periods of above or below normal temperatures are not as evident in the Gulf of St. Lawrence as they are for the Newfoundland and northern sub-areas (Fig. 6). Striking features of the SST variability on the Scotian Shelf and in the Gulf of Maine are the general trend of decreasing temperature from the early to late 80s and the broad scale warming of the past year (Fig. 7).

The accuracy of satellite-derived ocean temperatures has been a concern for a long time. It is difficult to compare in situ point data with satellite estimates that cover an area of about 1 km^2 at their finest resolution. This difficulty is further compounded because our satellite dataset has been averaged to give a spatial resolution of 18x18 km. Mason et al. (1998) examined this and their results were mentioned above. To address this issue further, we compare the monthly MCSST observations with in situ data for 3 locations: Avalon Channel and Sta. 27, the central Scotian Shelf and Emerald Basin, and the Bay of Fundy and the Prince 5 hydrographic station (Fig. 8, 9). The time series plots indicate that the remotely-sensed SSTs follow the general variation of the in situ data. This is reflected in the positive correlations; however, the values are not very high with a range of about 0.4 to 0.6. These correlations are lower than the individual pixel versus station comparisons presented by Mason et al. (1998). In our case, the MCSST data are taken from a large area relative to the in situ data, e. g., Prince 5 and Sta. 27 are fixed point stations close to shore. Thus, the discrepancies may be caused by the different areas of data recovery for these series. The in situ data are not from the surface, but are an average value from 0 to 5 m compared to a “skin” temperature for the satellite derived measurements. Filtering the data can remove some of the spatial and temporal variations (lower frequency variations tend to have larger scales). The annual anomalies calculated for the 3 intercomparison areas show higher correlations that range from 0.7 to 0.8 (Fig. 10). This plot indicates that the annual anomalies may be the most appropriate to analyse now for the whole of the region.

Empirical orthogonal function (EOF) analysis is an effective and sometimes informative method that can condense the information from a large number of data series into 1 or 2 time series or modes if the original series are correlated at reasonably high levels. We carried out this analysis on the annual temperature anomaly time series for the 20 sub-areas. In order to have complete time series for all sub-areas, we chose the period 1983-1999. The first 2 modes can account for 70% of the overall temperature variance (Table 1). Mode 1 captures 52% of the overall variance, with the largest contributions coming from Avalon Channel, Green-St. Pierre Bank, Cabot Strait and the eastern Scotian Shelf; for these areas, mode 1 accounts for 80-90% of the SST variability. With the exception of the Estuary, mode 1 describes 50-60% of the variability in sub-areas of the Gulf of St. Lawrence, about 60% in the central and western Scotian Shelf, and 35-40% for the sub-areas in the Gulf of Maine. The strength of the mode tapers to the north, accounting for 68% of the variance on the Northeast Newfoundland Shelf but dropping to about 33% in St. Anthony Basin and Hamilton Bank. Mode 2 is the northern mode, accounting for 35 to 74% of the variance from St. Anthony Basin to Hudson Strait on the shelf, to Bravo in the middle of the Labrador Sea.

We have plotted the time series that have most of their variance accounted for by modes 1 (southern group of sub-areas) and 2 (northern group) in the upper two panels of Fig. 11. Also shown are the time series variations of modes 1 and 2. The similarity of the time series grouped in this way and the modal variations is evident. These modes condense the SST variations in the 20 sub-areas into 2 groups, one with sub-areas found mainly north of the Grand Banks and one with sub-areas located on and to the west of the Grand Banks.

Fig. 3 showed that the northern sub-areas had far fewer data points than the southern ones. To obtain some confirmation of the EOF results, we extracted in situ data for the 1981-1999 period for the sub-regions Hudson Strait, Nain Bank, Hamilton Bank, Bravo, St. Anthony Basin and the Northeast Newfoundland Shelf. Of these only Hamilton Bank, St. Anthony Basin and the Northeast Newfoundland Shelf had sufficient data for a comparison, i.e. observations were required for at least 7 years before we would calculate a long-term monthly mean and anomaly and subsequently calculate an annual anomaly. We extended the in situ data retrieval for Bravo to a larger area (57N, 45W; 62N, 53W; 60N, 57W; 56N, 52.5W; 55N, 47.5W) in order to obtain a comparison with at least one far northern site. The number of data points (in situ, MCSST) for the Labrador Sea was (264, 689), Hamilton Bank (673, 2906), St Anthony Basin (1008, 7003) and Northeast Newfoundland Shelf (2482, 23631). The results, positive correlations in all cases, are encouraging, particularly for the Northeast Newfoundland Shelf where the correlation between the 2 datasets is 0.82. The correlations are 0.54 for the Labrador Sea and Hamilton Bank and 0.29 for St. Anthony Basin (the correlation is dramatically influenced by one outlier, without it, the correlation is 0.77) (Fig.12).

CONCLUSIONS

Satellite derived data can provide the broad temporal and spatial coverage that is difficult to achieve with sea-going vessels and moored instruments. However, the dataset we have examined is limited to sea surface temperature and is not always the most useful one to relate to other variables. Data from ships are required to provide sub-surface measures of physical variables and as a source of ground-truth observations for remotely-sensed data. Nonetheless, the satellite data have provided the broad spatial and temporal coverage that revealed the inception, spreading and variation of the large-scale temperature anomaly seen in most of the southern portion of our region of interest in 1999. It also suggested that the initial manifestation of this anomaly could have been the northward movement of the shelf-slope front. The subsequent development on the shelf regions could have been caused by the unusually warm year with implied large heat transfer from the atmosphere to the ocean. Analysis of the annual temperature anomalies also suggested that the SST climate in the area has been changing mainly in 2 spatial patterns: one located in the northern part, the second in the southern zone. Sea surface temperature data will continue to provide a set of observations that can facilitate the interpretation of observations from ships and moored instruments.

In the coming year, we would like to pursue more rigorous comparisons between satellite and in situ data. In addition, we hope to examine the higher spatial resolution AVHRR Pathfinder dataset which also provides better data return from the northern parts of our region.

ACKNOWLEDGEMENTS

The MCSST data are provided at no charge by the Physical Oceanography Archive Centre, Jet Propulsion Laboratory, Pasadena, USA. D. N. Gregory developed and H. Hayden maintains the DFO database used in this paper. Thanks are given to D. Gregory and K. Drinkwater for reviewing the report and providing helpful comments.

REFERENCES

Drinkwater, K., R. Pettipas and W. Petrie, 1999. Overview of meteorological and sea ice conditions off eastern Canada during 1998. CSAS Res. Doc. 99/51, 28 pp.

Drinkwater, K., R. Pettipas and W. Petrie, 2000. Overview of meteorological and sea ice conditions off eastern Canada during 1999. CSAS Res. Doc. 00/59, 27 pp.

Mason, C. S., B. Petrie and B. J. Topliss, 1998. Satellite Measurement of Sea-Surface Temperatures and the Study of Ocean Climate. Can. Tech. Rep. Hydrogr. Ocean Sci. 193, vii + 101 pp.

Petrie, B., P. Yeats and P. Strain, 1999. Development of a sea surface temperature index for the Canadian east coast; nutrient and dissolved oxygen variability on the Scotian Shelf a: a preliminary report from the zonal monitoring program. CSAS Res. Doc. 99/57, 16 pp.

