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SATELLITE MEASUREMENT OF SEA-SURFACE TEMPERATURE AND THE STUDY OF OCEAN CLIMATE

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Canada B2Y 4A2

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ABSTRACT

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We present the monthly climatologies and surface temperature anomaly maps for four regions: the Scotian Shelf, Gulf of St. Lawrence, Newfoundland Shelf and the Canadian World Ocean Circulation Experiment (WOCE) region (35-67°N, 35-77°W). The dataset covers the period October, 1981-December, 1996. Comparisons of *in situ* and satellite-derived temperatures over a range of -1.7 to 17.8°C indicate that the two datasets agree to within 1.45°C; this error represents the largest standard deviation of the temperature differences. Analysis also indicates that there is a small advantage (up to 0.2°C) to be gained by dividing the full temperature range into two sub-ranges. The amount of variance in the *in situ*, monthly temperature anomalies that can be accounted for by the satellite-derived data varies in the region from 0 to 42%; whereas, the satellite data can account for 25-81% of the annual surface temperature anomalies. The amount of variance that can be accounted for decreases with increasing depth. The data and the images created from them are available both as a database and as an image archive including WEB access.

RÉSUMÉ

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

Nous présentons les climatologies et les cartes d'anomalies de la température superficielle mensuelles pour quatre régions : plate-forme Néo-Écossaise, golfe du Saint-Laurent, plate-forme de Terre-Neuve et région canadienne de WOCE (35-67° N, 35-77° W). L'ensemble de données couvre la période d'octobre 1981 à décembre 1996. Les comparaisons des températures mesurées *in situ* et tirées des observations satellitaires sur une plage de -1,7 à 17,8 °C montrent que les deux jeux de données concordent avec un écart inférieur à 1,45 °C; cette erreur représente l'écart-type le plus élevé des différences de température. L'analyse révèle en outre que l'on a un peu avantage (jusqu'à 0,2 °C) à diviser la plage des températures en deux sous-plages. La variance des anomalies des températures mensuelles *in situ* qui peuvent s'expliquer par les données issues des mesures satellitaires varie dans la région entre 0 et 42 %, alors que ces données expliquent 25 à 81 % des anomalies annuelles des températures superficielles. La quantité de variance explicable baisse à mesure que la profondeur augmente. Les données et les images créées à partir de ces données sont disponibles sous forme de base de données et d'archives d'images, et accessibles sur le Web.

1. SST Database Description

Satellite measurements of sea-surface temperature (SST) may be obtained from the Physical Oceanography Archive Centre of the Jet Propulsion Laboratory (JPL). This study used the JPL product of weekly global 18 kilometre gridded multichannel sea-surface temperature (MCSST) derived from the daytime NOAA Advance Very High Resolution Radiometer (AVHRR). The JPL data are available as a global set (2048x1024 pixels) and cover the period from October 1981 through December 1996. Two time series of temperature values are available - one for daytime or ascending orbits and a second for night time or descending orbits. Because the night time data are sparse, only the daytime values were used in this study. Each data file contains a weekly map of gridded temperatures with a spatial resolution approximately 18 km by 18 km at the equator. A buoy match-up dataset has already been used by NOAA to compute global coefficients to calibrate the JPL product for sea-surface temperature. This study was provided with the calibrated satellite data, free of charge, in UNIX tar format on 4mm computer tape. The data can now also be downloaded from a JPL ftp site :

http://podacc.jpl.nasa.gov

The document describing the JPL MCSST sea-surface temperature dataset may also be found at this site. An updated satellite product called Pathfinder is currently being produced but so far only a few years of data have been processed. That future product uses an algorithm tuned to different ranges of atmospheric water vapour content and uses a more selective cloud cover algorithm. JPL describes the two datasets as follows:

The PO.DAAC Advanced Very High Resolution Radiometer (AVHRR) sea surface temperature products include the MCSST and the Pathfinder datasets. Both are derived from the 5-channel AVHRR instruments on board the NOAA -7, -9, -11 and -14 polar orbiting satellites. However, these products differ greatly in temporal resolution, spatial resolution and spatial coverage.

The MCSST data currently exist from 1981 to present. These products are provided as weekly and monthly averages on an equal-angle grid of 2048 pixels/360 degrees (nominally referred to as 18km resolution). These data were derived from the AVHRR Global Area Coverage (GAC) Level 1B data on the NOAA/NESDIS Global Retrieval Tapes, which do not contain the complete set of GAC 1B retrievals. As a result, MCSST datasets may contain fewer data points than expected.

The Pathfinder data are currently being reprocessed using the Version 3 algorithm and only exist between January 1991 and December 1993. However, data calculated using the Version 1 algorithm are available between January 1987 and December 1993. The data are provided as either daily or monthly averages with a spatial resolutions of 4096 pixels/360 degrees resolution (nominally referred to as 9km resolution), 2048 pixels/360 degrees resolution (nominally referred to as 18km resolution), and 720 pixels/360 degrees resolution (nominally referred to as 54km resolution). Pathfinder data are processed using the original 4km AVHRR GAC 1B data, and the Pathfinder algorithm

better handles the presence of clouds. As a result, the spatial coverage of the Pathfinder data is also much improved over the MCSST data.

In this report, we focus on the MCSST dataset because of its superior temporal coverage. We intend to examine the Pathfinder dataset when more becomes available.

2. SST Data Processing

The MCSST product consists of weekly composites; for each global grid point, the average of all MCSST measurements for one week are computed. JPL also provides the number of individual daily measurements available for that week as a second file of "flag" data. A third file contains the global interpolated values, where all missing data points have been replaced by extrapolated/interpolated values. [This third file was not used in this study]. Data were extracted into a set of weekly files for the Northwest Atlantic from October 1981 to December 1996. The extracted area covers from 35°N to 67°N and 35°W to 77°W. This region includes 3.3 million gridded satellite observations; however the temporal and spatial coverage is quite variable. Based on a count by 1 degree squares, the coverage is as high as 85% of all possible observations (15 years, weekly), but on average is closer to 20% with a median count of 12% coverage (~2000 observations within a 1 degree square). The co-ordinates of each grid point, the satellite temperature value and the flag value have been transferred to a FoxPro® database and now form part of the oceanographic data archive available from the Ocean Sciences Division (OSD).

The data have also been processed into a collection of false colour maps, for the entire Northwest Atlantic and for three sub-regions - Scotian Shelf, Gulf of St Lawrence and Newfoundland Shelf. Each map has been produced in both a gif format (for Web page viewing) and an encapsulated postscript version (for publication quality). In addition, weekly maps have been produced for the Scotian Shelf region in both gif and postscript versions. These images can be obtained now from the authors, and the gif versions will be available via links in the OSD Web Pages in the near future at the following address.

http://www.mar.dfo-mpo.gc.ca/science/ocean

3. Monthly Averages

The SST values for production of a time series of monthly images (maps) and for a local data validation were obtained by compiling the individual weekly files into data composites. Typically the JPL weekly files ended on a Wednesday. If that Wednesday fell into a given month, then data from that file were assigned to that month. Hence the number of weeks per month may be either 4 or 5. Each temperature value was weighted by the value of the corresponding flag, i.e., by the number of daily measurements available for that week. Thus a given weekly temperature value based on three measurements was assigned a weight three times greater than a subsequent week in which

there may have been only one measurement. [In other studies the more usual procedure has been to disregard the flag value]. A second analysis indicted there was no statistical difference between a weighted and non-weighted procedure.

4. Validation

NOAA has performed global validations of the MCSST product. However a regional validation acts as a check for local biases. This check might be important in cold water regions and regions with large seasonal changes in water vapour content (see Topliss, 1995). For a regional satellite SST validation, local monthly *in situ* temperatures were accessed from the AFAP database (Petrie et al., 1996a). Though the *in situ* data are subject to error (generally smaller than the satellite derived values), for the purposes of this report we shall consider them to be the standard. Three long term *in-situ* open ocean monitoring sites are maintained by OSD and provide a time series of ship based temperature measurements, on a more or less monthly sampling basis. Since 1981 measurements at these sites have been collected mostly with calibrated CTD (Conductivity-Temperature-Depth) profilers. The shallowest temperature data available, to a maximum depth of 5m, were used. The locations of each of these *in situ* sites and the co-ordinates of the nearest MCSST pixel are given below (Mason & Topliss, 1997). The Emerald Basin site is the climatological area defined by Petrie et al. (1996a). The coordinates for the Basin correspond to Station 3 of the Halifax section, where most of the data were collected for the comparison.

TABLE 1. STATIONS.

	STATION		MCSST	
Station/	Latitude	Longitude	Latitude	Longitude
Prince 5	44.95	66.81	44.82	66.62
Station 27	47.55	52.58	47.46	52.38
Emerald	43.88	62.88	43.95	62.93

These temperature values have been compared to the MCSST monthly averages using the first 14+ years (October 1981-December 1995) in the time series. For the Prince 5 and Station 27 sites, a second comparison was done which included the 1996 data. For a direct comparison with the *in situ* (ship) observations, the weekly JPL values were all given equal weighting. Linear regressions of the form:

satellite temperature = slope * *in situ* temperature + intercept

were performed. A summary of the regression statistics is given in Table 2 and the detailed statistics are given in Table 3. The linear regressions for the three sites are shown in Figures 1a-1c.

TABLE 2. STATION REGRESSIONS.

Station	No. of data	Slope /(error)	Intercept /(error)	Avg. Diff.	Std. Dev.
Prince 5	94	1.04 (0.03)	-0.026 (0.22)	-0.28	1.03
15+ years [1]	102	1.03 (0.03)	0.085 (0.23)	-0.32	1.11
Station 27	66	1.05 (0.03)	0.097 (0.26)	-0.39	1.45
15+ years[1]	76	1.05 (0.03)	0.080 (0.23)	-.040	1.39
Emerald	45	1.03 (0.03)	0.30 (0.38)	-0.55	1.45

[1] D. Gregory (pers. comm.)

The Emerald Basin site is monitored only on an opportunity basis and therefore has a considerably smaller dataset than the other two sites. For all sites, the number of comparisons is considerably less than the maximum number possible from 14 or 15 years of observations. For the regularly sampled Prince 5 and Station 27 sites, this was mainly caused by missing MCSST data. Factors such as poor weather and ice cover contribute to a reduced satellite dataset.

For each dataset there is good agreement between the ship and MCSST measurements with only a small temperature offset (intercept) with a standard error of about 0.3°C. In all the comparisons the slope of the regression is just slightly greater than 1 (the value if datasets were in perfect agreement). The standard deviations of temperature differences between the two datasets is less than 1.5°C. The average difference represents the *in situ* observations minus the satellite values. In addition, there is no statistical difference between the weighted data and the more straight-forward equal weighting of the MCSST data.

It is possible that the MCSST measurements may have a different offset for different portions of the temperature range. This tendency is seen in Figure 1a where MCSST data points at higher temperatures cluster above the regression line; whereas, those at lower temperatures have a greater spread below the regression line. To explore potential non-linearity, the three datasets for the 14.25 year period were combined to form a total of 205 measurements (Table 4). The combined data were then split into two temperature ranges, -1.7 to 8.0°C and greater than 8.0°C to 17.8°C. There is no apparent difference in the regression slope between the MCSST and ship measurements; however, there is a difference of 0.5°C in the intercept (though not significantly different from zero, see Table 4, Figures 2a-2c).

TABLE 4. TEMPERATURE DIVISIONS.

Group	No. of data	Slope /(error)	Intercept /(error)	Avg. Diff.	Std. Dev.
All 3	205	1.04 (0.02)	0.082 (0.15)	-0.37	1.27
-1.7 to 8.0	104	1.03 (0.05)	0.088 (0.17)	-0.16	1.22
>8.0 to 17.8	101	1.00 (0.06)	0.584 (0.71)	-0.59	1.28

Temperatures may be calculated using the three regressions given in Table 4. For higher temperatures (>15°C), the difference between the regression using the entire dataset and that using the upper range only is about 0.2°C. At lower temperatures (~ -1°C) the difference between the all-data fit and that using the lower range is only about 0.02°C. These results suggest that there would be a gain in accuracy at higher temperatures of 0.2°C by using the high temperature regression over the general regression.

The mean difference changes from -0.16 to -0.59 between the lower and upper temperature ranges; examination of the annual temperature cycle illustrates the increase in MCSST values in the warmer months. Figures 2d-2f show the 14.25 year mean annual cycle for each station and the corresponding 14.25 year MCSST annual cycle. In this format, potential temperature range (or seasonal) differences between the satellite and *in situ* data are clearer. In the summer the satellite data records a higher temperature (by approximately 0.4°C); in the winter the satellite shows better agreement with the station values. There may be several reasons behind these differences. The wider range of satellite values may be linked to spatial sampling: the satellite data consist of 4kmx4km observations averaged over an 18kmx18km box. Within the box, there likely are temperature gradients. Only one 4kmx4km value is necessary to give the 18kmx18km average. That reading may occur anywhere within the box, and may therefore represent a wider temperature range; on the other hand, the ships are making spot measurements. The satellites measure the temperature of the top few millimetres of the ocean, the CTD measures the temperature at some depth, typically 1 metre. The surface "skin" as observed by satellites often exhibits a marked temperature difference from the underlying waters. In summer this is related to solar heating under periods of sunny conditions (Topliss, 1995). Since the satellite data can only be collected under cloud-free conditions, this may result in small biases. No specific winter skin effects have been noted in the literature. In general, winter wind activity produces a well-mixed surface layer. If however, light winds preferentially cooled the surface skin, this mechanism would again result in a differential between the satellite and ship measurement.

Another possible explanation for the satellite difference would be the effect of seasonal variations in atmospheric water vapour content: moist/humid air in summer and very dry/cold air in winter. Any summer effects should be minimal as the NOAA calibrations tended to include many southern, warm regions.

5. Average Annual Temperatures

The average annual temperature has been calculated for the three validation sites using both the MCSST data and the ships' measurements. Results are shown in Figure 3. The comparison is made for coincident measurements - only those months which have both an MCSST temperature and ship temperature. There is good agreement between the two datasets. The dashed line also shown is the annual averages using all data from the more complete dataset [i.e., ships' values for Prince 5 and Station 27 and MCSST values for Emerald Basin].

The distributions of measurements by month and by year are shown in Figures 4 and 5. For Prince 5 and Station 27, the number of *in situ* (ship) observations generally exceeds the MCSST data return. On the other hand, for the more remote Emerald Basin site, the MCSST data are the more numerous.

6. Monthly MCSST Climatology

False colour images of the average annual temperatures for the large Northwest Atlantic (full) region and for the three sub-regions are provided in Annex A. Map A07 for the full region shows that for northern latitudes the data are sparse - almost no measurements from November to May. Coverage on the Scotian Shelf is more complete. Coverage up to the shelf break is extensive for all months except December and January. There is almost complete coverage for the entire Scotian Shelf from April to October.

It is necessary because of data scarcity to ensure that a reasonable number of monthly measurements are included before an annual average is calculated. For a given pixel, at least 7 years of data were required before monthly average temperatures and their anomalies were calculated. The averaging value of seven was chosen as the cut-off based on experience with the images and since this choice reduced the spatial noise in the temperature anomaly fields. If all data were included, the "annual average" pixel in some areas would be based on a single year; if measurements in all years were the required, then data for most pixels would be rejected.

Contours of the temperature are also provided in Annex A. Contours are overlaid on the false colour image and also on a blank chart where labels on some of the contours are also provided. These contour distributions of SST show similar features to the distributions derived from ships' data (see Drinkwater and Trites, 1986, 1987; Petrie at al., 1996a, 1996b).

7. Monthly Anomalies

Monthly anomalies of surface temperature were examined for the Prince 5 site which has the greatest number (94) of coincident measurements of temperature. The results are given in Figure 6 and Table 3(G). Although the data are scattered, the correlation is

positive (r=0.44), that is in the correct sense, and hence is encouraging. The standard deviation of the temperature difference for the Prince site (Table 3A) is 1.03 and for the temperature anomaly (Table 3G), 0.92. Given these errors, at best we would expect a correlation of 0.67 for anomalies determined from the MCSST database. False colour images of the monthly anomalies are provided in Annexes B to E. There are obvious variations in the monthly and interannual patterns of surface temperature anomaly which are intriguing. These images along with the validation of MCSST data at the three monitoring sites encourage the use of the MCSST database for more detailed evaluations of monthly and annual variability.

8. Correlations between Surface MCSST and Deeper Temperatures

We also explored the possibility of using the MCSST dataset as a proxy for sub-surface temperature anomalies. The monthly and annual temperature anomalies for the MCSST dataset, and for 0 and 50 m *in situ* observations for the North Avalon Channel as defined by Drinkwater and Trites (1986) are shown in Figure 7. The vertical profiles of the standard deviation, correlation coefficient, slope (in situ temperature = slope*satellite temperature + intercept) and intercept are also shown. The correlation at the surface is 0.52 and decreases quickly to 0.18 at 50 m for the monthly anomalies. The correlation for the annual anomalies is 0.58 for 0 m and decreases more slowly to 0.43 at 50 m. The distributions seen in this figure are fairly typical for the east coast region. Our best correlation, 0.65, was for surface monthly temperature anomalies on the shallow southeastern Grand Bank. Generally, the correlations are highest for the Newfoundland Shelf, somewhat smaller for the Scotian Shelf and are the least for the Gulf of St. Lawrence. This indicates that unless the accuracy of the satellite temperatures can be improved to $< 1^{\circ}C$ or the climate variability increases (typically we found that the standard deviations of the monthly surface temperatures anomalies for 1981-1996 were in the range of 0.8-1.6°C), we can at best account for 42% of the variability of monthly temperature anomalies. On the other hand, correlations improve everywhere for the annual temperature anomalies. Our best correlation for surface temperatures was 0.9 for Emerald Bank. The correlation decreased with depth but in the case of Emerald Bank remained high at 0.82. The MCSST dataset does show more promise in accounting for interannual variability.

9. Summary

The MCSST dataset is useful in determining the annual cycle of temperature to within approximately 1°C in any single month over large areas of our region. The positive and negative temperature anomalies occur in broad continuous patterns in the region indicating consistency in MCSST data. However, comparisons indicate that at best we may be able to characterize about 40% of the monthly surface temperature anomalies. The situation is more promising when it comes to the annual temperature anomalies where tests indicate that we may be able to describe 35-80% of the surface variability. These comparisons were made when a typical monthly (annual) surface *in situ*

temperature anomaly was 1.36°C (0.73°C). Thus, 1981-1996 represents a period of low surface temperature variability. In the past, a greater *in situ* surface temperature variability has been measured. Comparisons between the MCSST dataset and ships' observations should improve during periods of greater temperature anomalies, i.e. when the signal to noise ratio has increased. Finally, satellite data can assist in the interpretation of ships' measurements by broadening the coverage in some localities and also providing data for remote regions.

10. Acknowledgements

The MCSST data are provided at no charge by :

User Services Office
Physical Oceanography Archive Centre (PO.DAAC)
Jet Propulsion Laboratory
M/S 300-320
4800 Oak Grove Drive
Pasadena, CA 91109, USA

D.N. Gregory transferred the data from our database into the Regional DFO FoxPro® database and provided the second validation (unweighted) of the MCSST data for the Station 27 and Prince monitoring sites using the dataset 1981-1996. Thanks are given to Dr. K. Drinkwater and A. Isenor for reviewing the report and providing helpful comments.