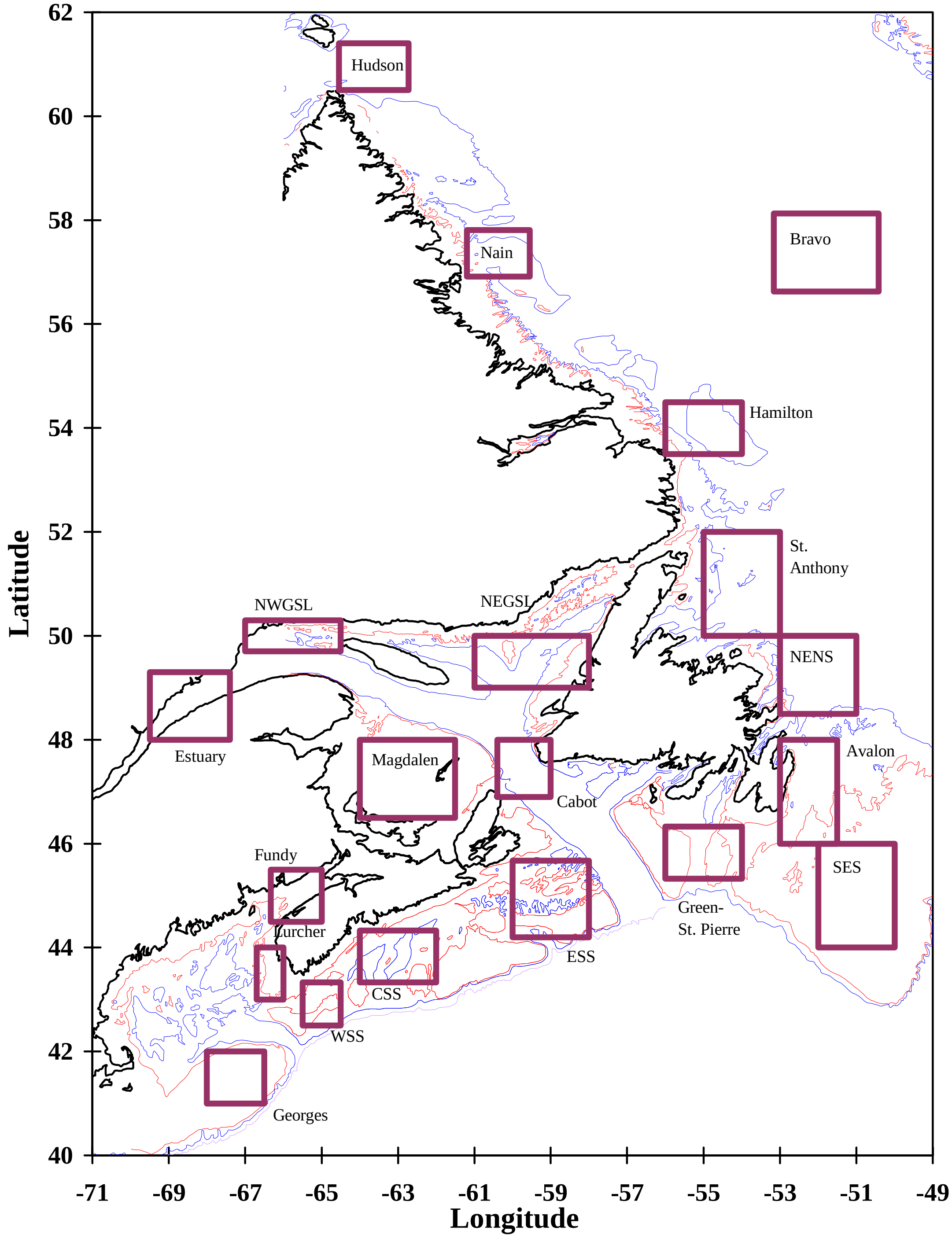


Figure 1. Twenty sub-areas of the Canadian east coast selected for detailed analysis.

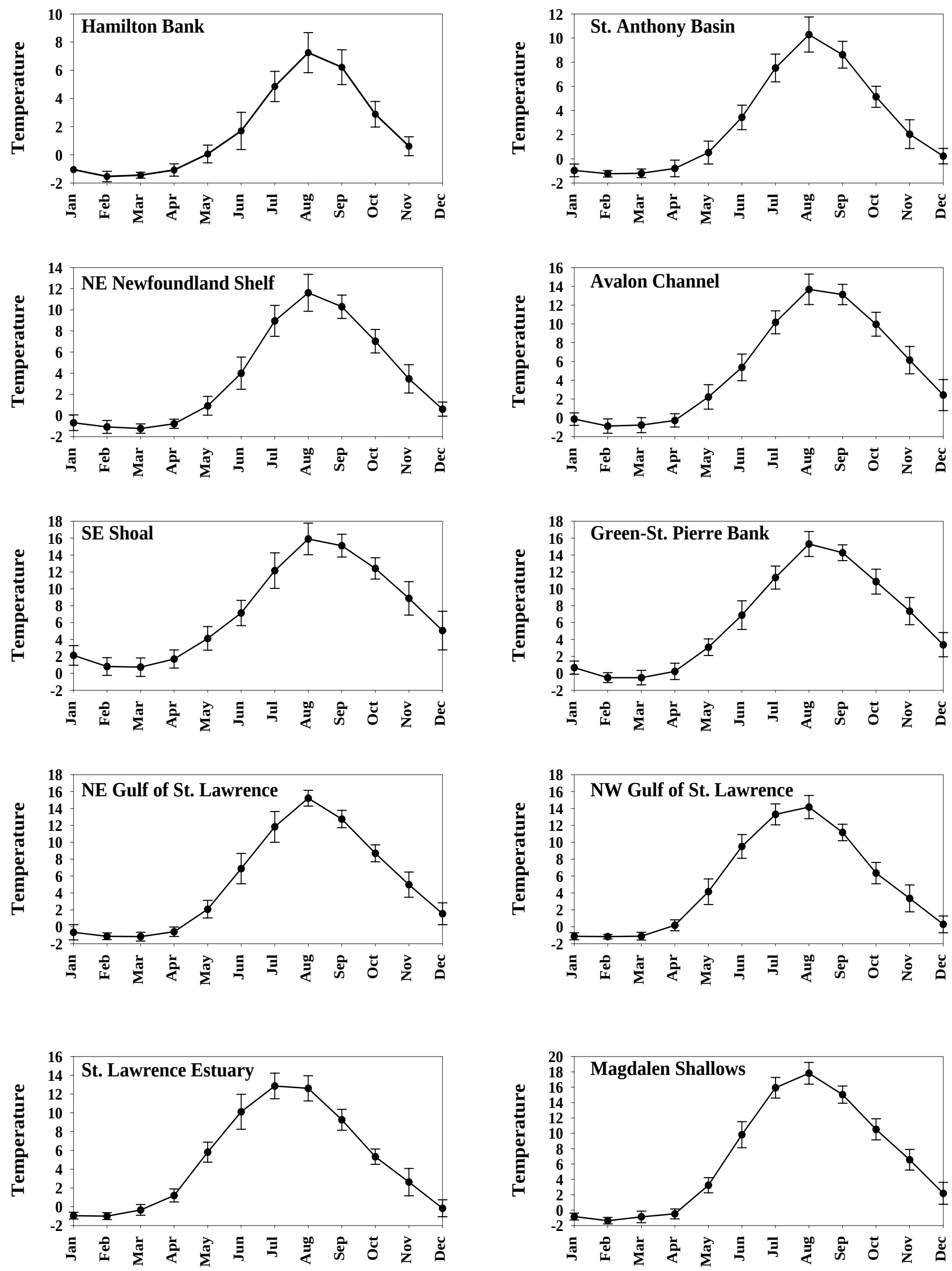


Figure 2. Long-term monthly means and standard deviations of sea surface temperature for 20 sub-areas of the Canadian east coast. Statistics are based on 1981-1999 JPL dataset.

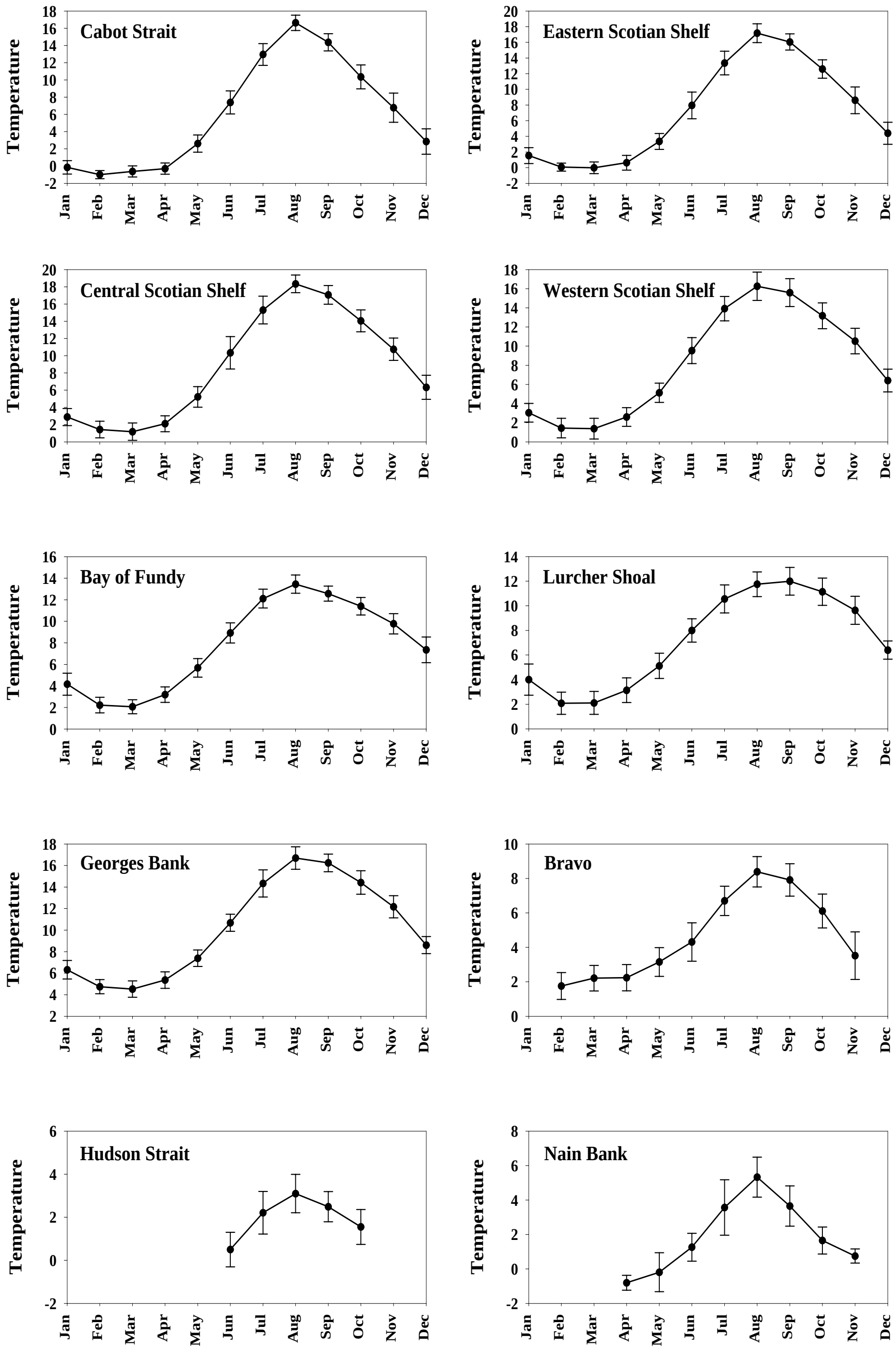


Figure 2. Continued.

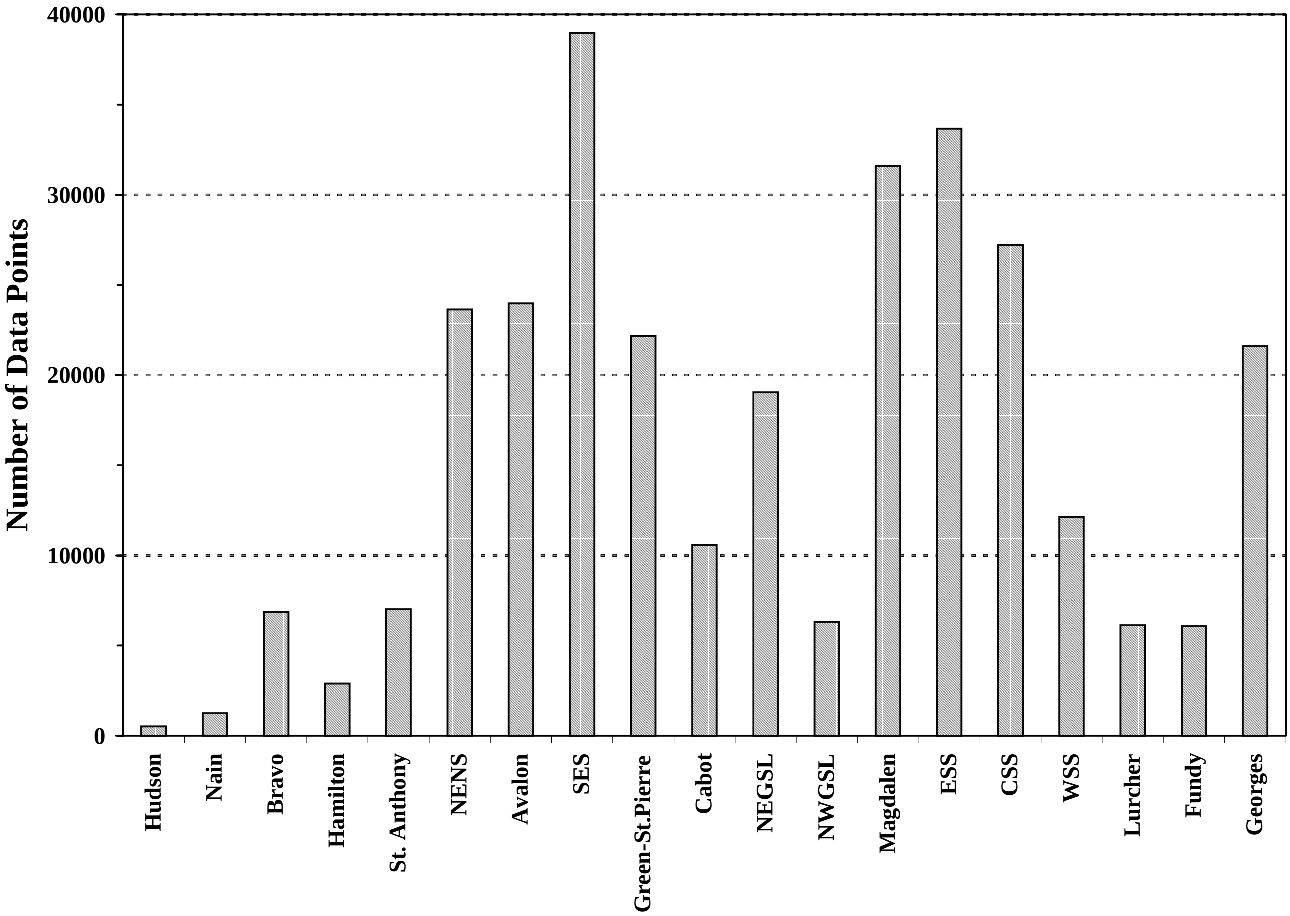


Figure 3. Histogram of total number of data points from the 20 sub-areas.