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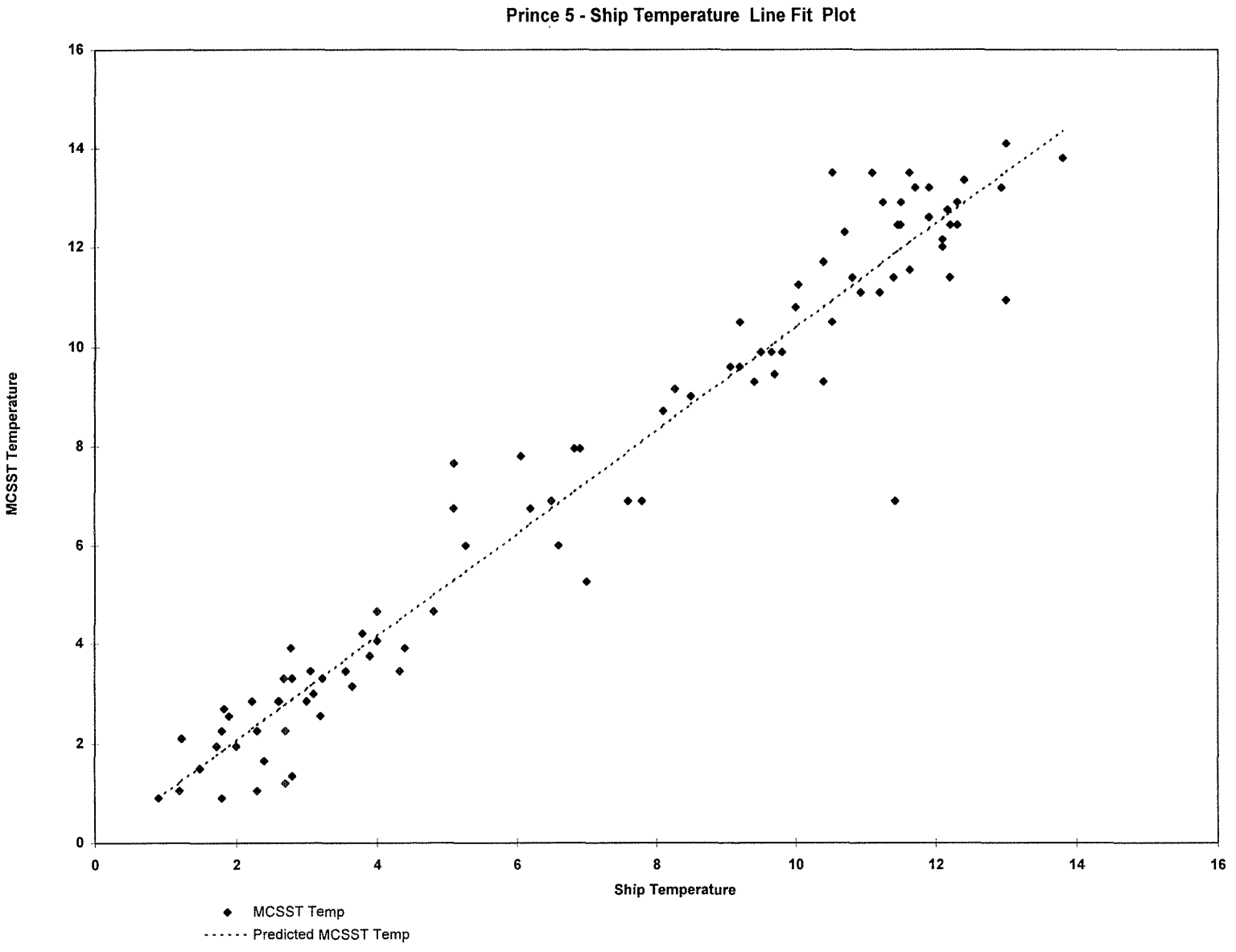


Figure 1a. Comparison between monthly temperature measurements from MCSST and the oceanographic station at Prince 5.

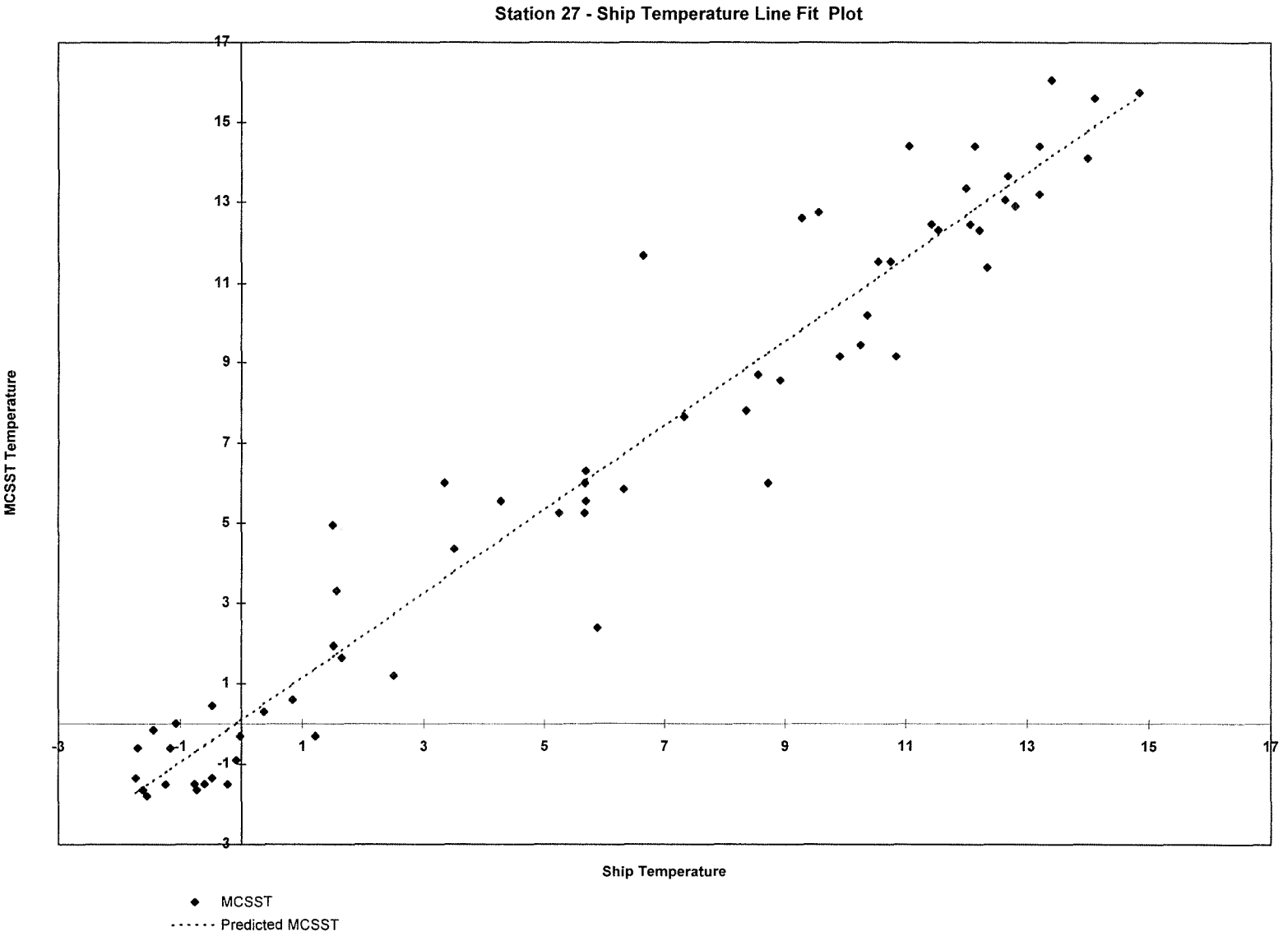


Figure 1b. Comparison between monthly temperature measurements from MCSST and the oceanographic station at Station 27.

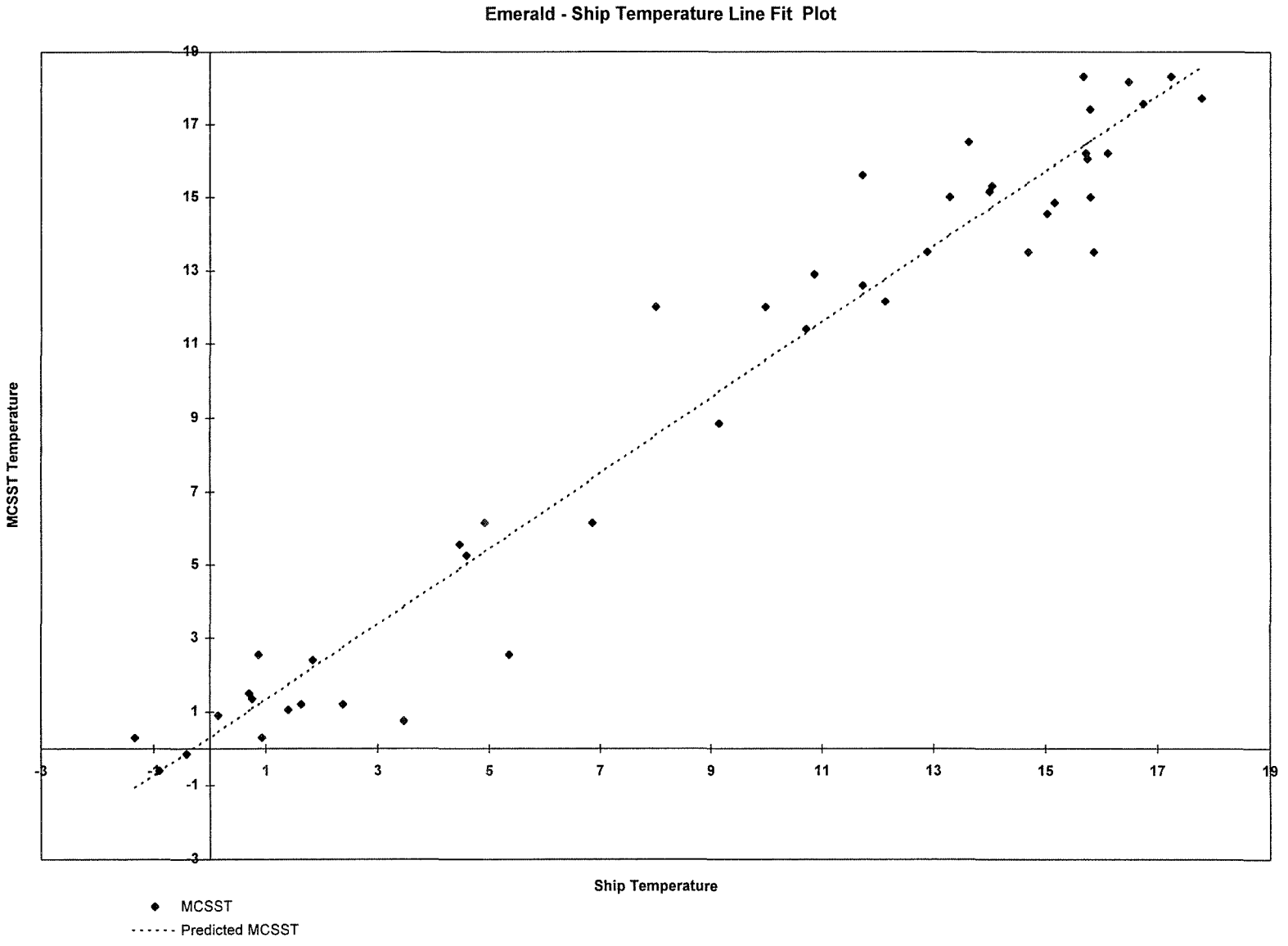


Figure 1c. Comparison between monthly temperature measurements from MCSST and the oceanographic station at Emerald Basin.

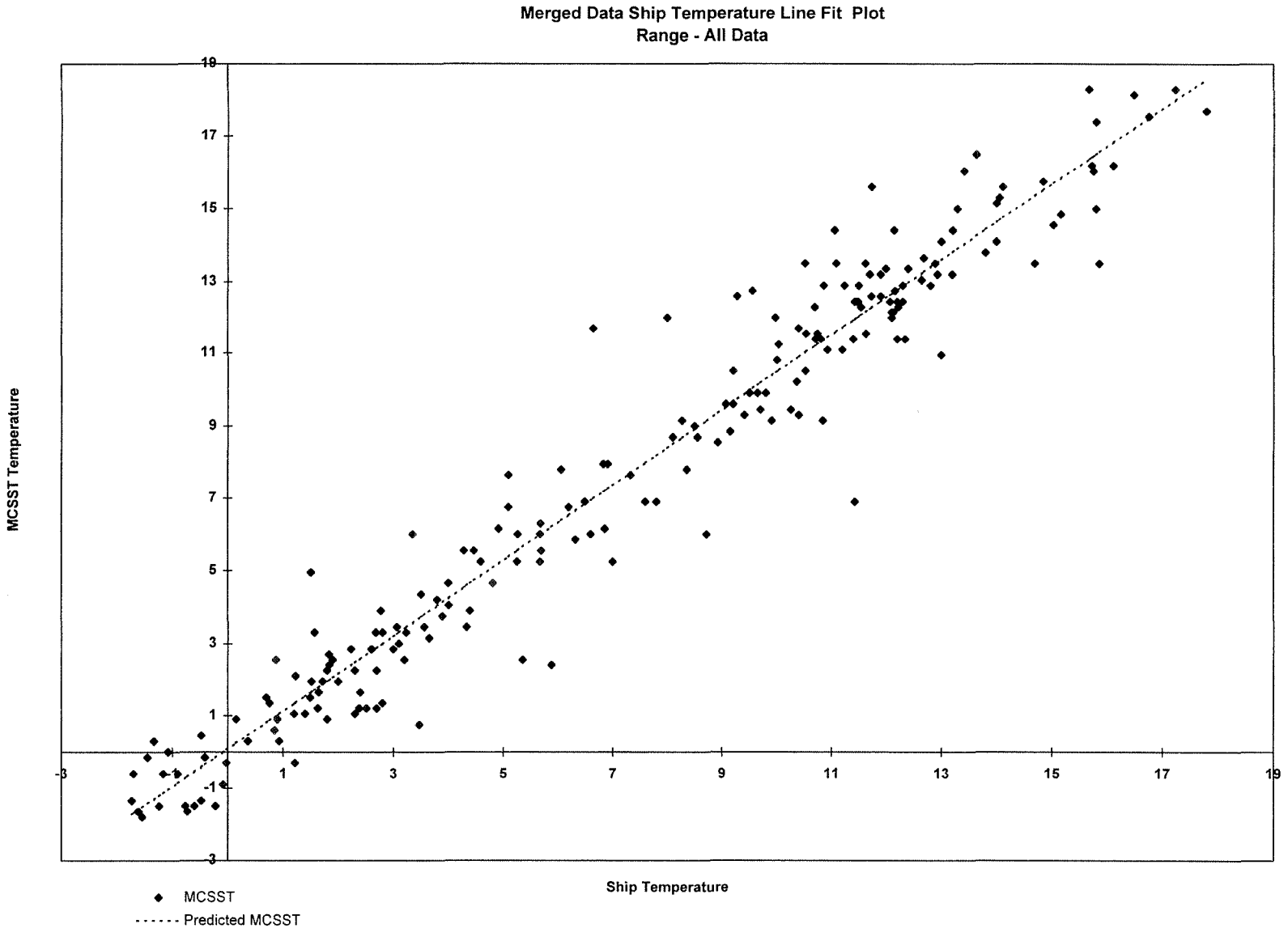


Figure 2a. Comparison of merged temperature data - MCSST and ships' measurements for the 3 stations, full temperature range.

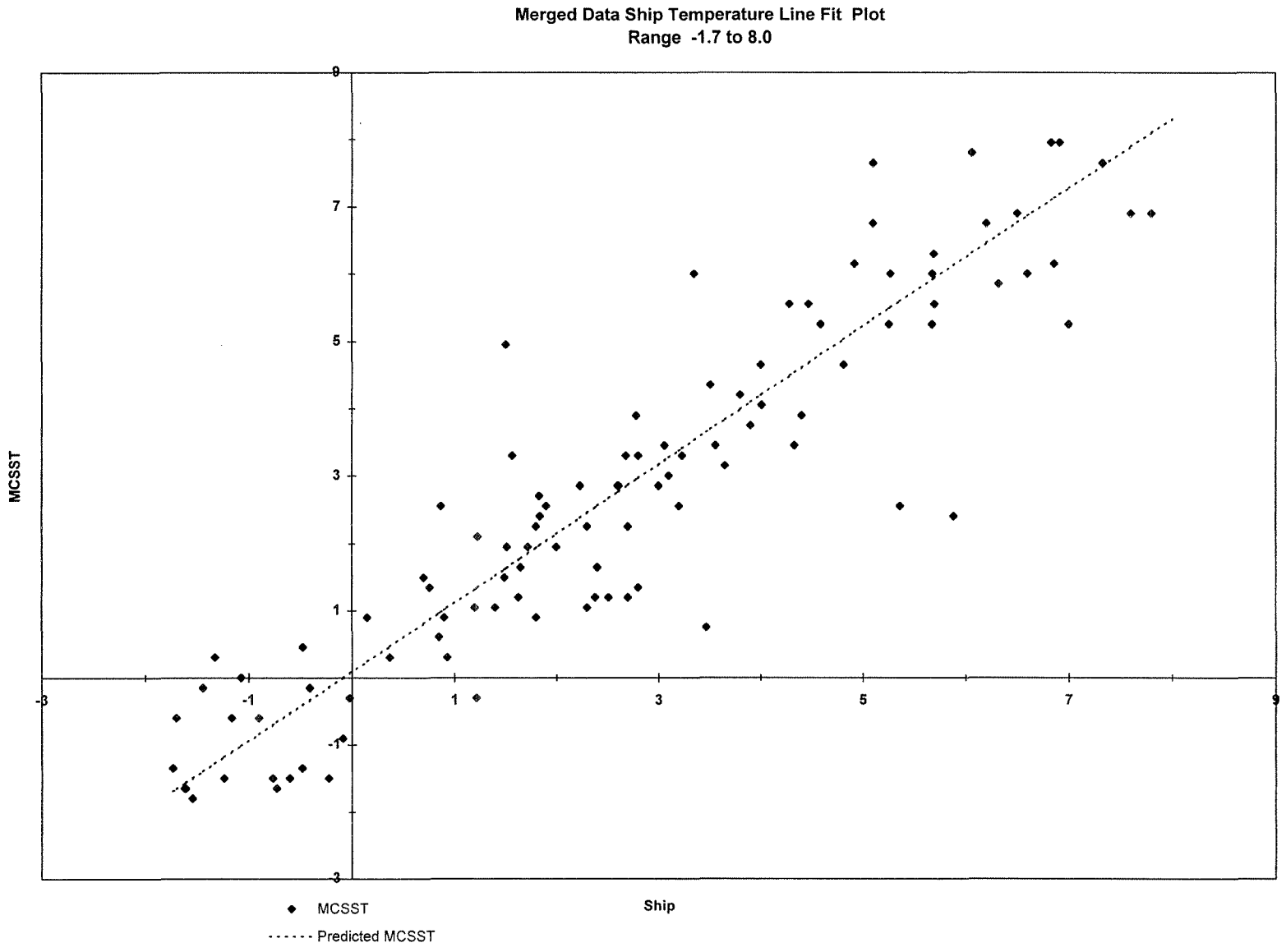


Figure 2b. Comparison of merged temperature data - MCSST and ships' measurements for the 3 stations, lower temperature range.

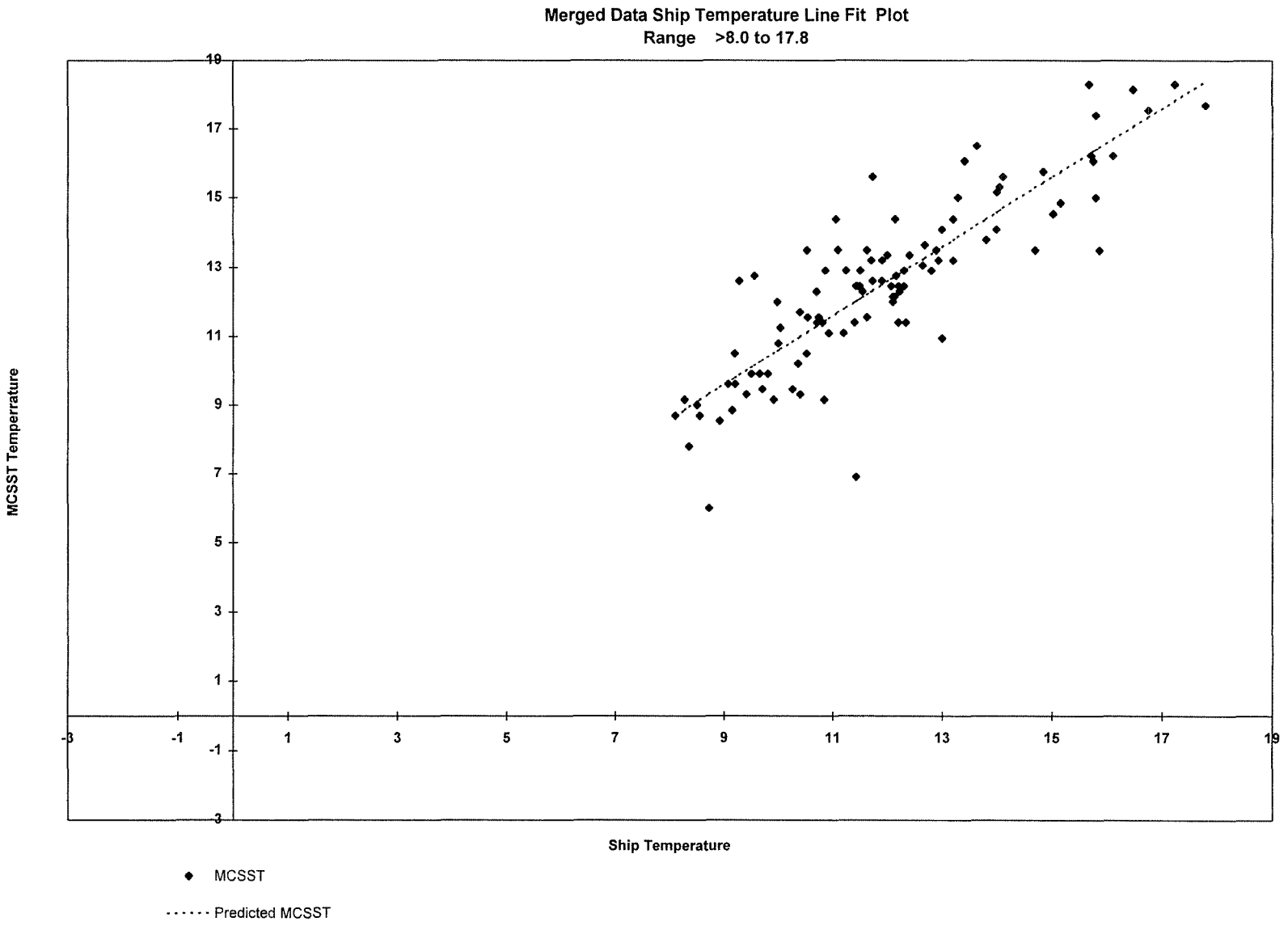
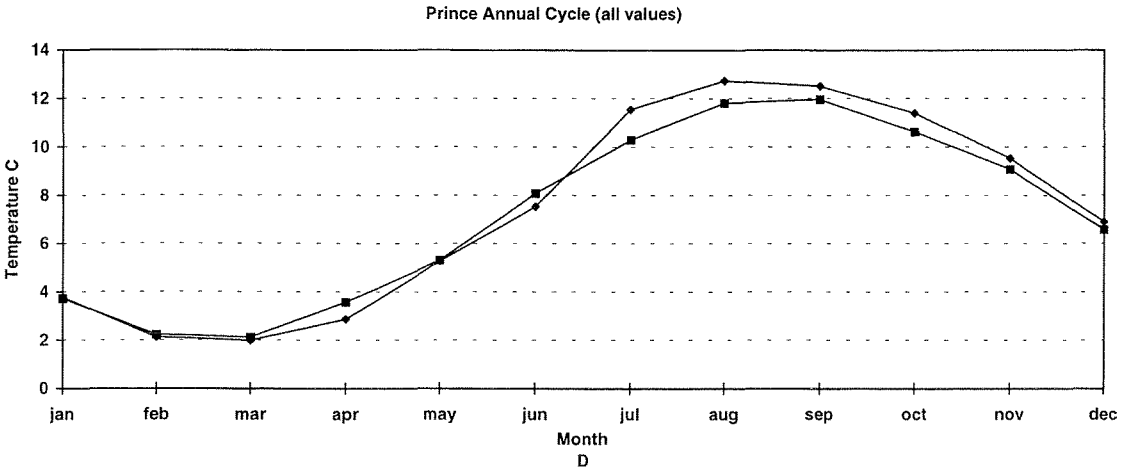
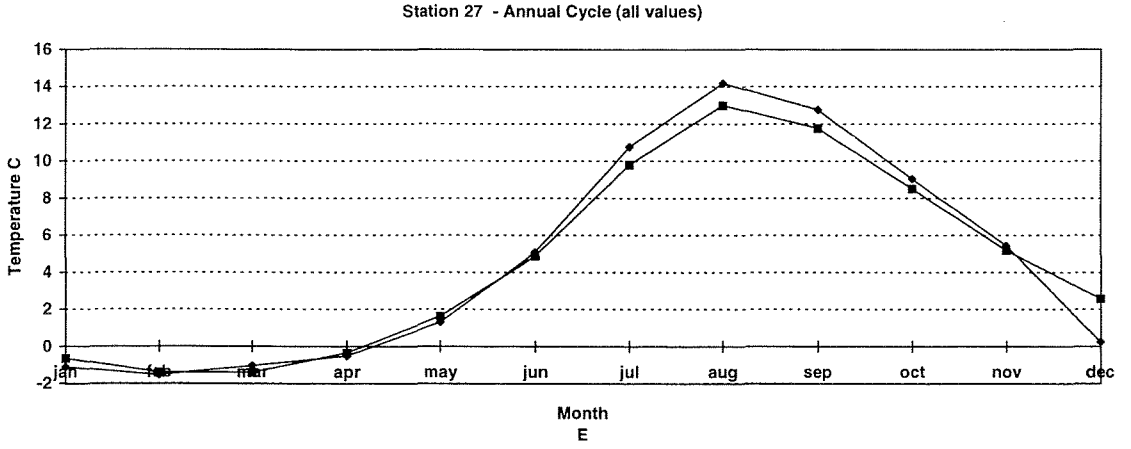


Figure 2c. Comparison of merged temperature data - MCSST and ships' measurements for the 3 stations, upper temperature range.





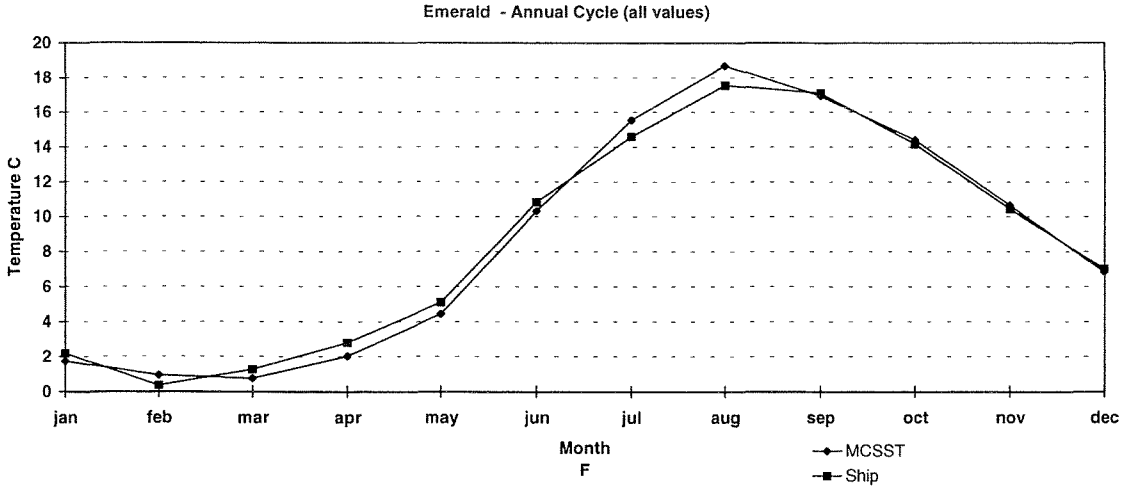
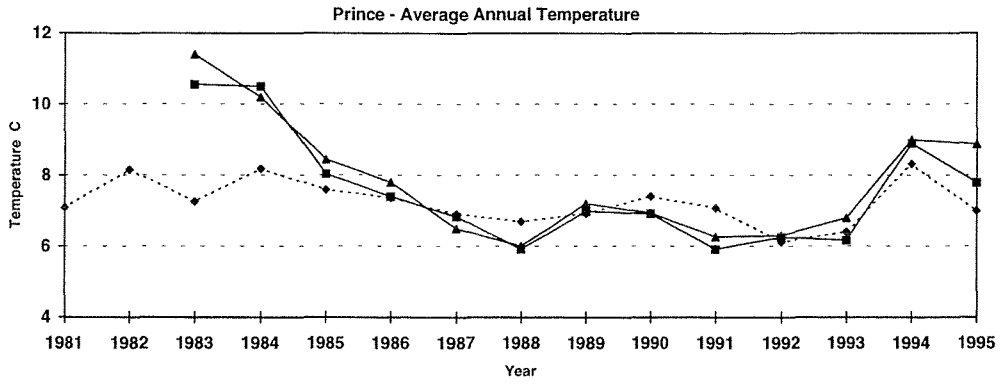
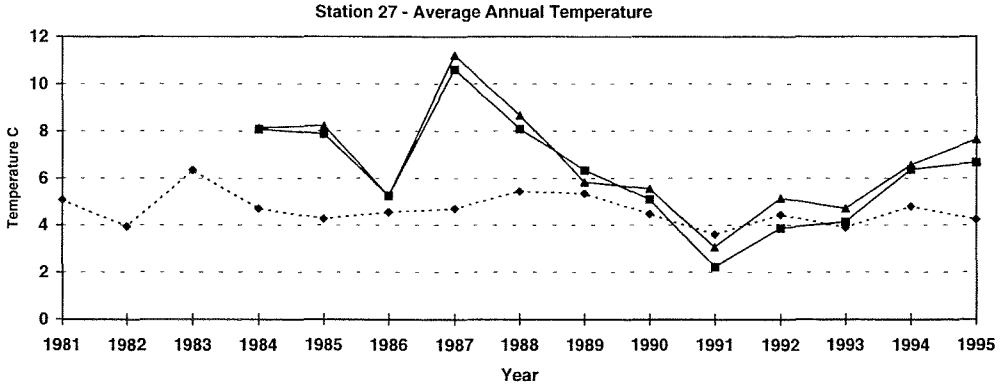


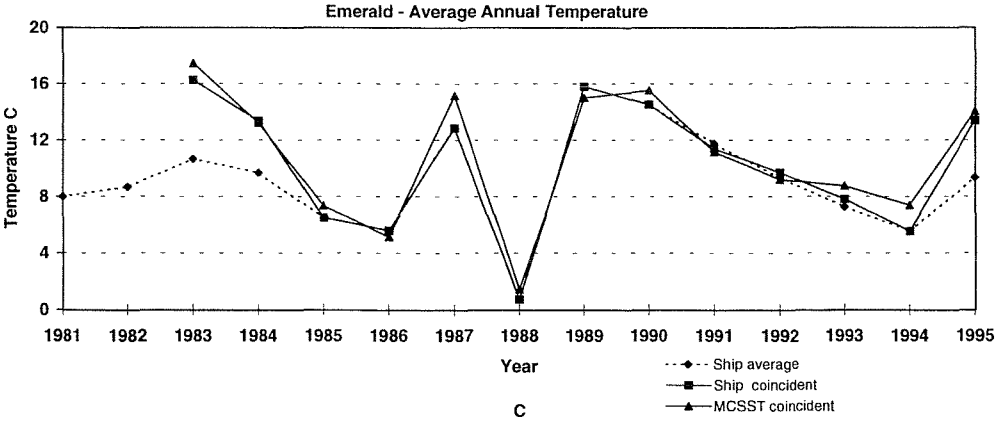
Figure 2d-f. Comparison between the annual temperature cycle from the MCSST and in situ data at (d) Prince 5; (e) Station 27; and (f) Emerald Basin.



A



B



C

Figure 3. Comparison of annual average MCSST and in situ temperature measurements for (a) Prince 5; (b) Station 27; and (c) Emerald Basin. The dashed line shows the annual average using all data (Ships' values for Prince and Station 27, MCSST for Emerald)

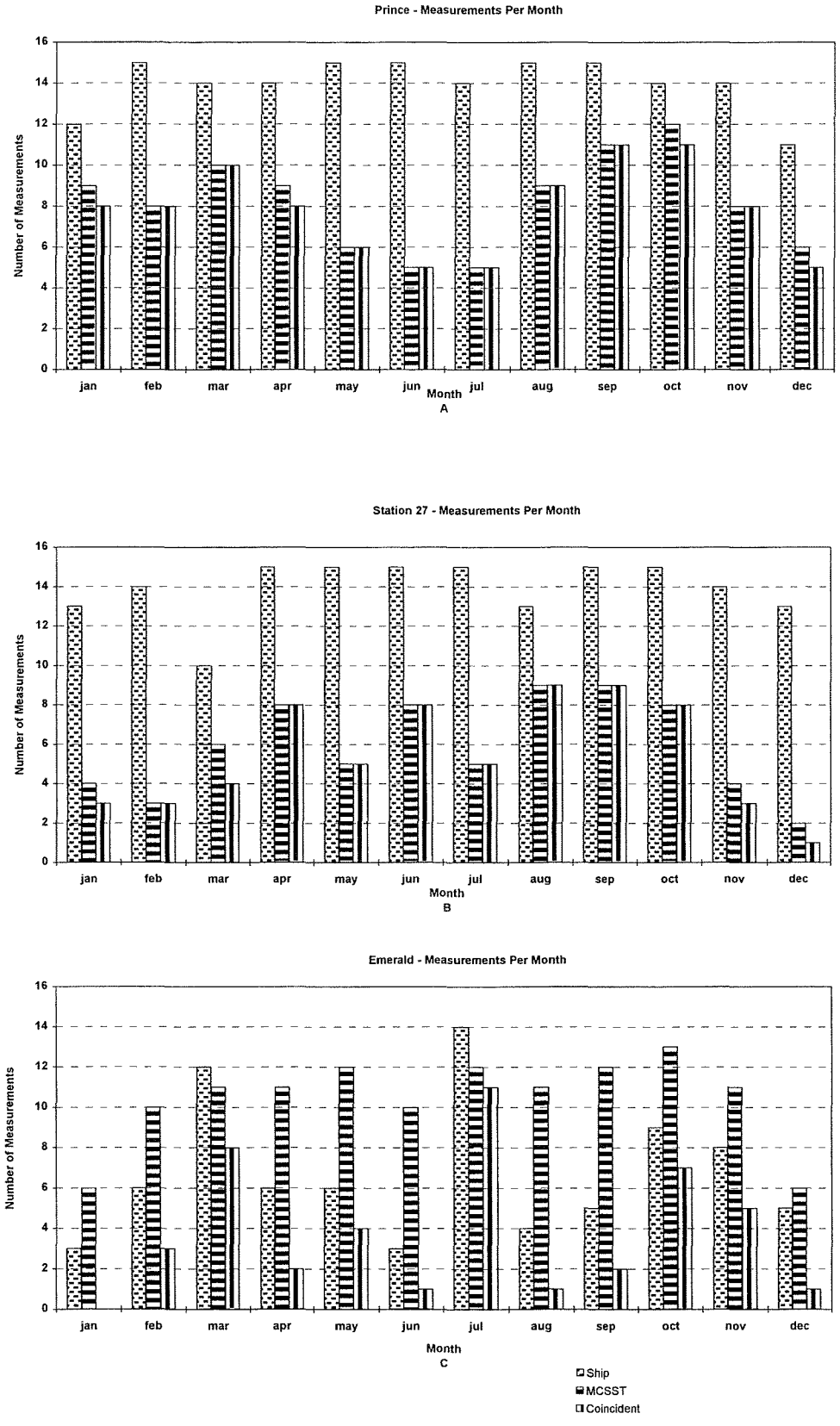


Figure 4a-c. Number of measurements obtained by month and number of months with coincident data for (a) Prince 5; (b) Station 27; and (c) Emerald Basin.