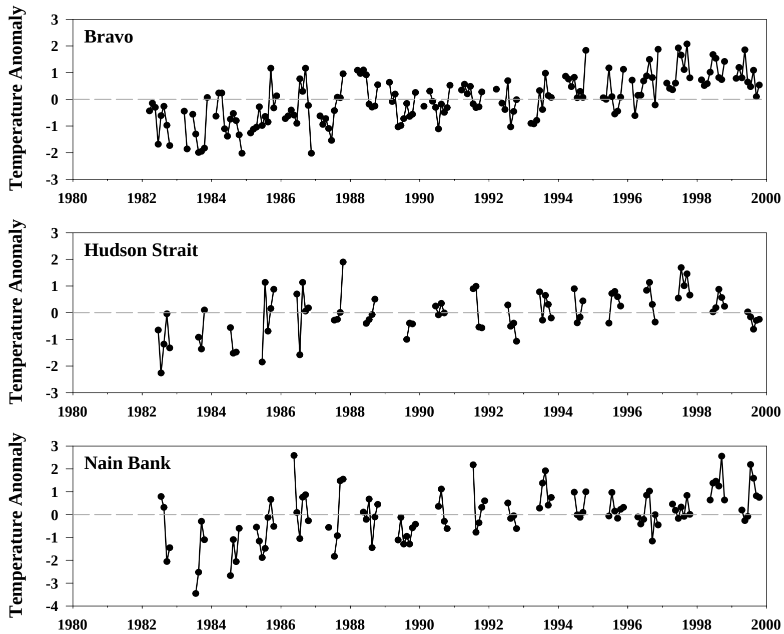


Figure 4. Monthly surface temperature anomalies for the northern sub-areas.

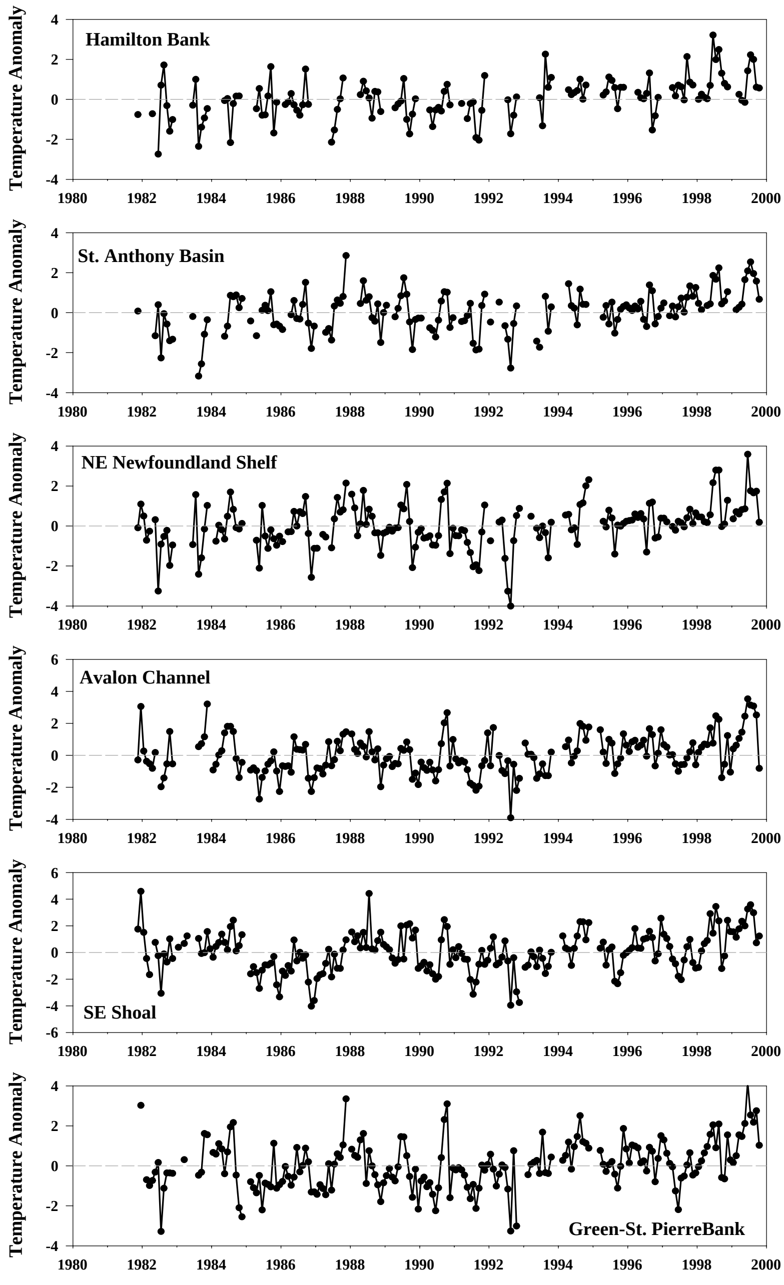


Figure 5. Monthly surface temperature anomalies for the Newfoundland Shelf.

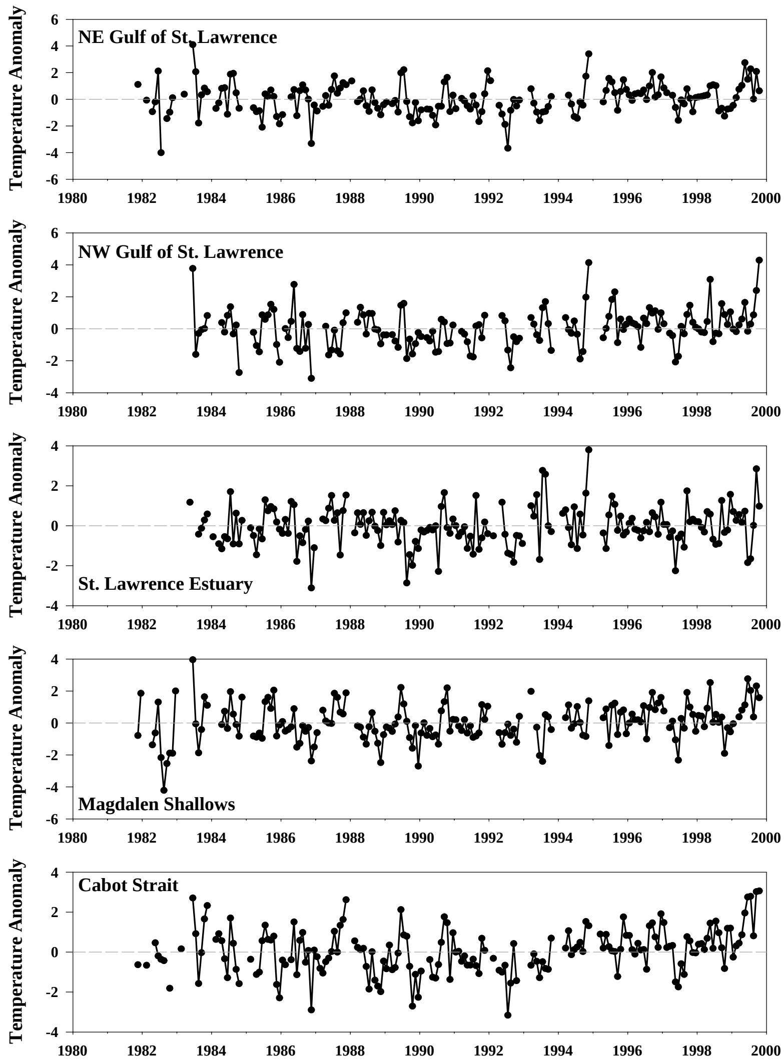


Figure 6. Monthly surface temperature anomalies for the Gulf of St. Lawrence.