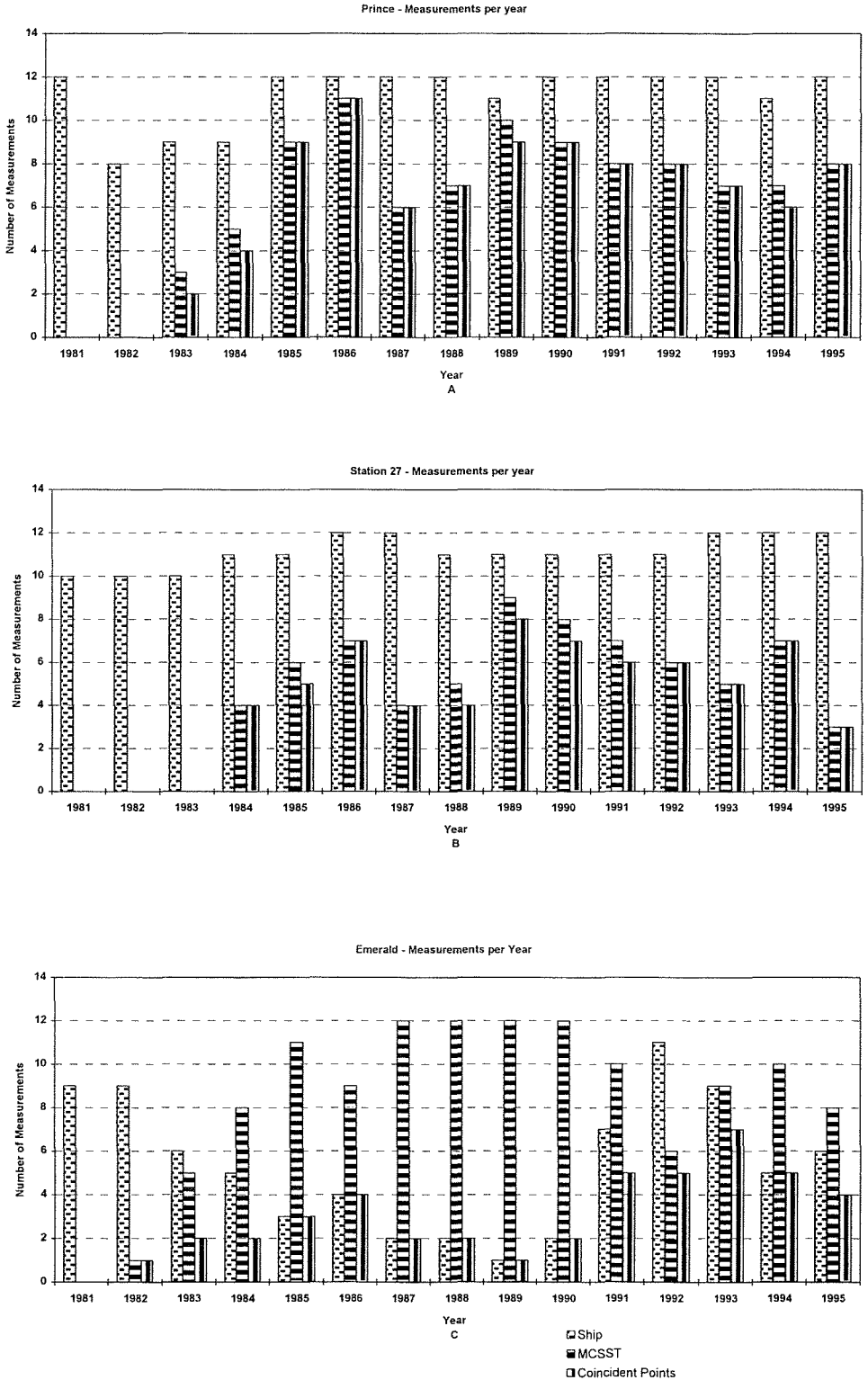


Figure 5a-c. Number of measurements obtained by year including coincident data for (a) Prince 5; (b) Station 27; and (c) Emerald Basin.

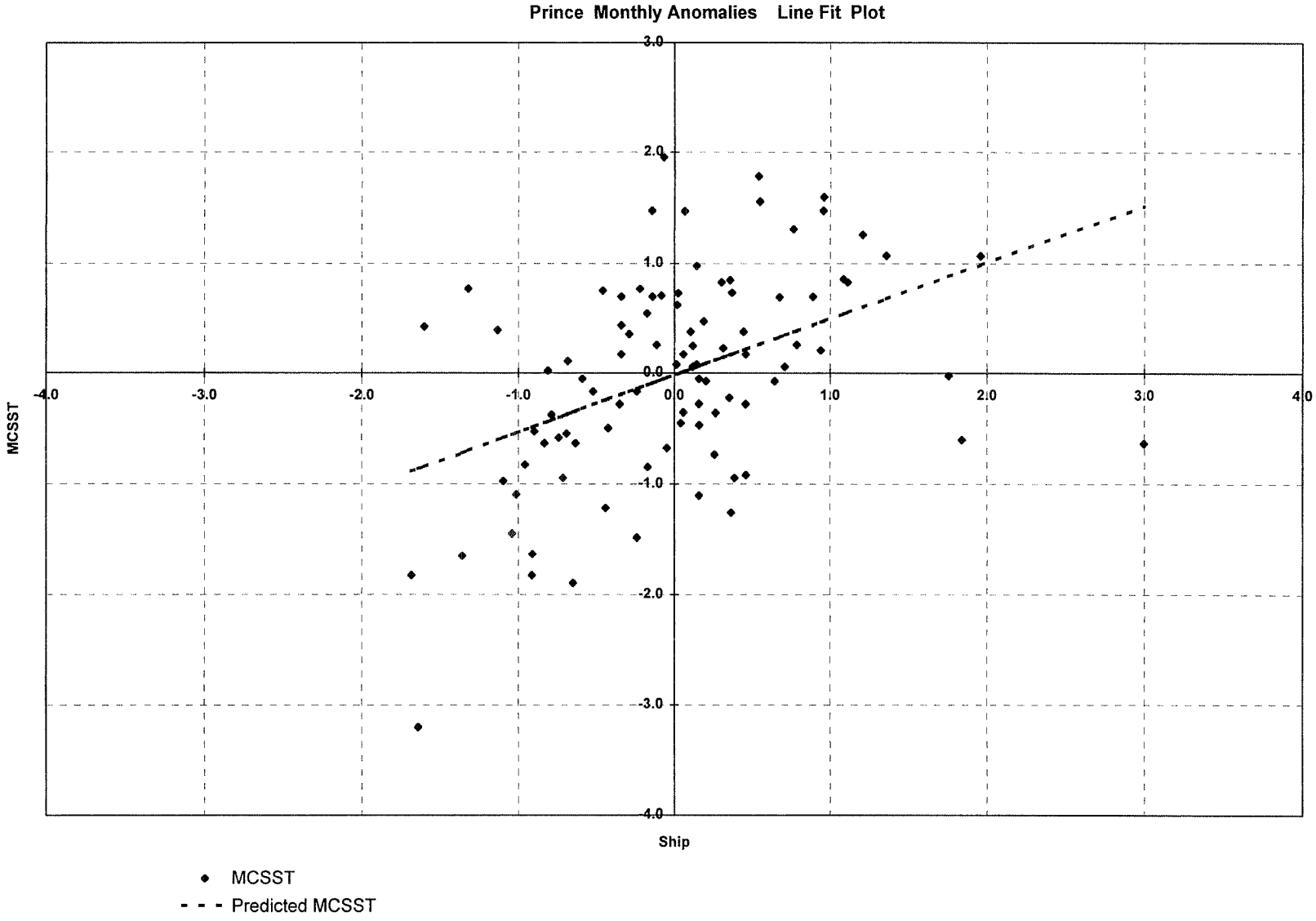


Figure 6. Comparison of the monthly anomalies from MCSST and ships' measurements at Prince 5.

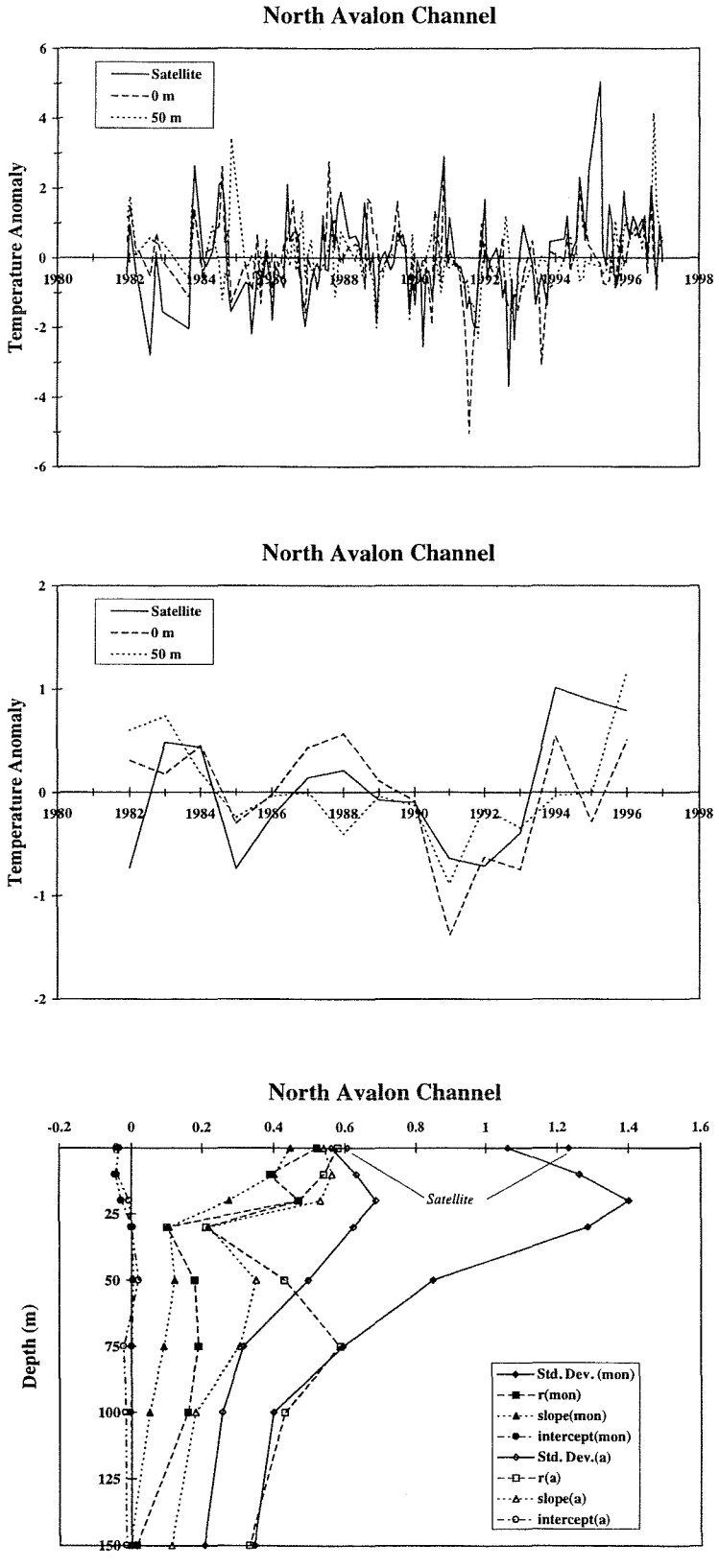


Figure 7. Monthly (top panel) and annual (middle panel) temperature anomalies for the North Avalon Channel. Profiles of the monthly (mon) and annual (a) standard deviations, correlations, and regression slopes and intercepts of MCSST versus in situ data.

Table Three Detailed Comparison MCSST & Ship Measurements

A: Prince Ship-MCSST

Mean	-0.28
Standard Error	0.11
Median	-0.26
Mode	-0.40
Standard Deviation	1.03
Sample Variance	1.05
Kurtosis	4.72
Skewness	0.95
Range	7.51
Minimum	-2.98
Maximum	4.53
Sum	-26.10
Count	94
Confidence Level(95.0%)	0.21

Regression Statistics	
Multiple R	0.97
R Square	0.94
Adjusted R Square	0.94
Standard Error	1.02
Observations	94

	Coefficients	Standard Error
Intercept	-0.026	0.22
Ship temp	1.04	0.03

B: Station 27 Ship-MCSST

Mean	-0.39
Standard Error	0.18
Median	-0.22
Mode	#N/A
Standard Deviation	1.45
Sample Variance	2.09
Kurtosis	1.60
Skewness	-0.56
Range	8.54
Minimum	-5.05
Maximum	3.48
Sum	-25.80
Count	66
Confidence Level(95.0%)	0.36

Regression Statistics	
Multiple R	0.97
R Square	0.94
Adjusted R Square	0.94
Standard Error	1.43
Observations	66

	Coefficients	Standard Error
Intercept	0.10	0.26
Ship temp	1.05	0.032

C: Emerald Ship-MCSST

Mean	-0.55
Standard Error	0.22
Median	-0.61
Mode	#N/A
Standard Deviation	1.45
Sample Variance	2.09
Kurtosis	0.79
Skewness	0.05
Range	6.81
Minimum	-4.00
Maximum	2.81
Sum	-24.9
Count	45
Confidence Level(95.0%)	0.43

Regression Statistics	
Multiple R	0.98
R Square	0.95
Adjusted R Square	0.95
Standard Error	1.45
Observations	45

	Coefficients	Standard Error
Intercept	0.30	0.38
Emerald	1.03	0.034

D: All data Ship-MCSST

Mean	-0.37
Standard Error	0.089
Median	-0.32
Mode	0.00
Standard Deviation	1.27
Sample Variance	1.61
Kurtosis	2.25
Skewness	-0.09
Range	9.58
Minimum	-5.05
Maximum	4.53
Sum	-76.43
Count	205
Confidence Level(95.0%)	0.17

Regression Statistics	
Multiple R	0.97
R Square	0.95
Adjusted R Square	0.95
Standard Error	1.25
Observations	205

	Coefficients	Standard Error
Intercept	0.08	0.15
Ship	1.04	0.017

Table Three (continued)

E: All Data Ship-MCSST
SHIP RANGE -1.7 to 8.0

Mean	-0.161
Standard Error	0.12
Median	-0.025
Mode	0.15
Standard Deviation	1.226
Sample Variance	1.502
Kurtosis	3.311
Skewness	-0.662
Range	8.537
Minimum	-5.053
Maximum	3.484
Sum	-16.74
Count	104
Confidence Level(95.0%)	0.238

Regression Statistics

Multiple R	0.909
R Square	0.826
Adjusted R Square	0.824
Standard Error	1.23
Observations	104

	Coefficients	Standard Error
Intercept	0.088	0.175
Ship	1.027	0.047

F: All Data Ship-MCSST
SHIP RANGE 8.1 to 17.8

Mean	-0.591
Standard Error	0.127
Median	-0.59
Mode	-0.8
Standard Deviation	1.281
Sample Variance	1.641
Kurtosis	2.481
Skewness	0.461
Range	8.4
Minimum	-3.87
Maximum	4.53
Sum	-59.69
Count	101
Confidence Level(95.0%)	0.253

Regression Statistics

Multiple R	0.865
R Square	0.749
Adjusted R Square	0.746
Standard Error	1.288
Observations	101

	Coefficients	Standard Error
Intercept	0.585	0.706
Ship	1.001	0.058

G: Temperature Anomalies Prince
Ship Anomaly-MCSST Anomaly

Mean	0.02
Standard Error	0.10
Median	-0.03
Mode	-0.14
Standard Deviation	0.92
Sample Variance	0.85
Kurtosis	2.06
Skewness	0.56
Range	5.71
Minimum	-2.09
Maximum	3.63
Sum	1.80
Count	94
Confidence Level(95.0%)	0.19

Regression Statistics

Multiple R	0.44
R Square	0.20
Adjusted R Square	0.19
Standard Error	0.84
Observations	94

	Coefficients	Standard Error
Intercept	-0.019	0.087
Ship	0.51	0.11

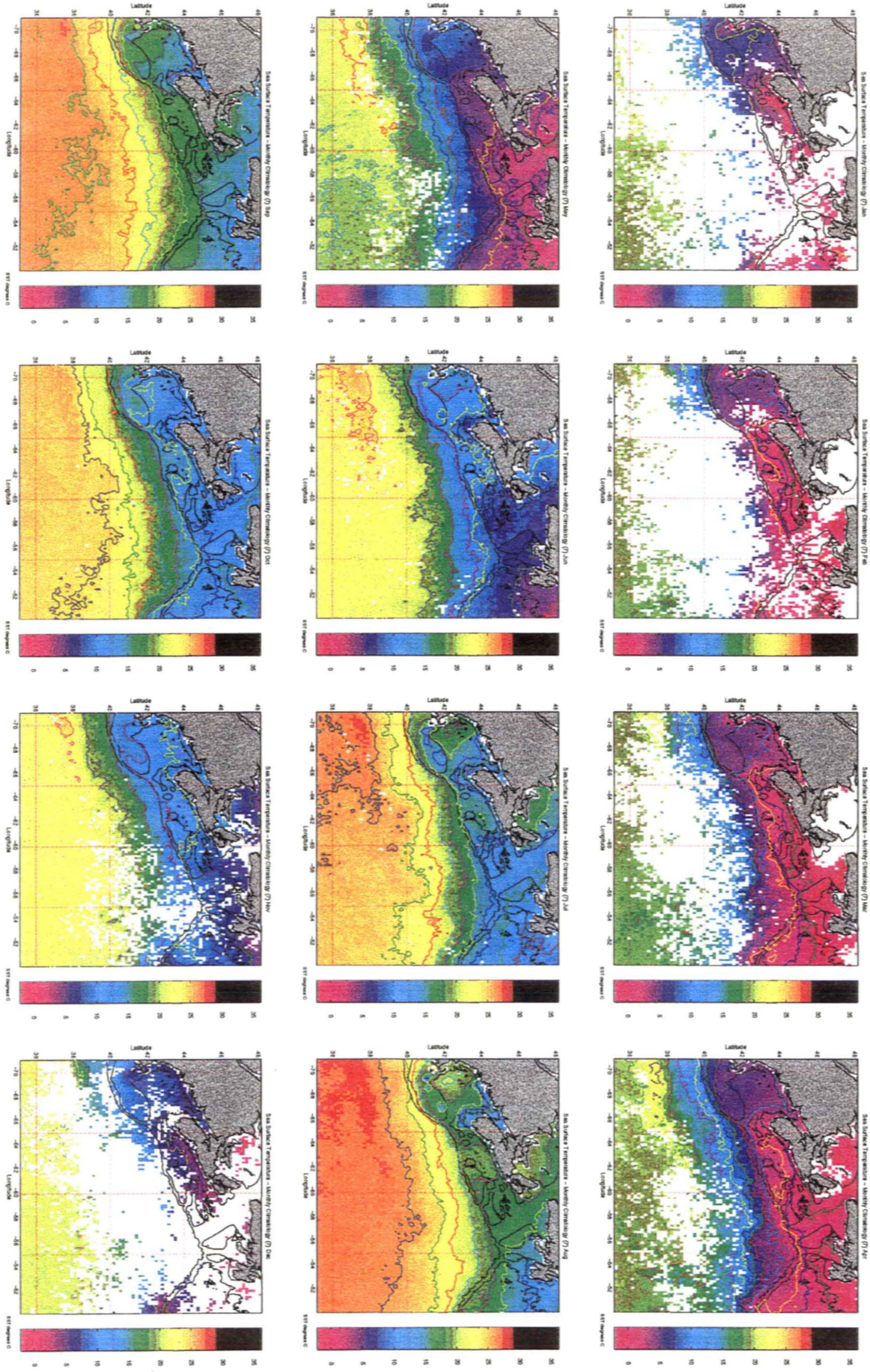
Annex A

Monthly Average Sea-Surface Temperature

and

Contours of Monthly Averages

WOCE Region
Scotian Shelf
Gulf
Newfoundland

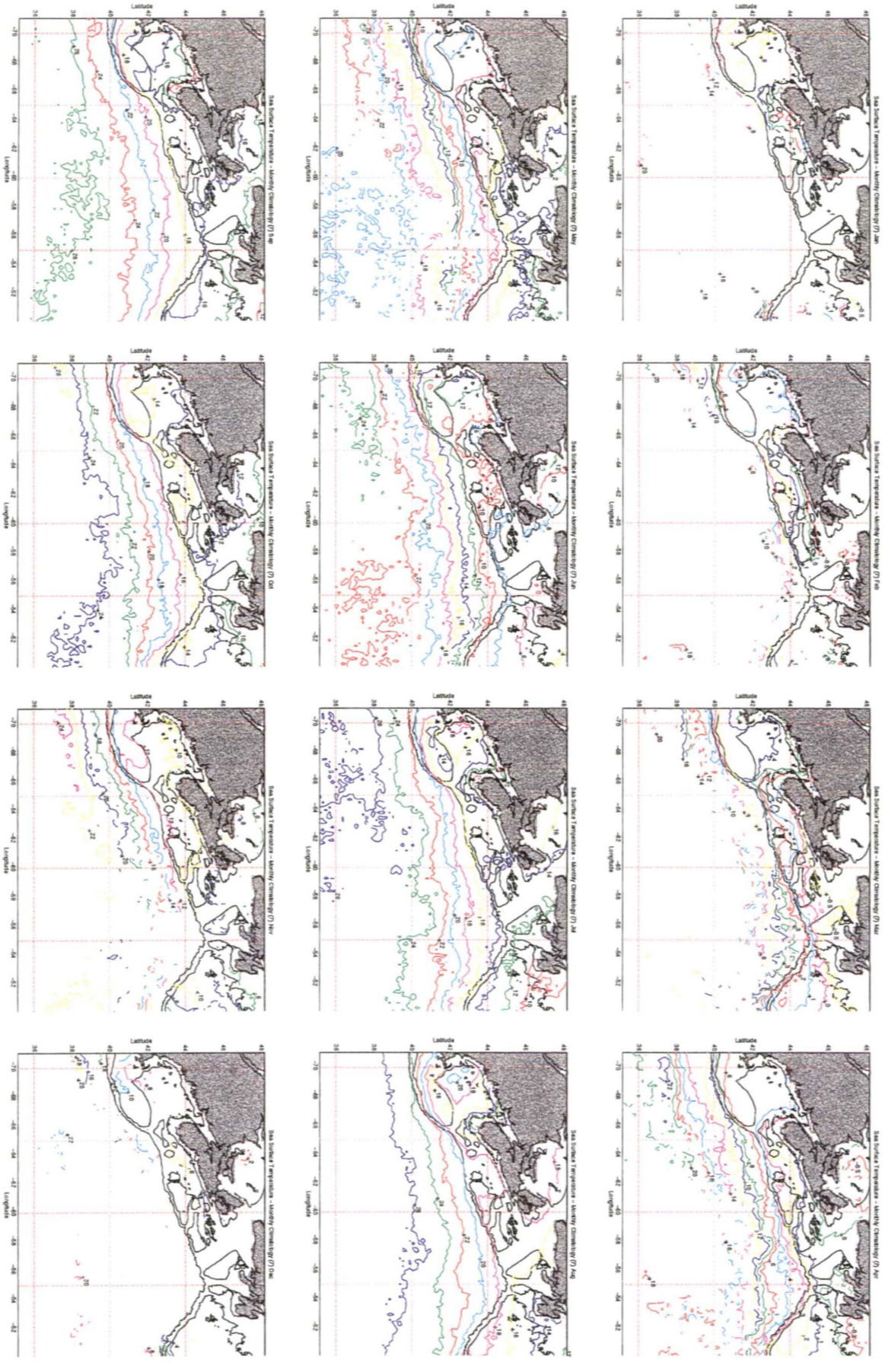


Monthly Average Sea-Surface Temperature

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map A 01

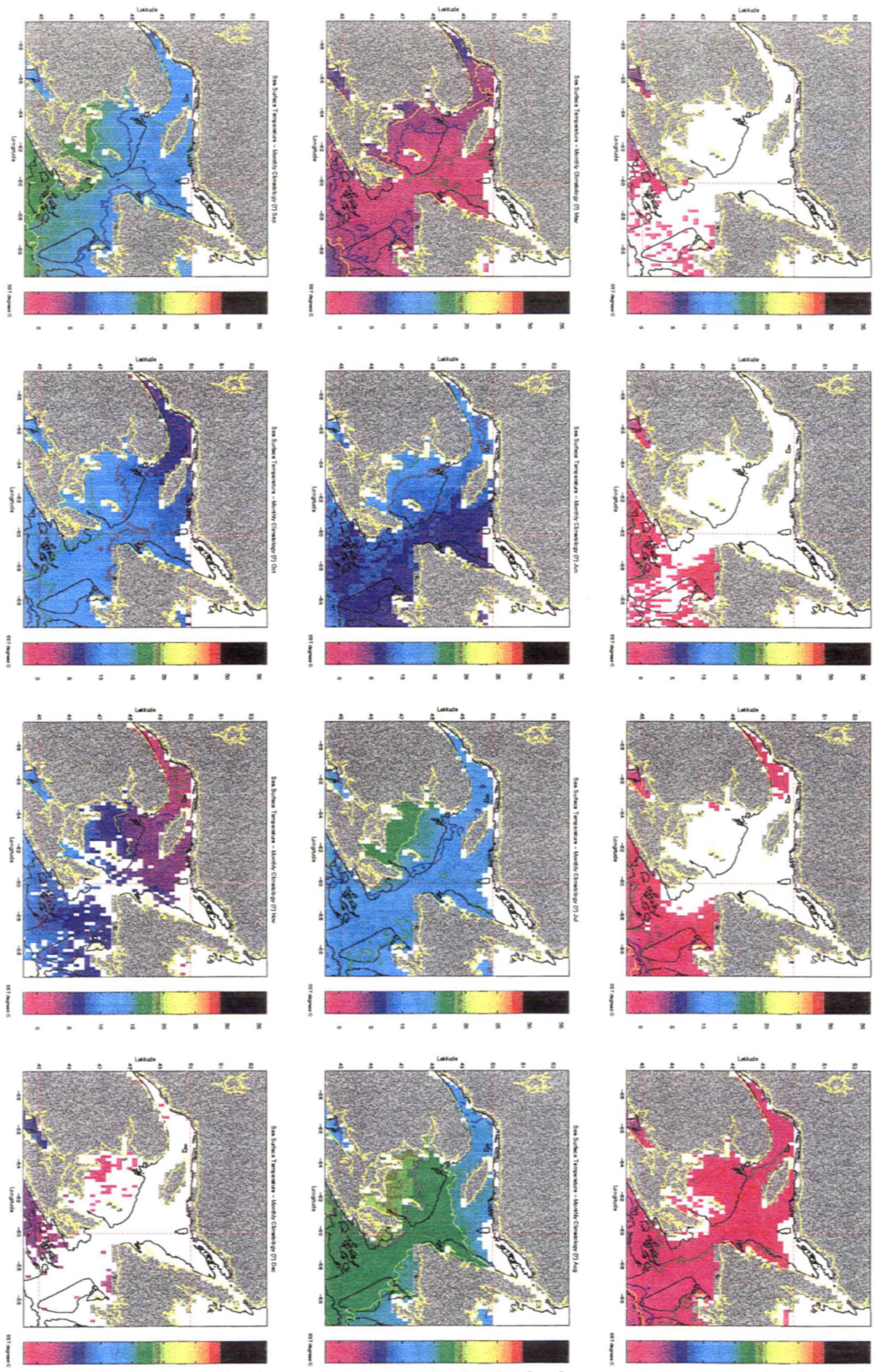


Contours of Monthly Average Sea-Surface Temperature

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map A 02

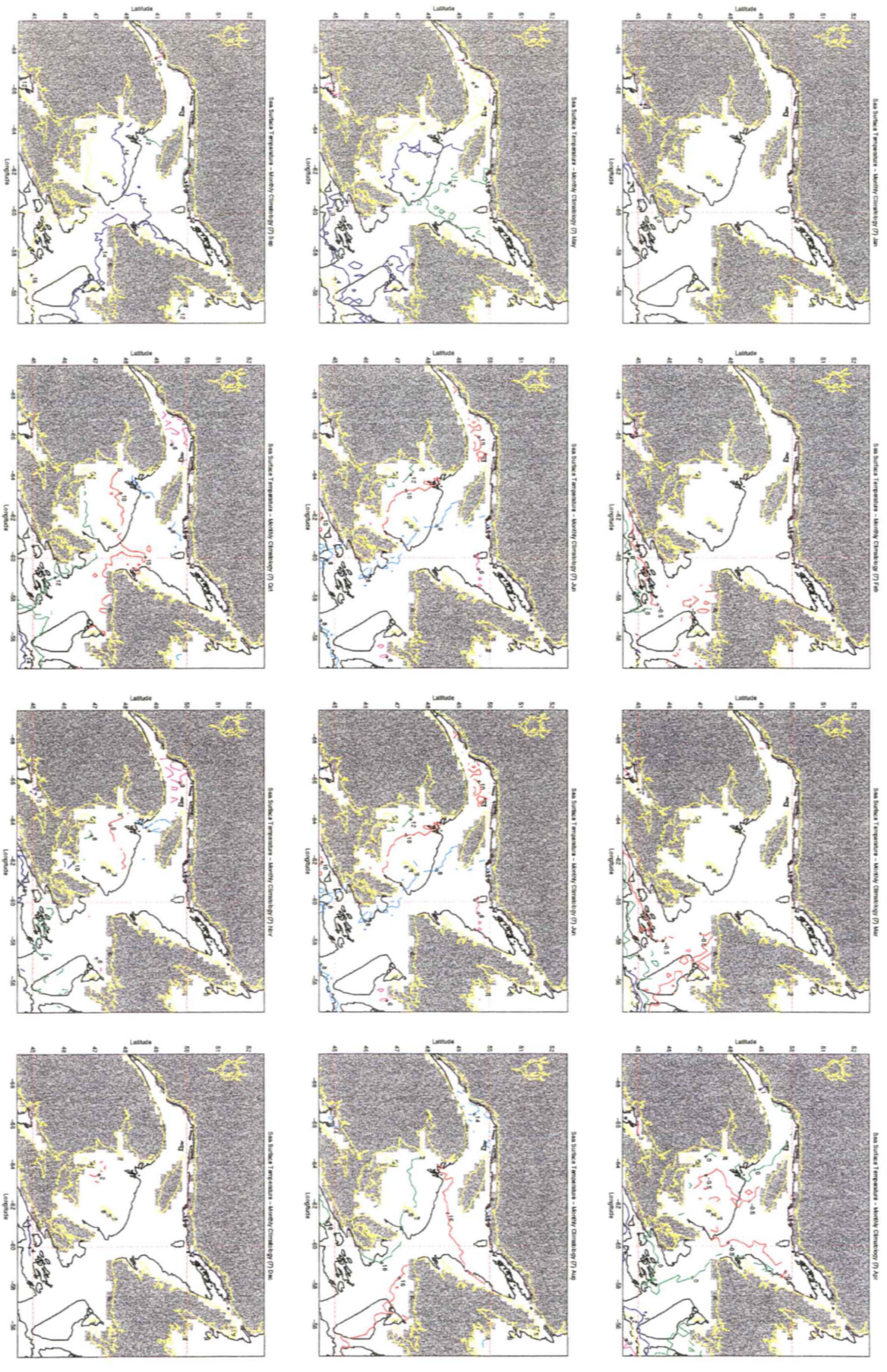


Monthly Average Sea-Surface Temperatures

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map A 03

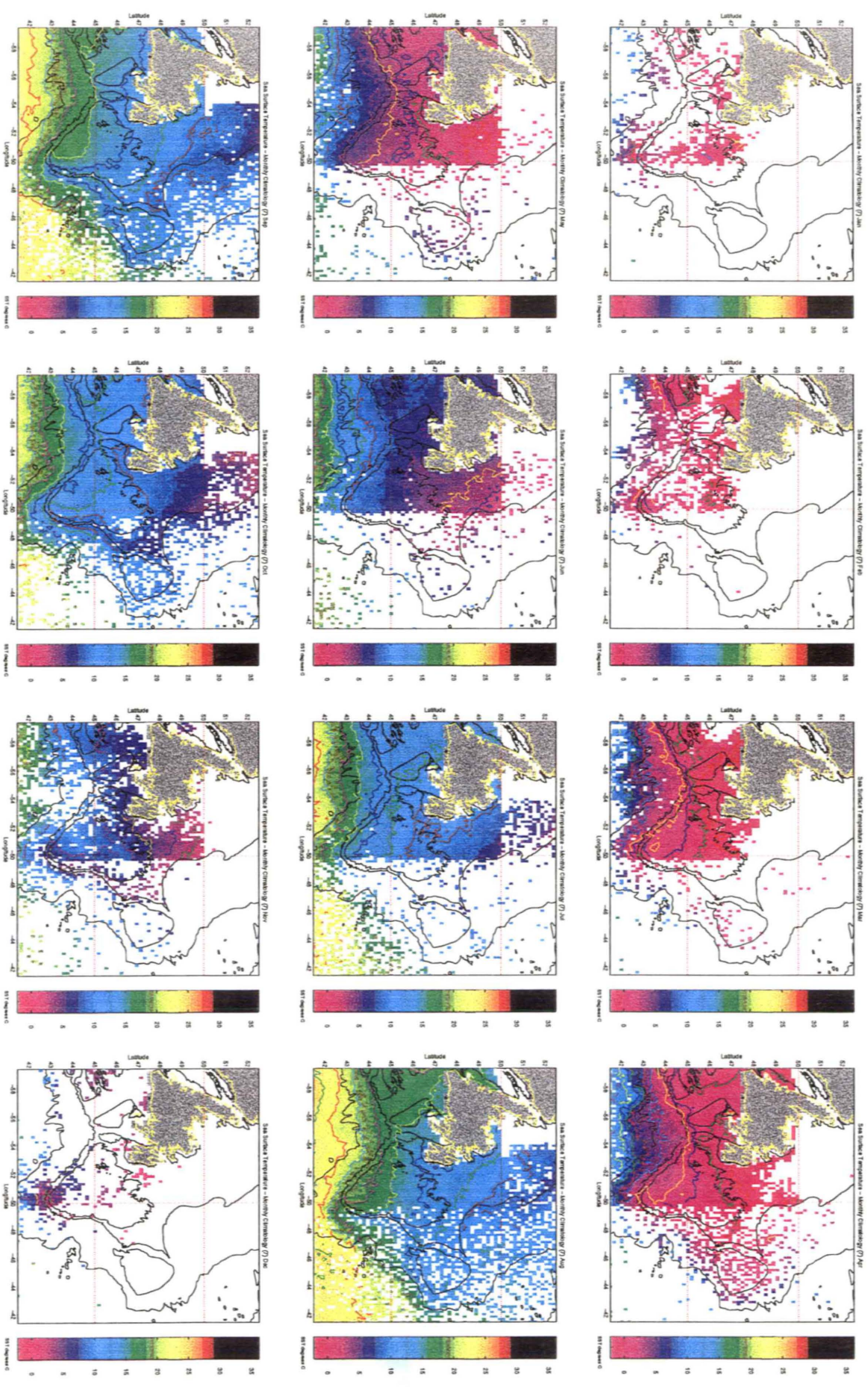


Contours of Monthly Average Sea-Surface Temperature

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map A 04

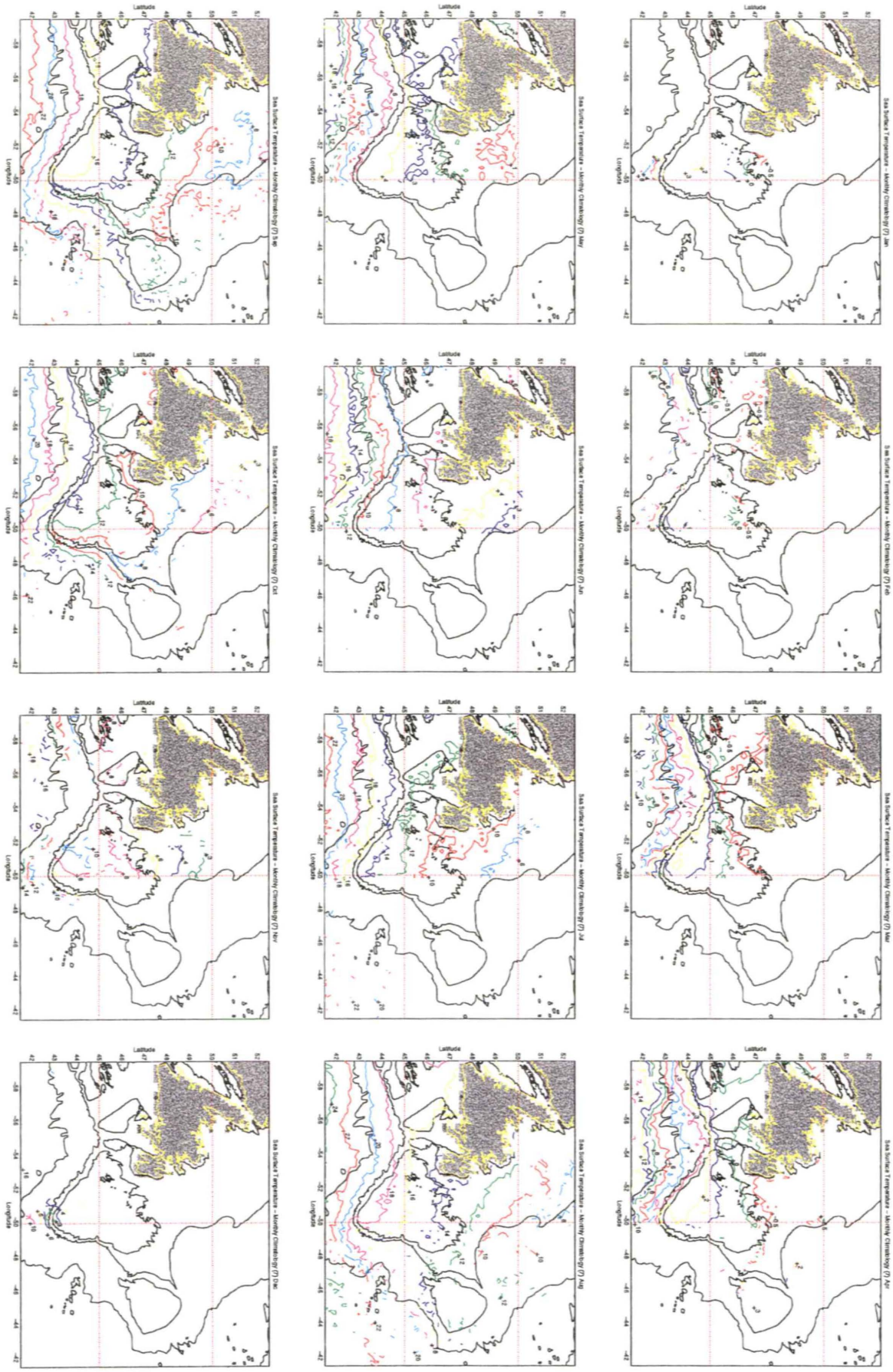


Monthly Average Sea-Surface Temperatures