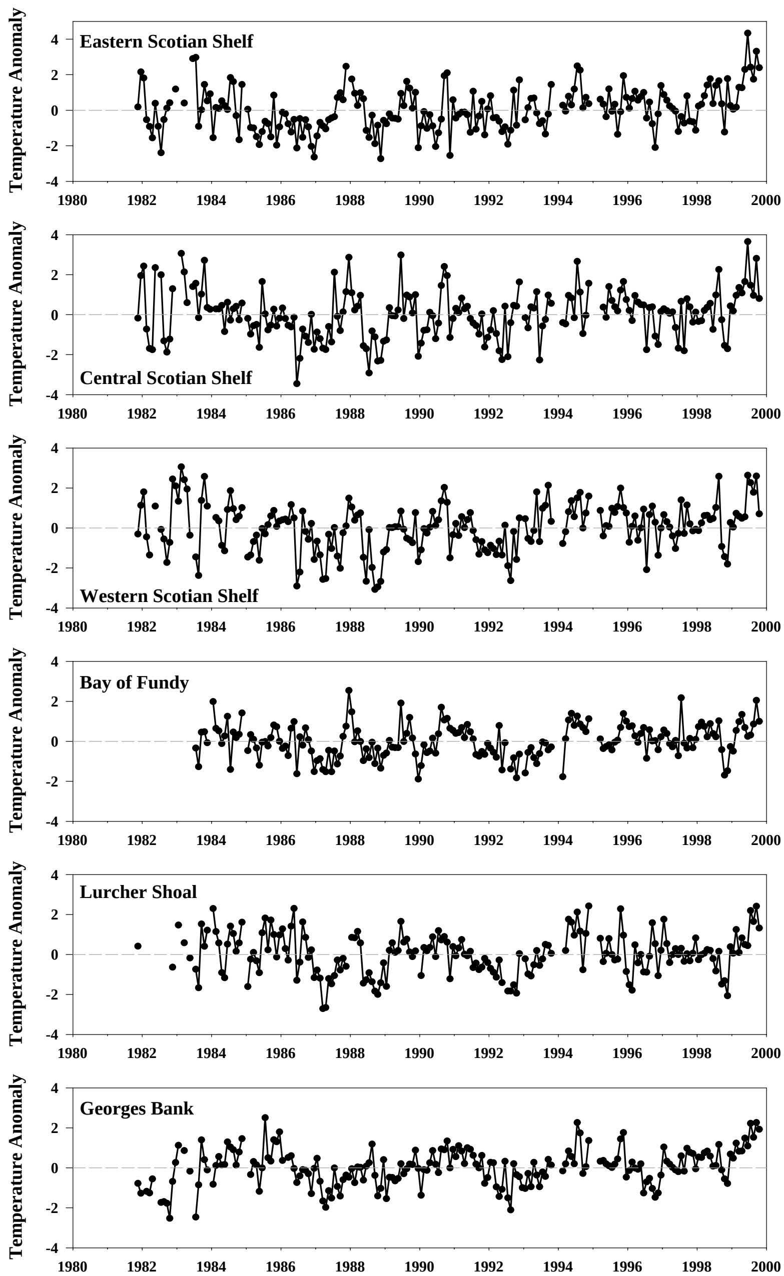


Figure 7. Monthly surface temperature anomalies for the Scotian Shelf-Gulf of Maine.

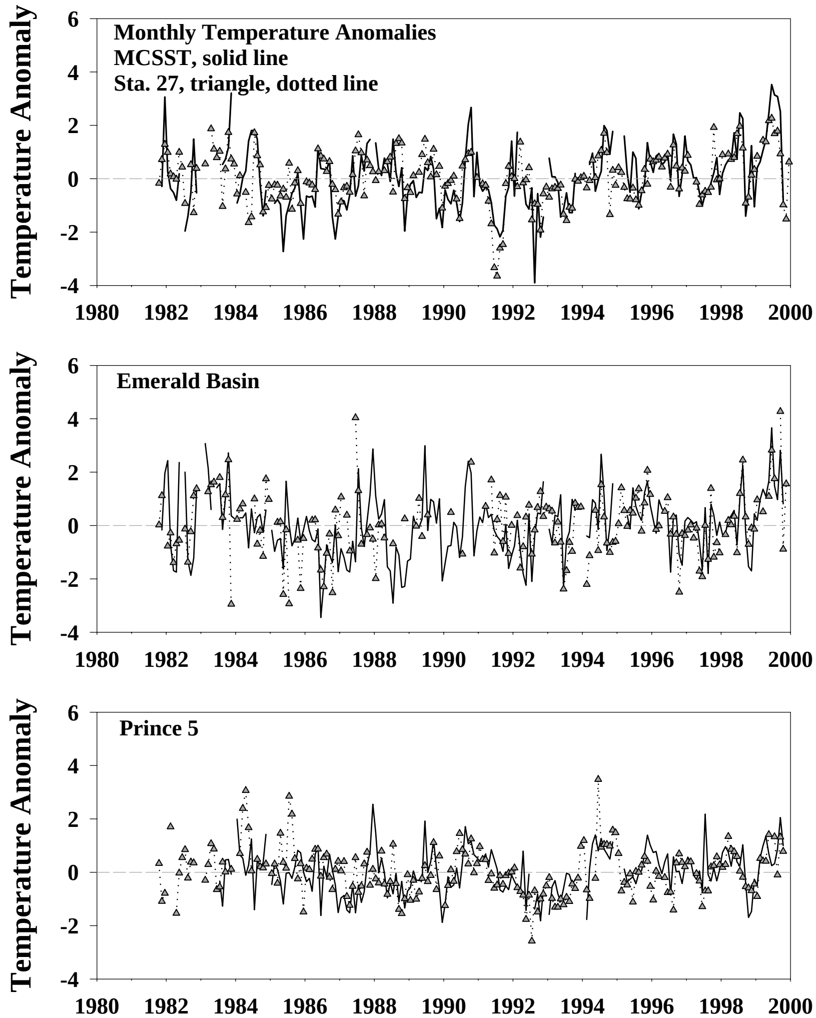


Figure 8. Monthly sea surface temperature anomalies for Avalon Channel and Sta. 27, the central Scotian Shelf and Emerald Basin, and the Bay of Fundy and Prince 5.

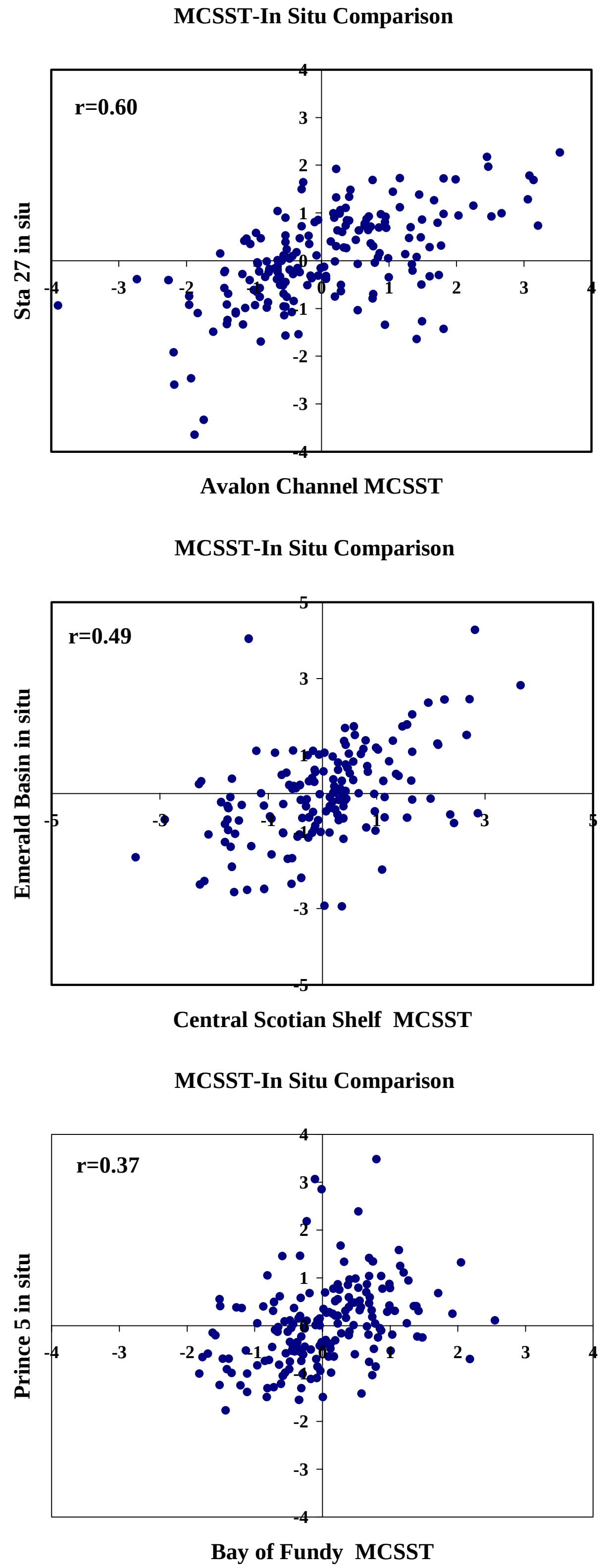


Figure 9. Correlations of monthly temperature anomalies for Avalon Channel and Sta. 27, the central Scotian Shelf and Emerald Basin, and the Bay of Fundy and Prince 5.