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map A 05

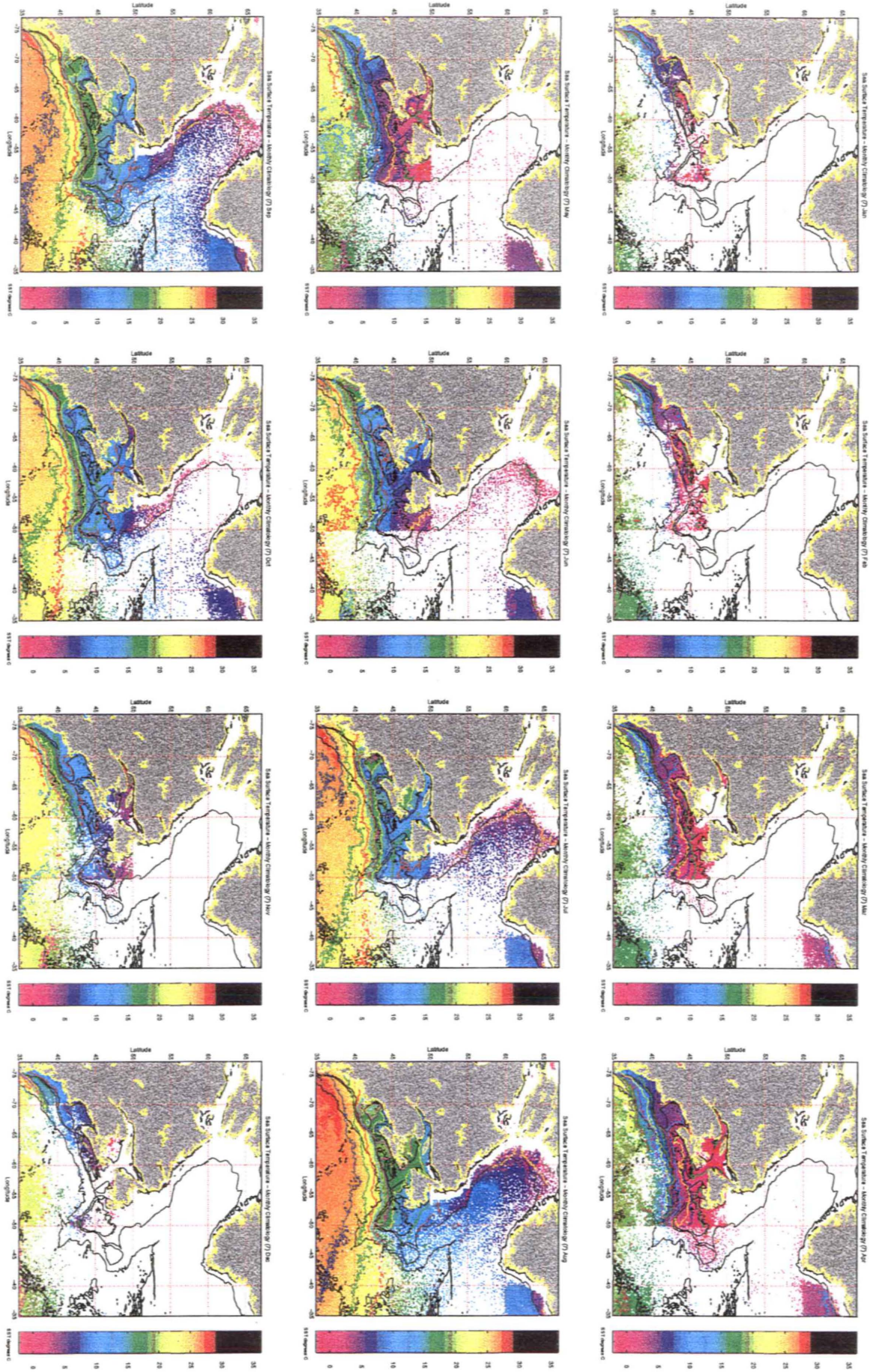


Contours of Monthly Average Sea-Surface Temperature

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map A 06

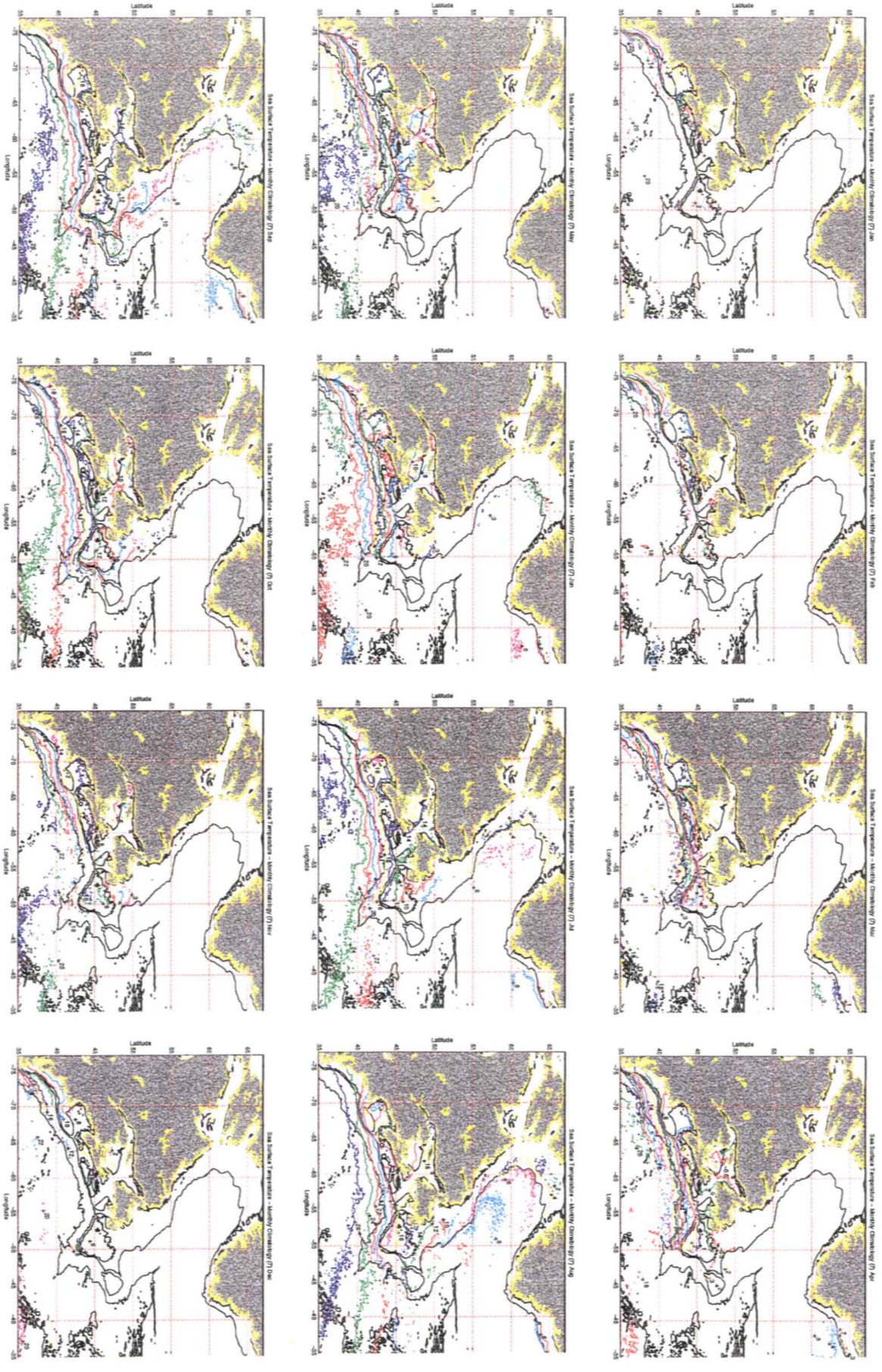


Monthly Average Sea-Surface Temperatures

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map A 07



Contours of Monthly Average Sea-Surface Temperature

Average Values must occur in at least 7 years ('81-'96)

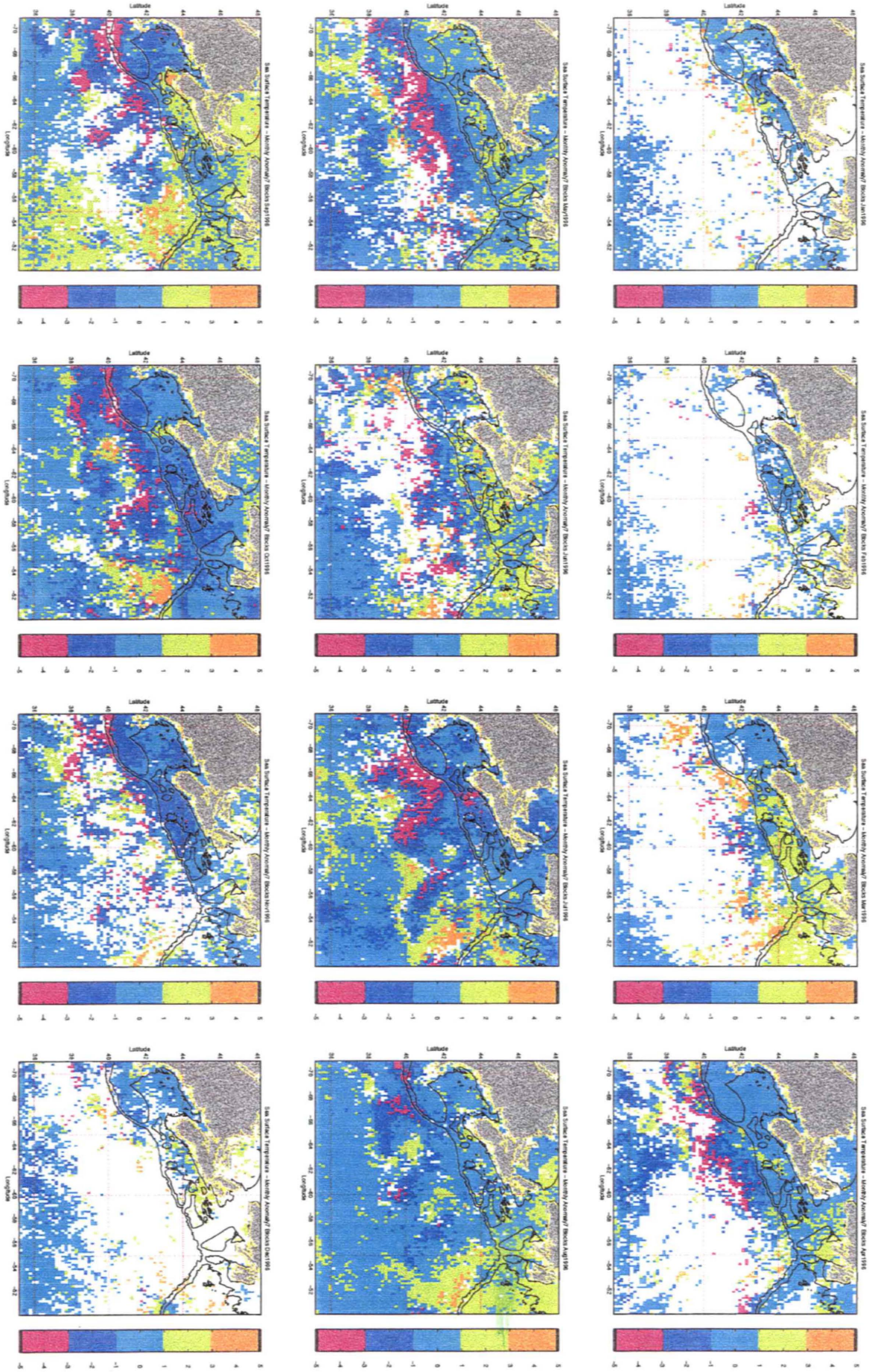
Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map A 08

Annex B

Monthly Anomalies in Sea-Surface Temperature

Scotian Shelf

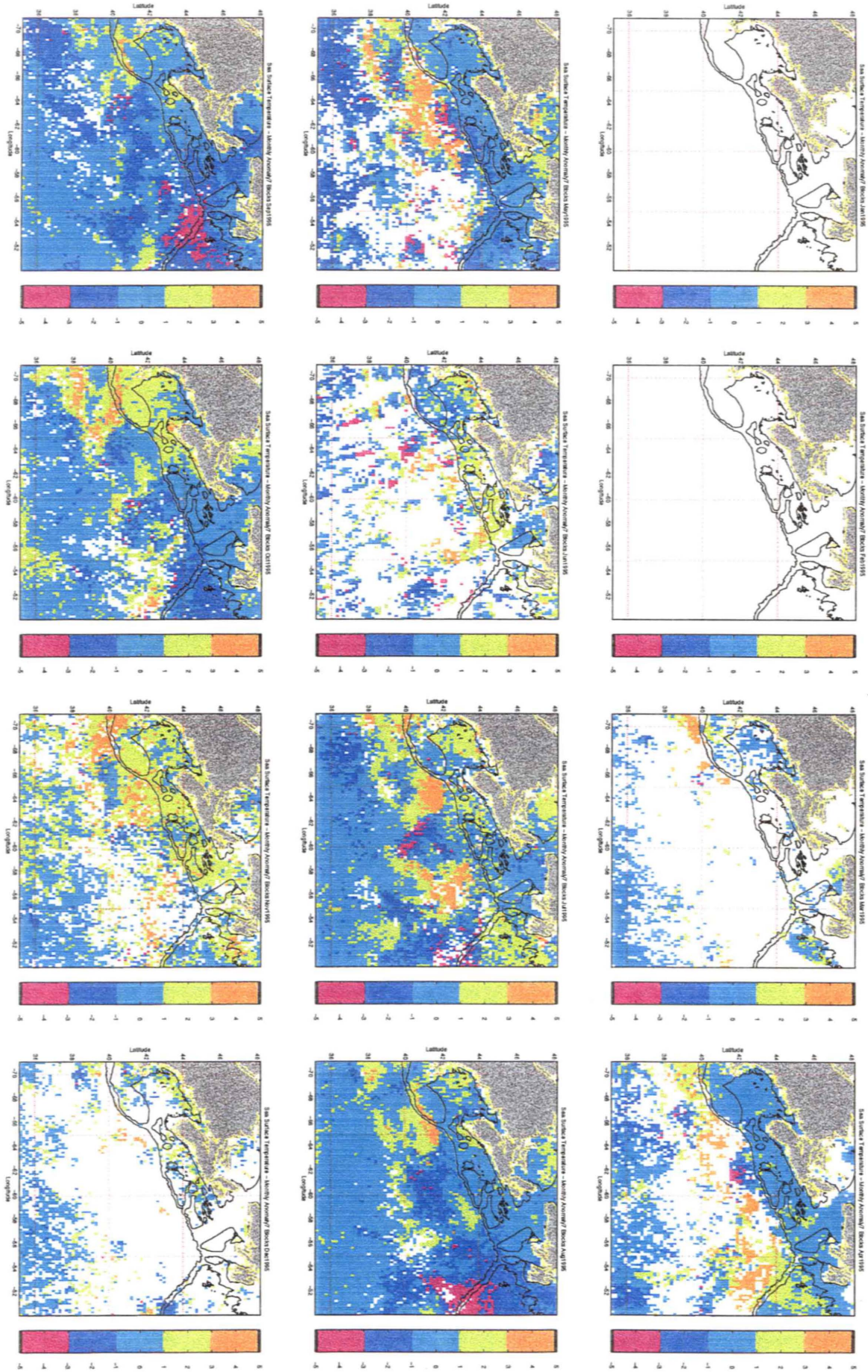


Monthly Anomalies in Sea-Surface Temperatures 1996

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

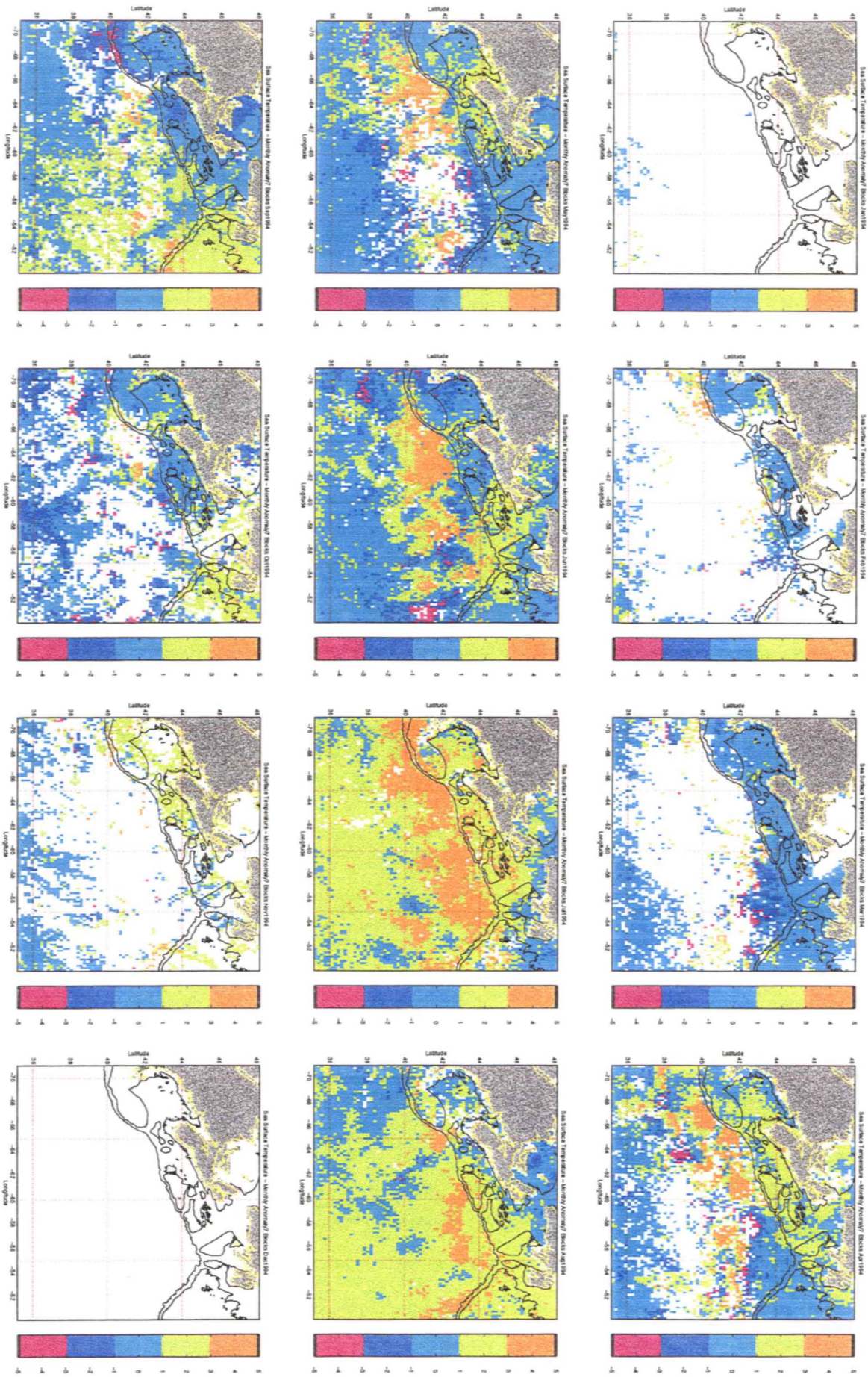
Map B 01



Monthly Anomalies in Sea-Surface Temperatures 1995

Average Values must occur in at least 7 years ('81-'96)