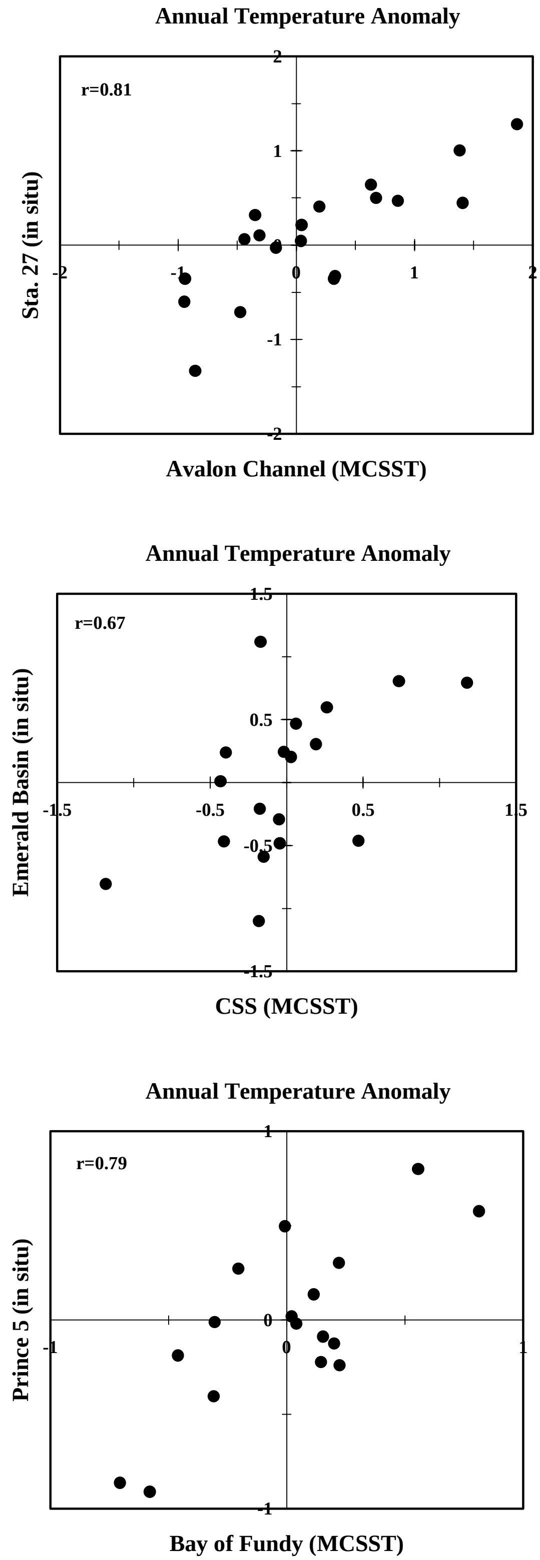


Figure 10. Correlations of the annual temperature anomalies for Avalon Channel and Sta. 27, the central Scotian Shelf and Emerald Basin, and the Bay of Fundy and Prince 5.

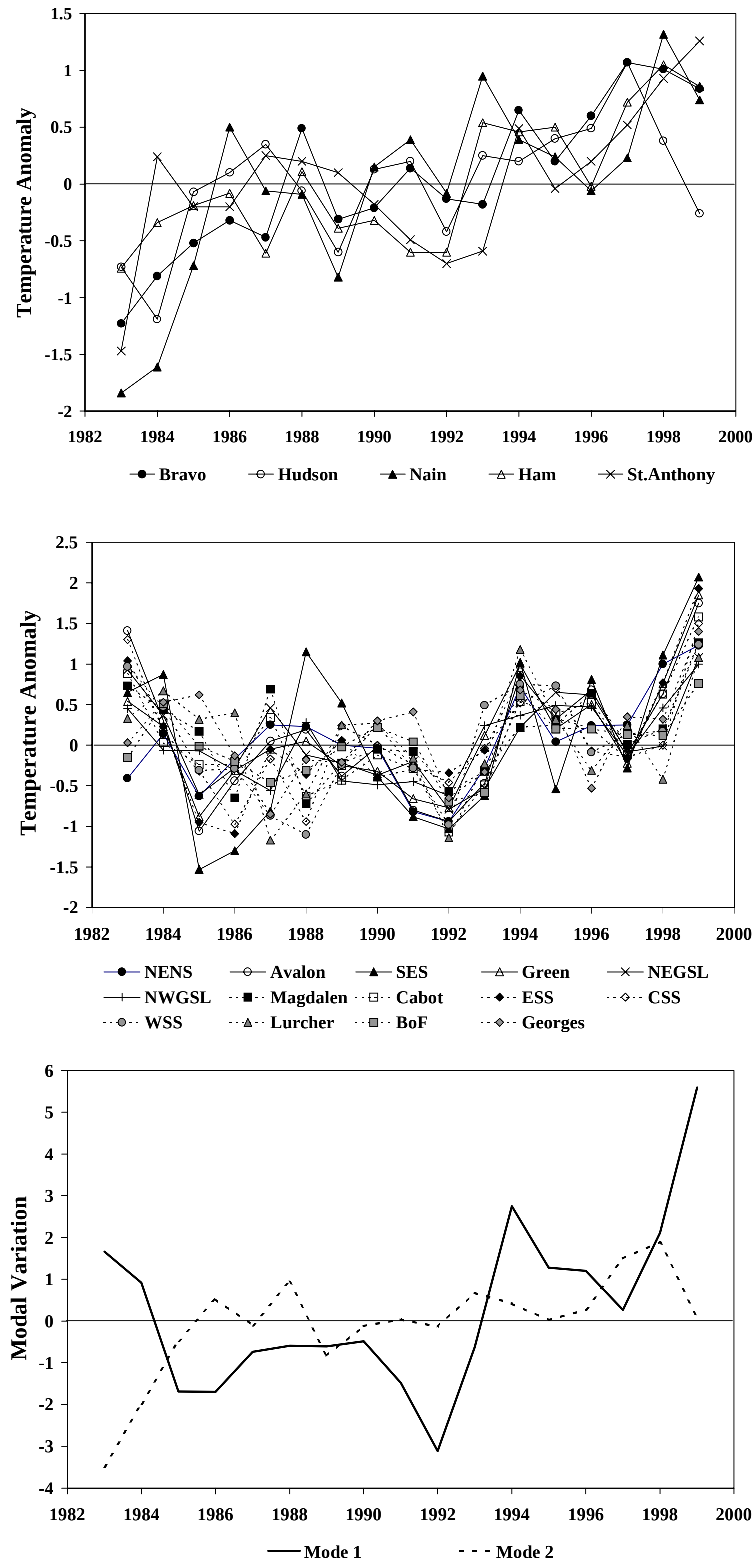


Figure 11. Annual temperature anomalies of the northern sub-areas, southern sub-areas and variations of EOF modes 1 and 2.