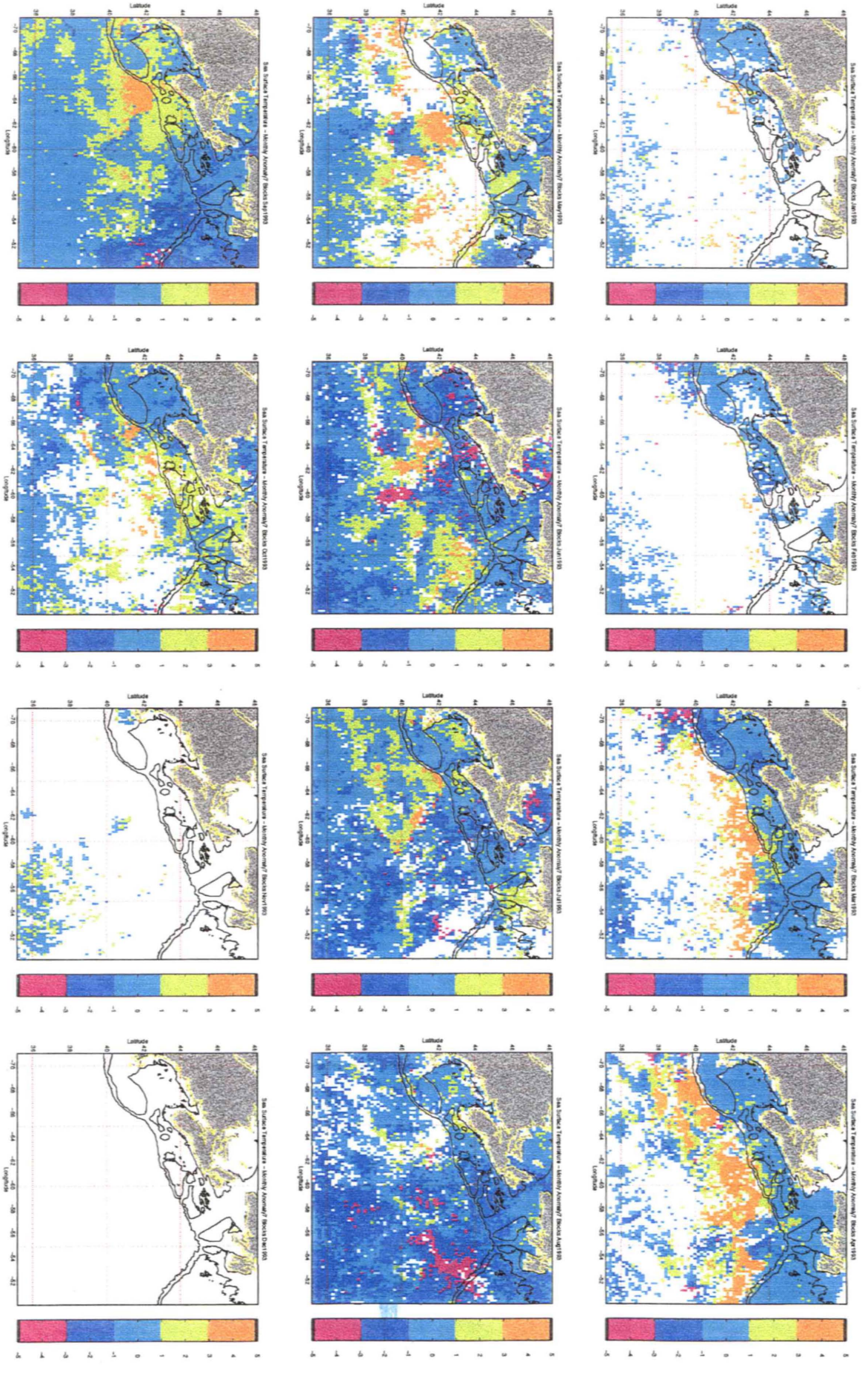
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1994

Average Values must occur in at least 7 years ('81-'96)

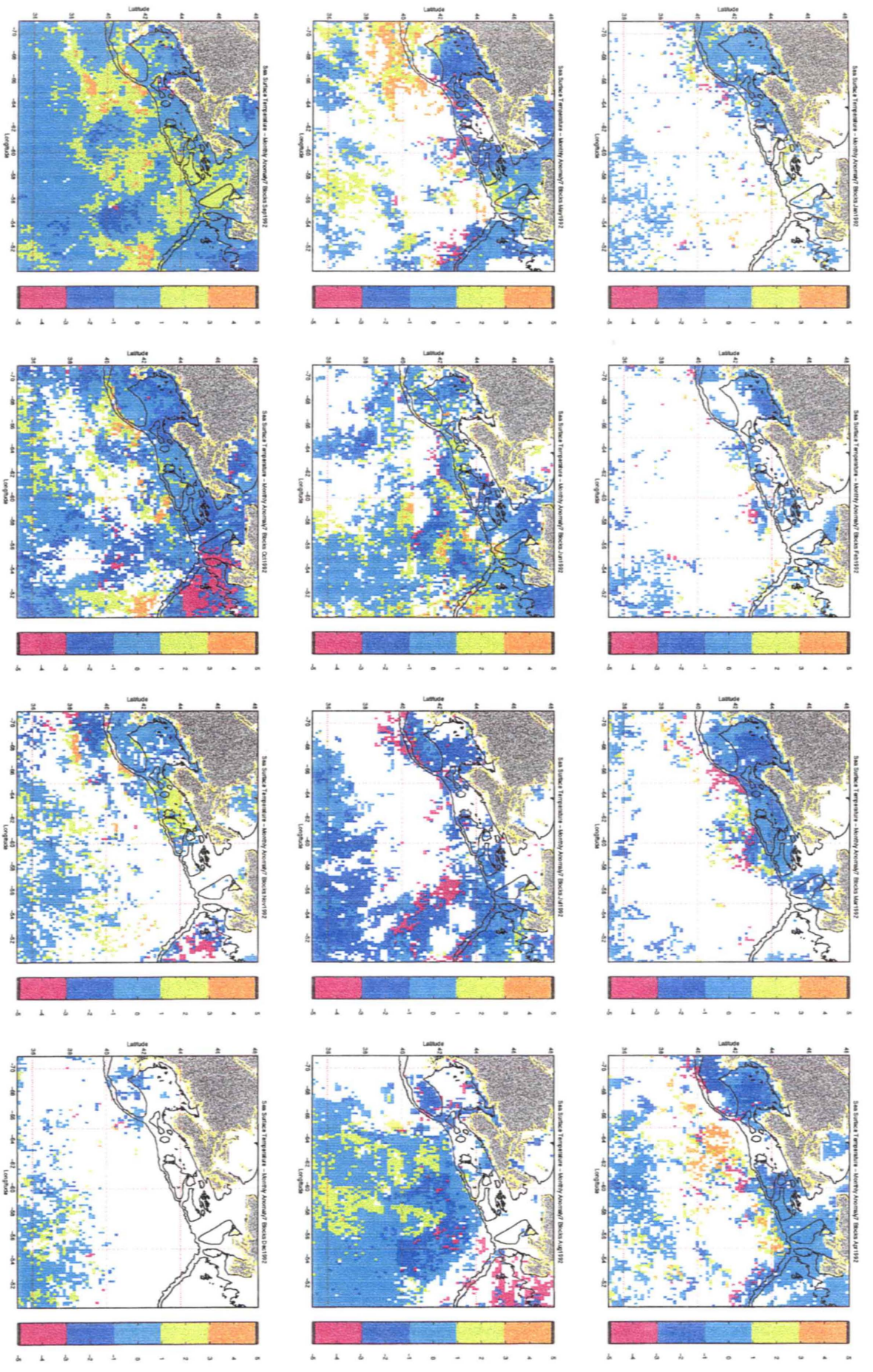
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1993

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

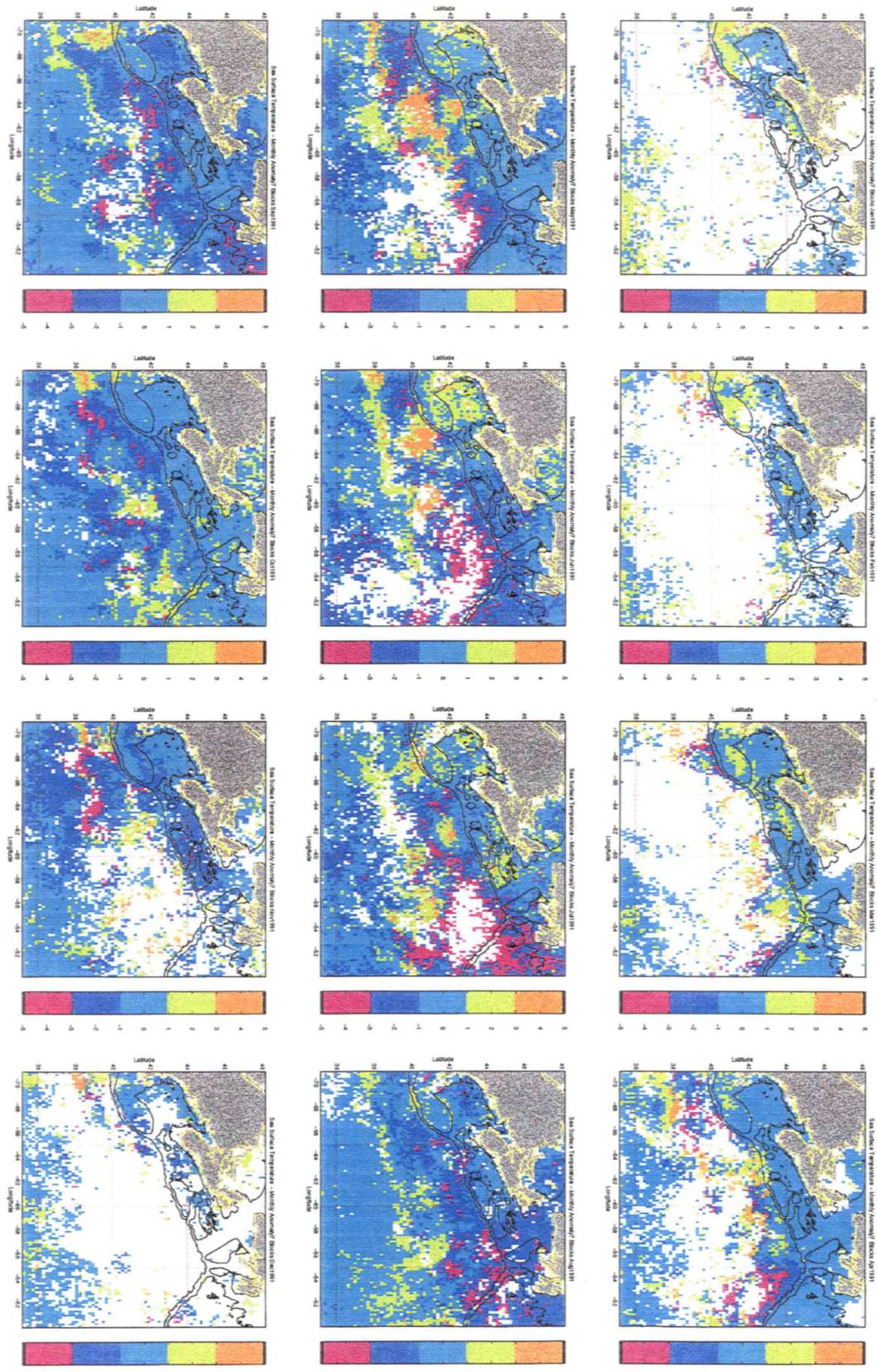


Monthly Anomalies in Sea-Surface Temperatures 1992

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map B 05

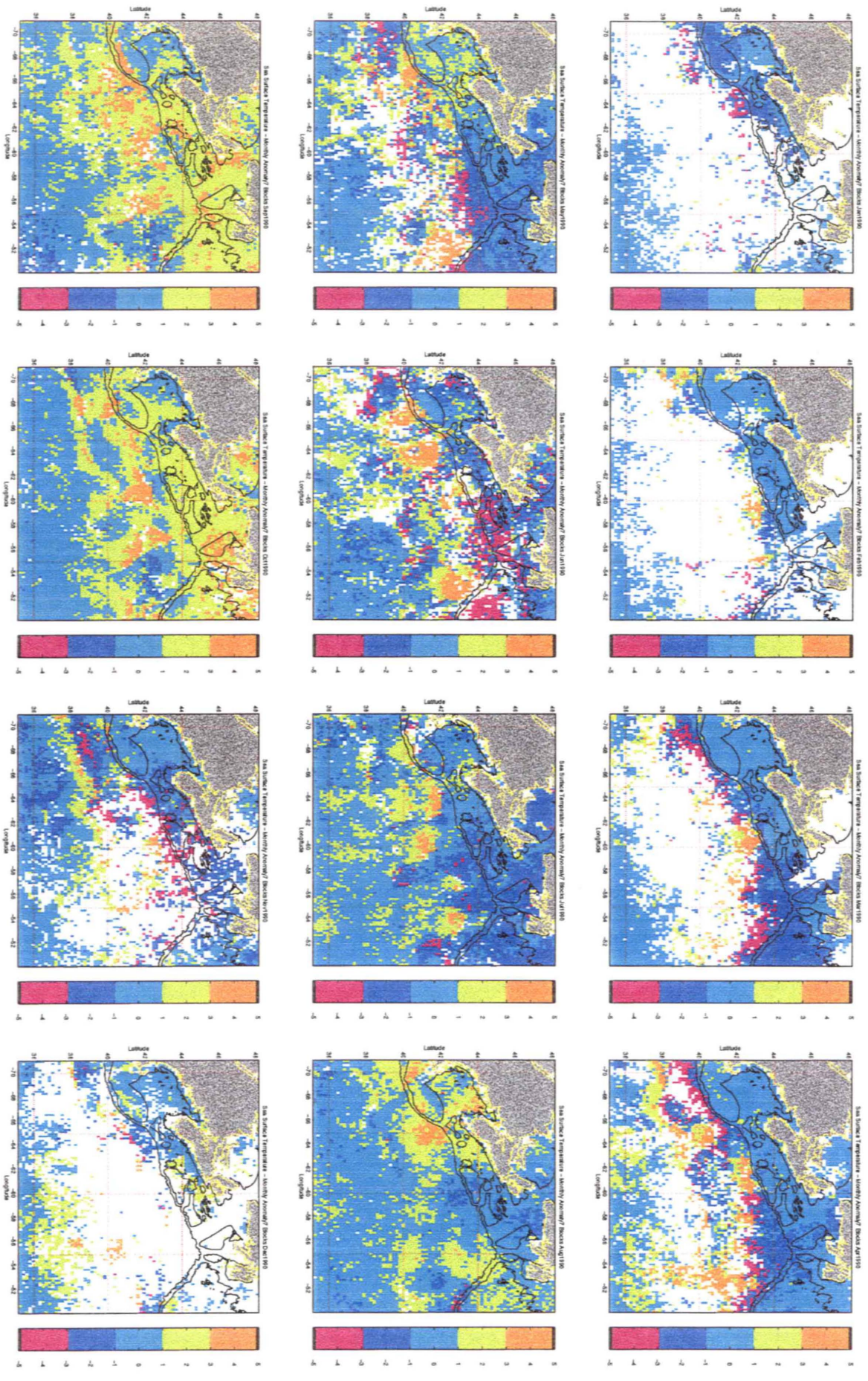


Monthly Anomalies in Sea-Surface Temperatures 1991

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

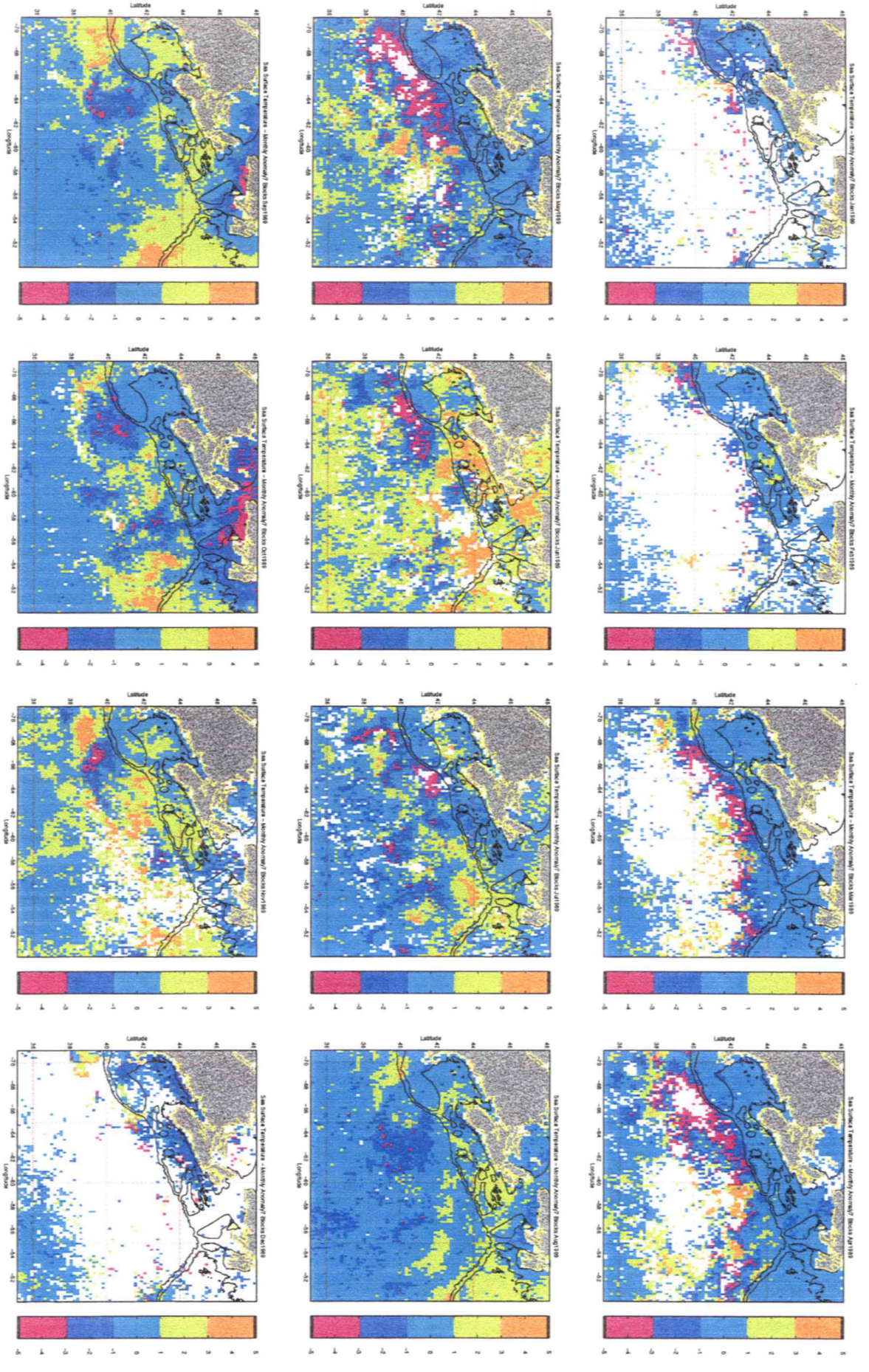
Map B 06



Monthly Anomalies in Sea-Surface Temperatures 1990

Average Values must occur in at least 7 years ('81-'96)