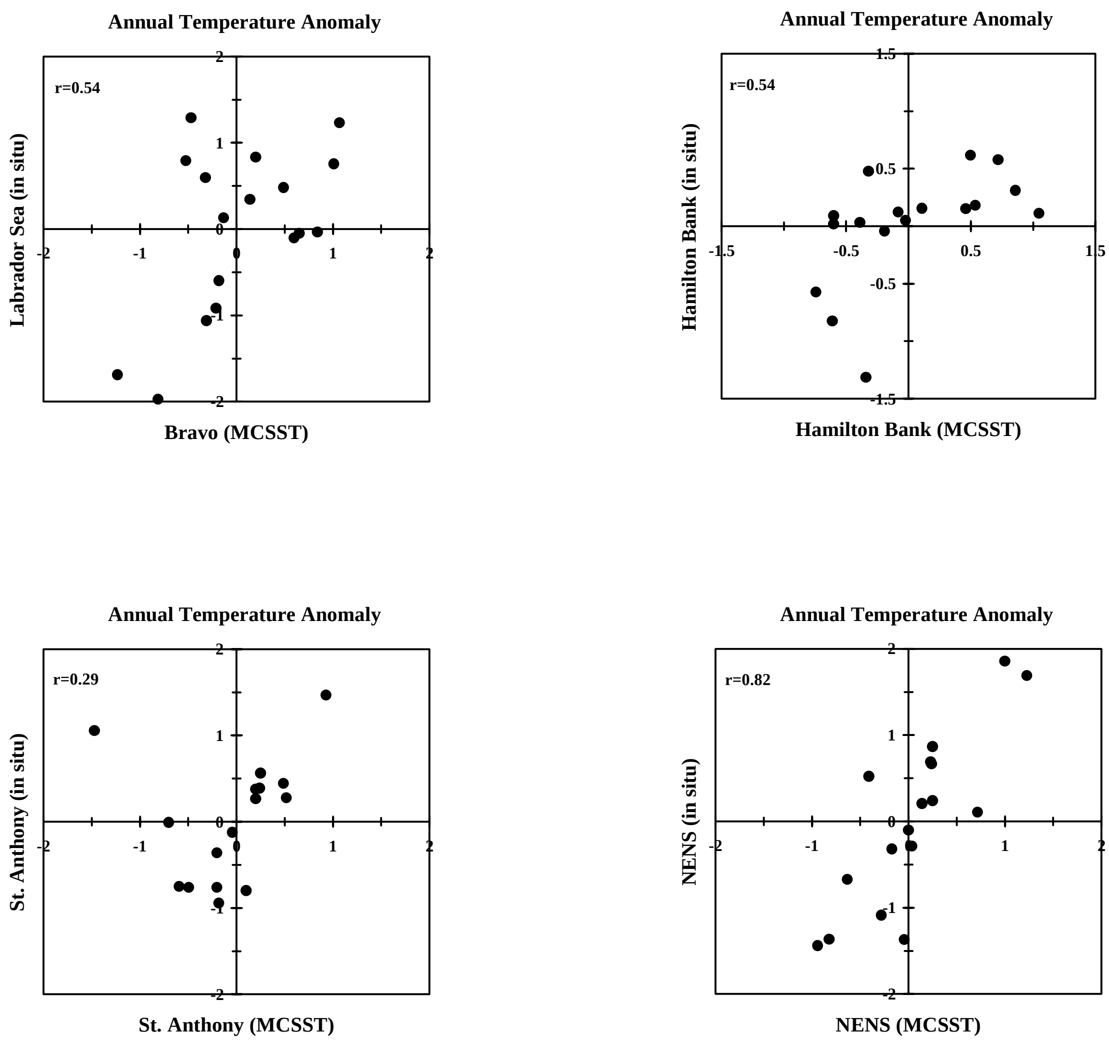
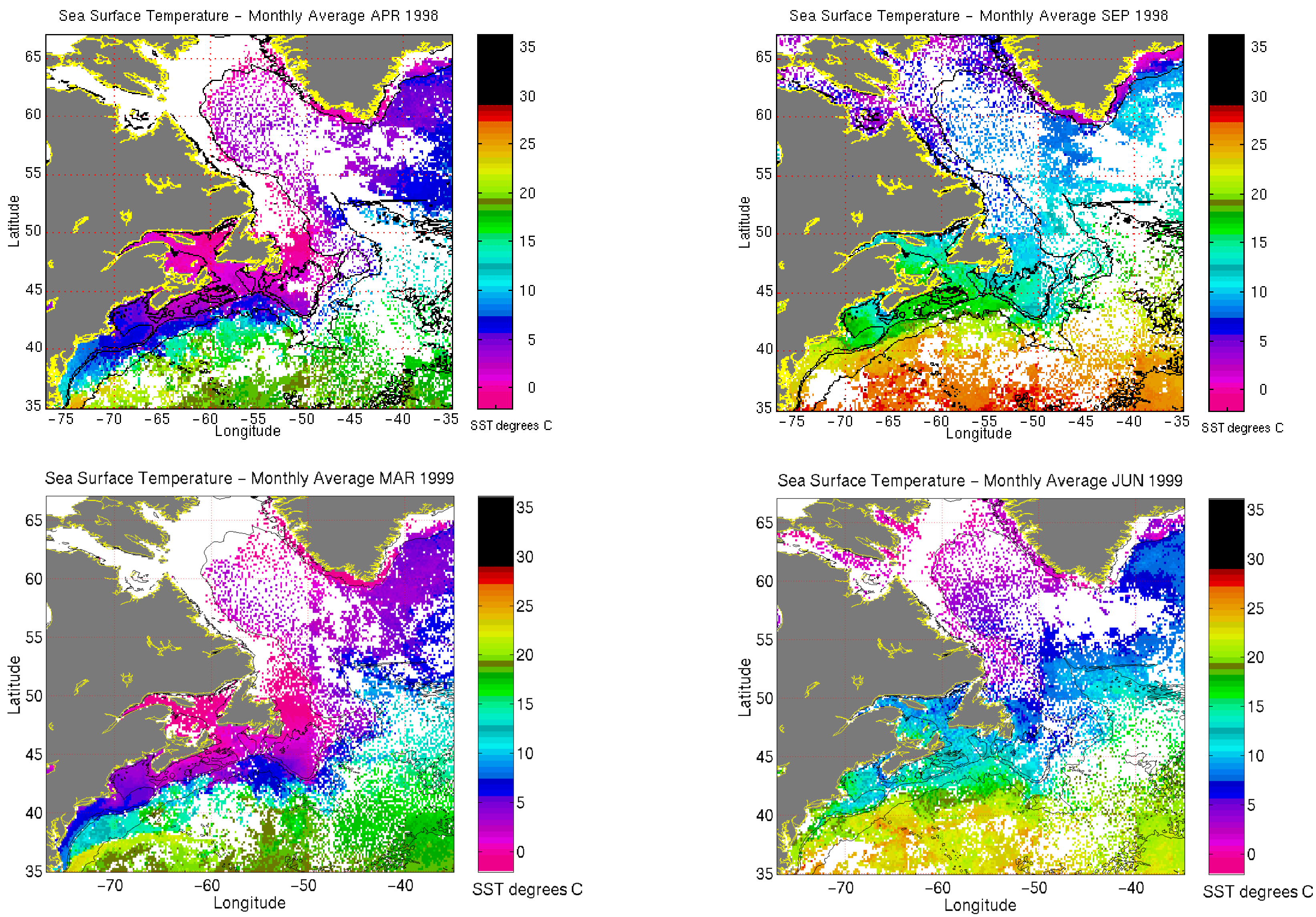
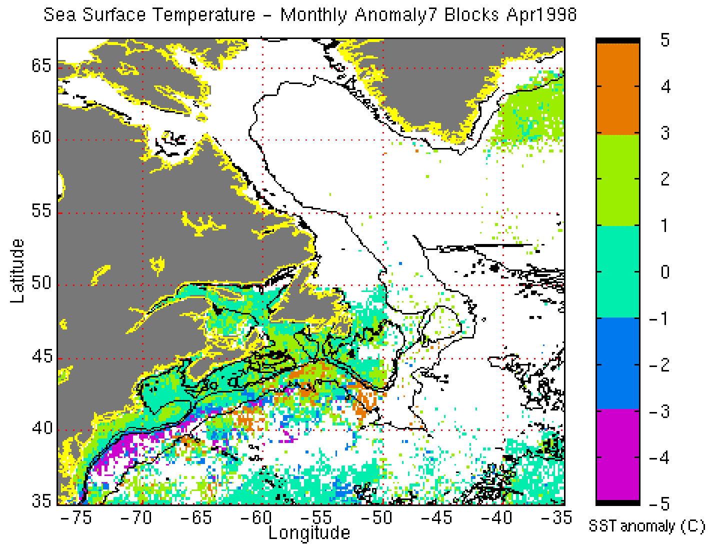
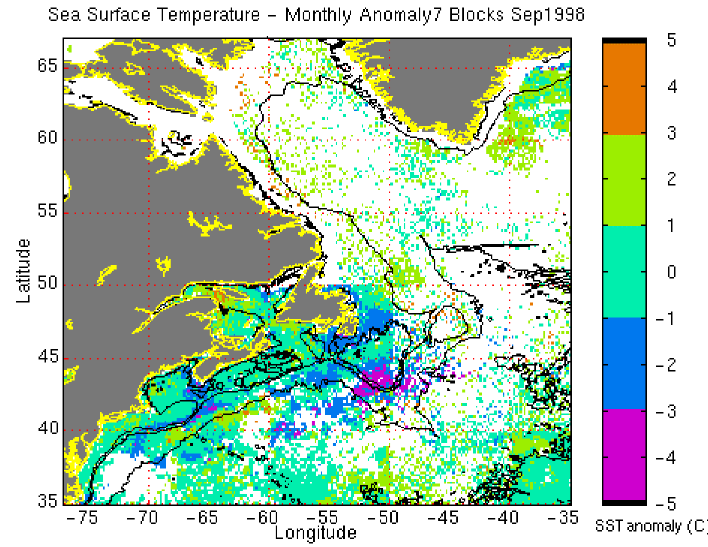


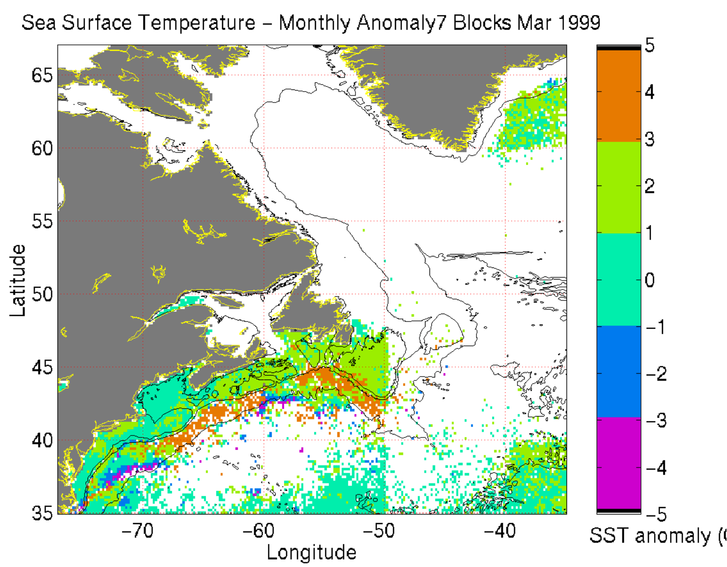
Figure 12. Correlations of the annual temperature anomalies for the Labrador Sea and Bravo, Hamilton Bank, St. Anthony Basin and the Northeast Newfoundland Shelf.

Appendix
Selected Monthly Sea Surface Temperatures and Temperature Anomalies
for the
Western North Atlantic Ocean


Sea Surface Temperature – Monthly Average APR 1998
Latitude
Longitude
SST degrees C
Sea Surface Temperature – Monthly Average SEP 1998
Latitude
Longitude
SST degrees C
Sea Surface Temperature – Monthly Average MAR 1999
Latitude
Longitude
SST degrees C
Sea Surface Temperature – Monthly Average JUN 1999
Latitude
Longitude
SST degrees C


Sea Surface Temperature – Monthly Anomaly7 Blocks Apr1998
Latitude
65
60
55
50
45
40
35
-75 -70 -65 -60 -55 -50 -45 -40 -35
Longitude
5 4 3 2 1 0 -1 -2 -3 -4 -5
SST anomaly (C)


Sea Surface Temperature – Monthly Anomaly7 Blocks Sep1998
Latitude
65
60
55
50
45
40
35
-75 -70 -65 -60 -55 -50 -45 -40 -35
Longitude
5 4 3 2 1 0 -1 -2 -3 -4 -5
SST anomaly (C)


Sea Surface Temperature – Monthly Anomaly7 Blocks Mar 1999
Latitude
65
60
55
50
45
40
35
−70 −60 −50 −40
Longitude
5 4 3 2 1 0 −1 −2 −3 −4 −5
SST anomaly (

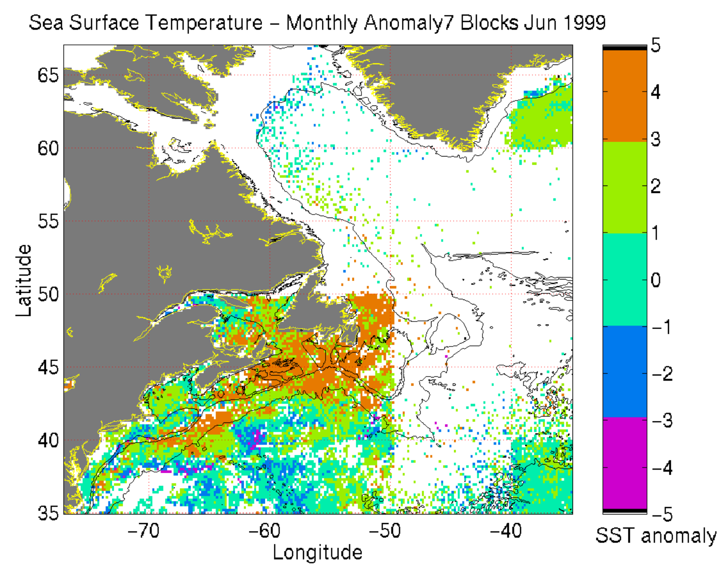

Sea Surface Temperature – Monthly Anomaly7 Blocks Jun 1999
Latitude
65
60
55
50
45
40
35
−70 −60 −50 −40
Longitude
5 4 3 2 1 0 −1 −2 −3 −4 −5
SST anomaly (

Table 1.

Percentage Variance Accounted For				Eigenvectors	
Labrador Shelf and Sea	Mode 1	Mode 2	Modes 1,2	Mode 1	Mode 2
Bravo	17	70	87	0.13	0.44
Hudson Strait	0	56	56	0.00	0.41
Nain Bank	2	74	75	0.05	0.45
Hamilton Bank	34	47	81	0.19	0.36
Newfoundland Shelf					
St.Anthony Basin	33	35	68	0.18	0.31
NE Nfld Shelf	68	15	83	0.26	0.20
Avalon Channel	81	3	84	0.28	-0.09
SE Shoal	56	0	56	0.25	-0.01
Green-St. Pierre Bank	91	0	91	0.29	0.02
Gulf of St. Lawrence					
NEGSL	62	10	71	0.25	-0.17
NWGSL	61	1	62	0.26	0.04
Estuary	15	1	15	0.15	0.04
Magdalen Shallows	53	10	63	0.24	-0.18
Cabot Strait	82	2	84	0.28	-0.07
Scotian Shelf					
Eastern SS	81	3	83	0.28	-0.09
Central SS	62	19	81	0.24	-0.23
WesternSS	61	6	67	0.25	-0.13
Gulf of Maine					
Lurcher Shoal	36	5	40	0.19	-0.11
Bay of Fundy	35	0	35	0.24	-0.01
Georges Bank	39	0	39	0.20	0.00
Overall	52	18	70		