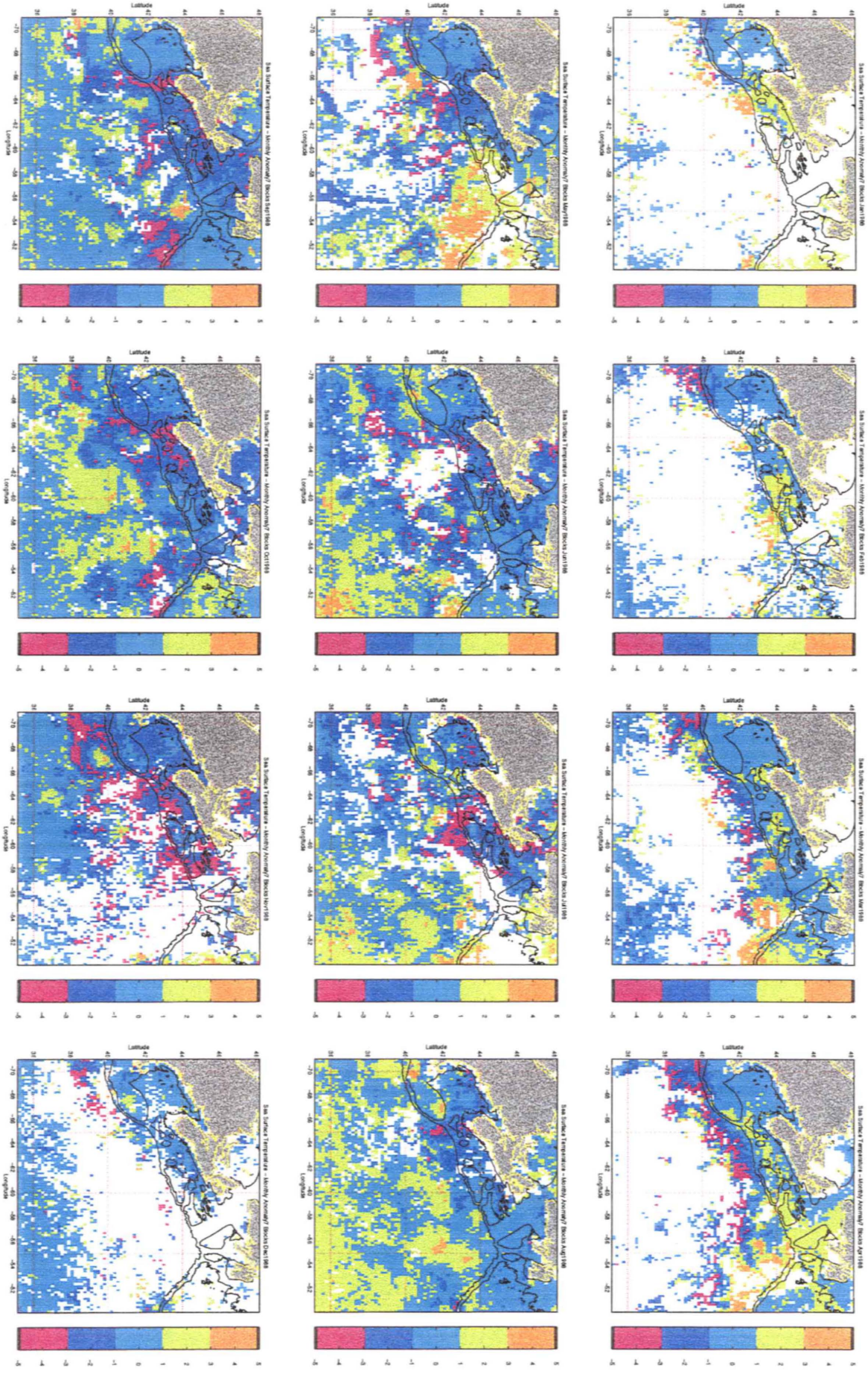
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1989

Average Values must occur in at least 7 years ('81-'96)

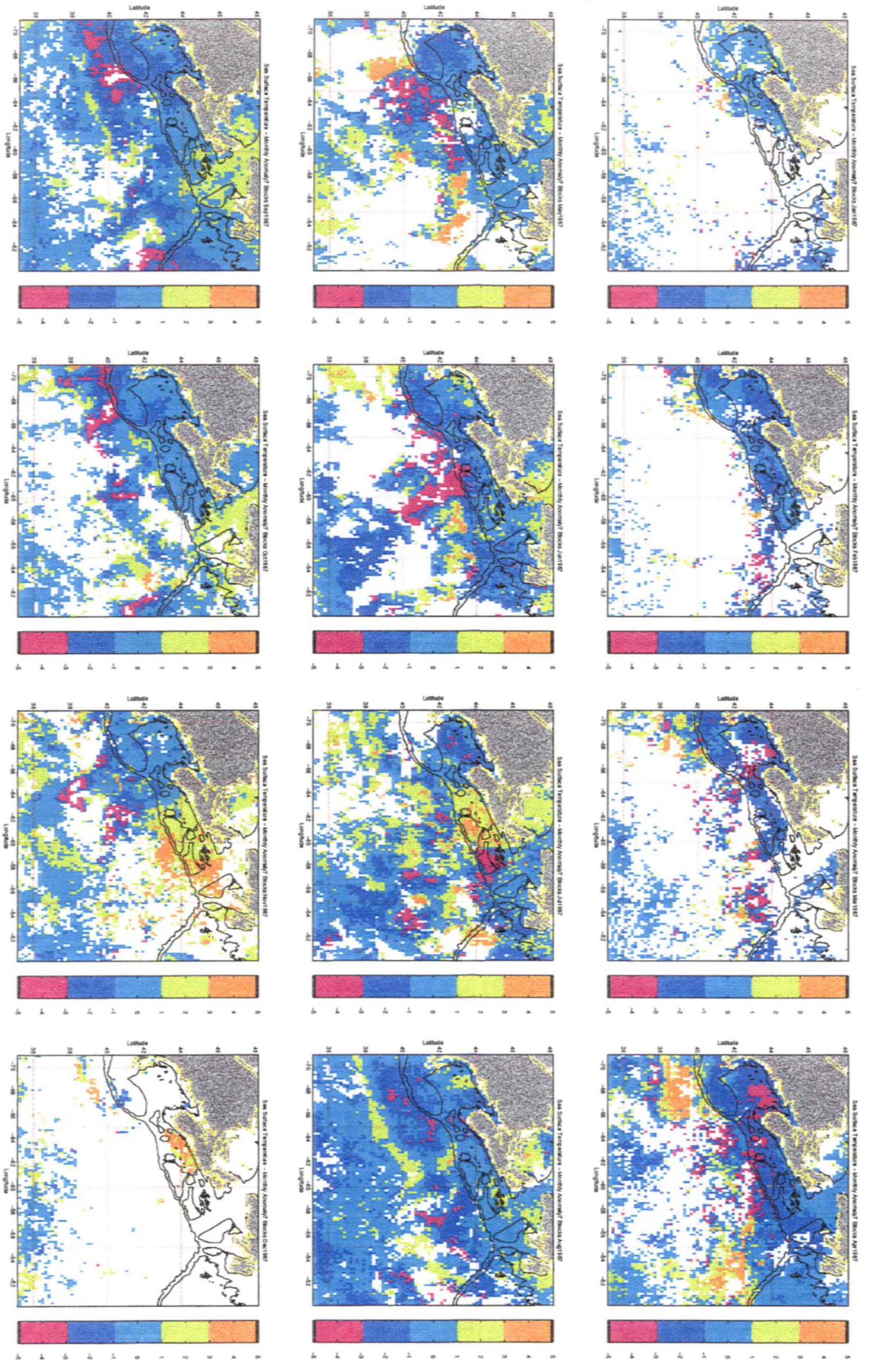
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1988

Average Values must occur in at least 7 years ('81-'96)

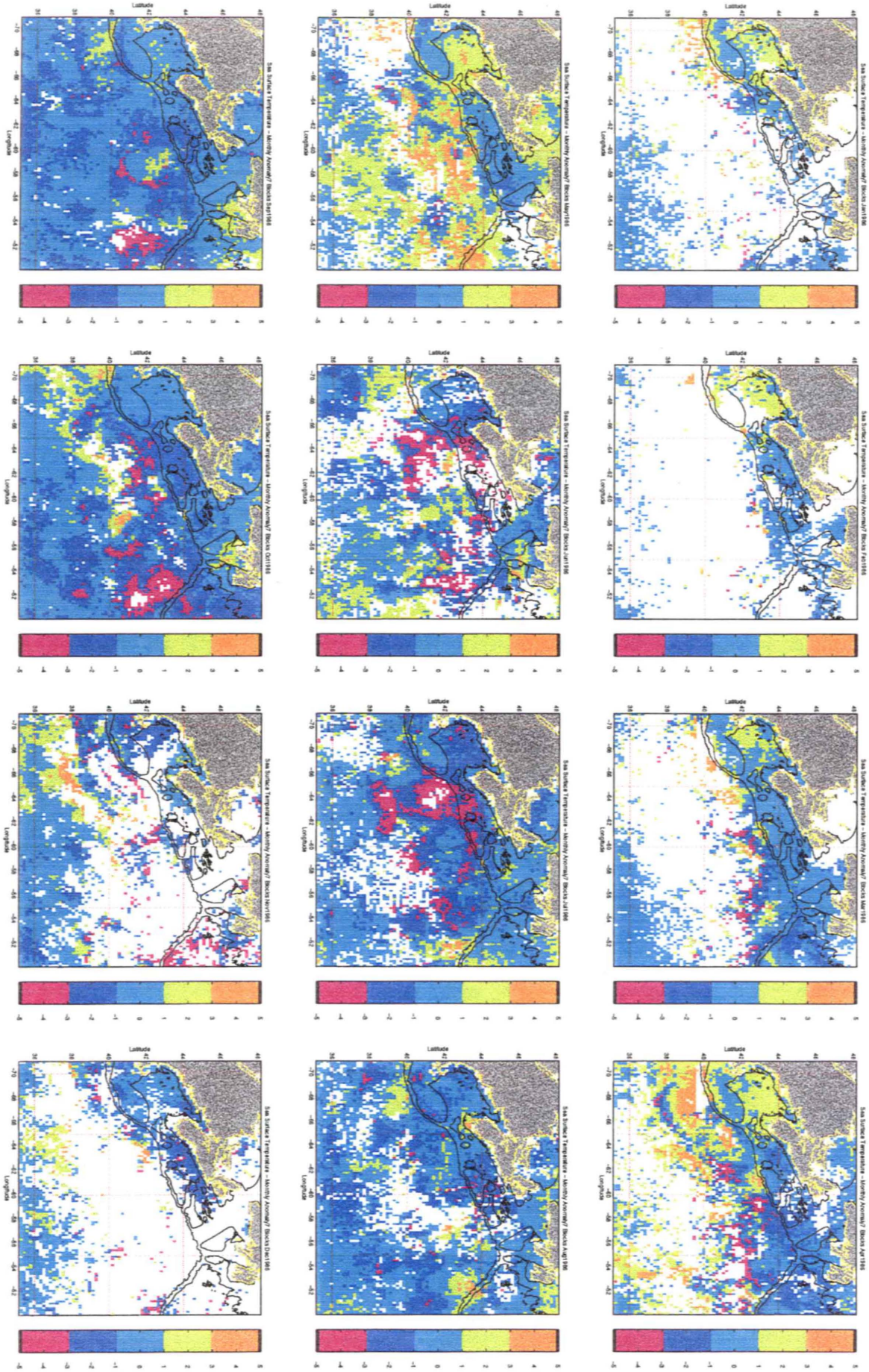
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1987

Average Values must occur in at least 7 years ('81-'96)

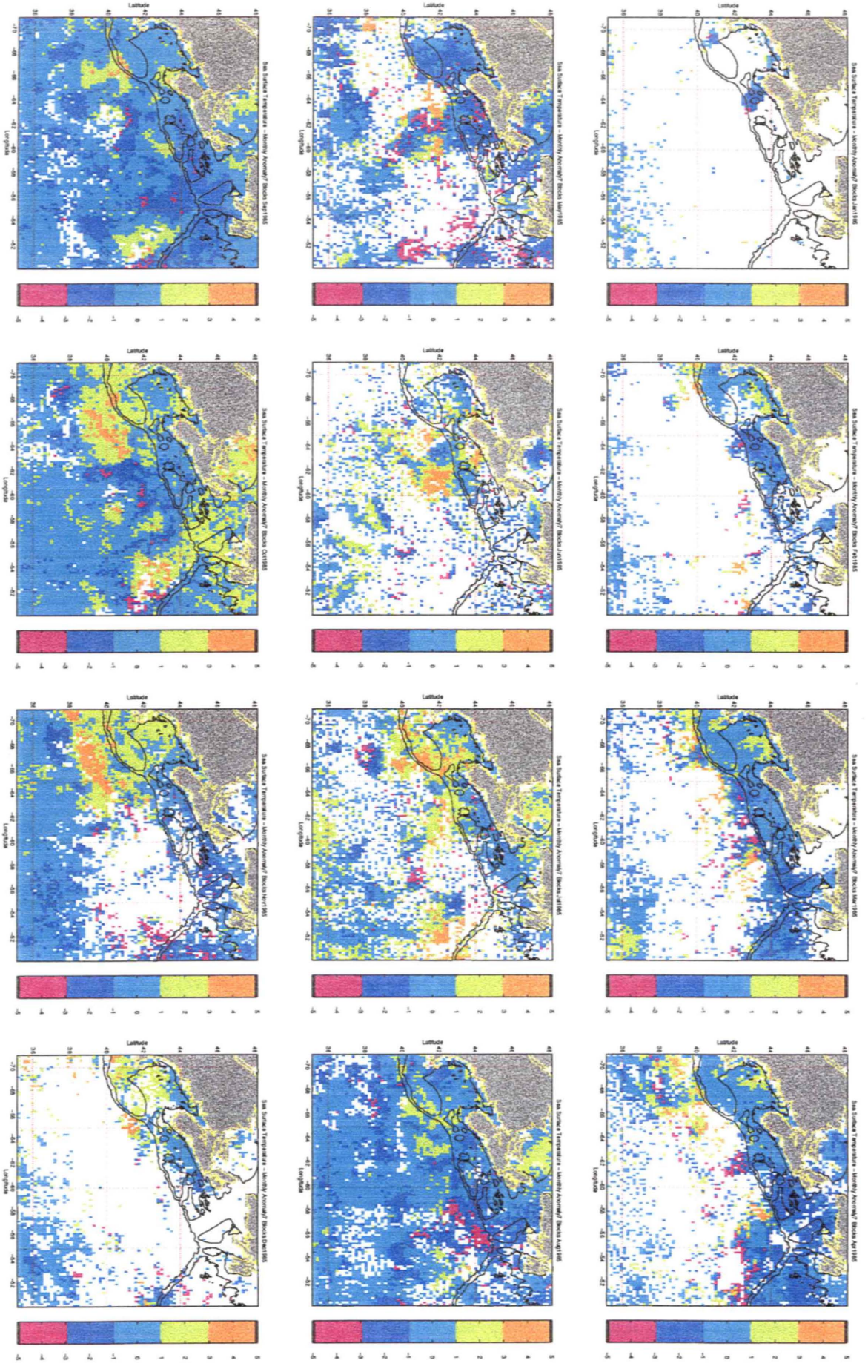
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1986

Average Values must occur in at least 7 years ('81-'96)

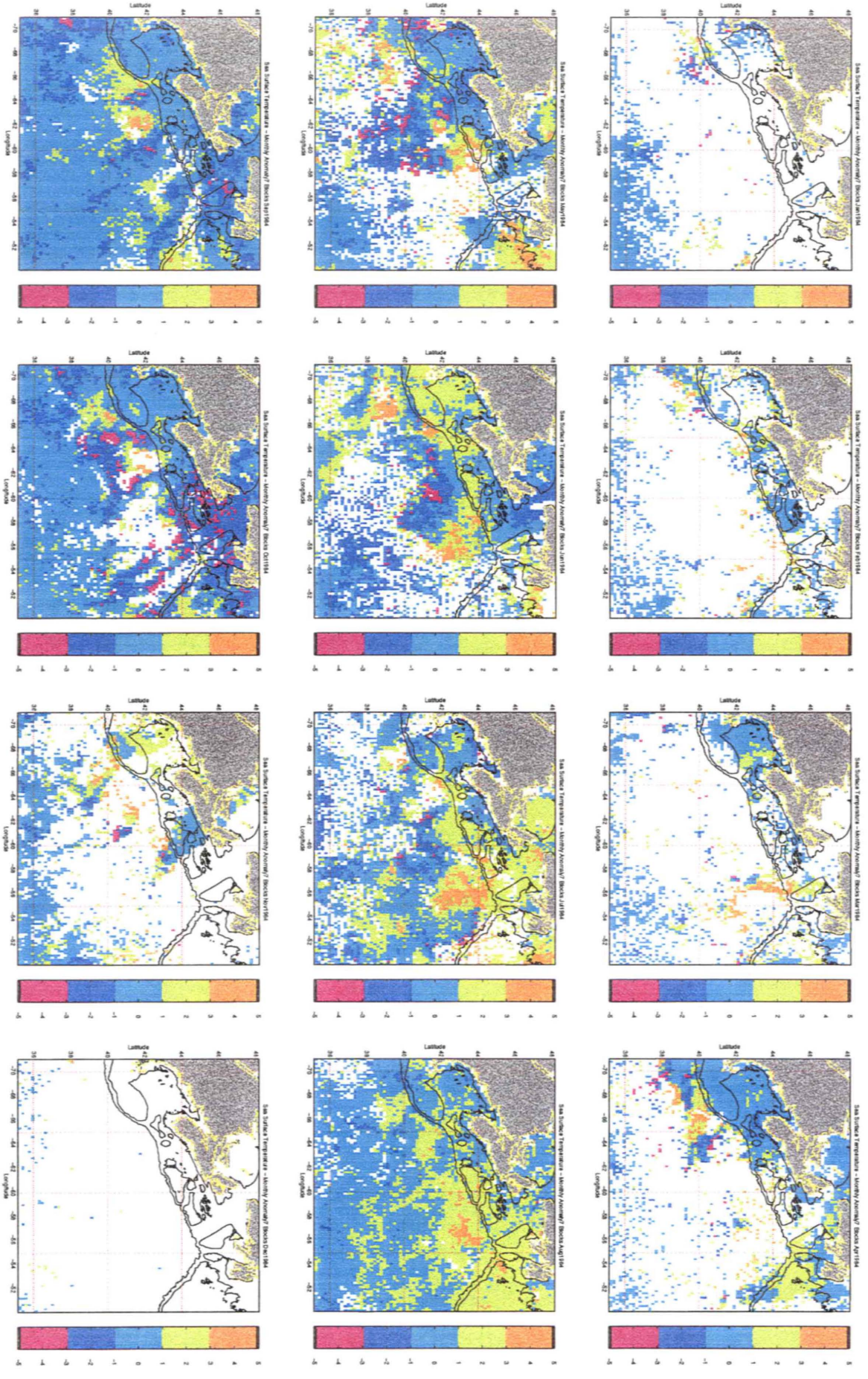
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1985

Average Values must occur in at least 7 years ('81-'96)

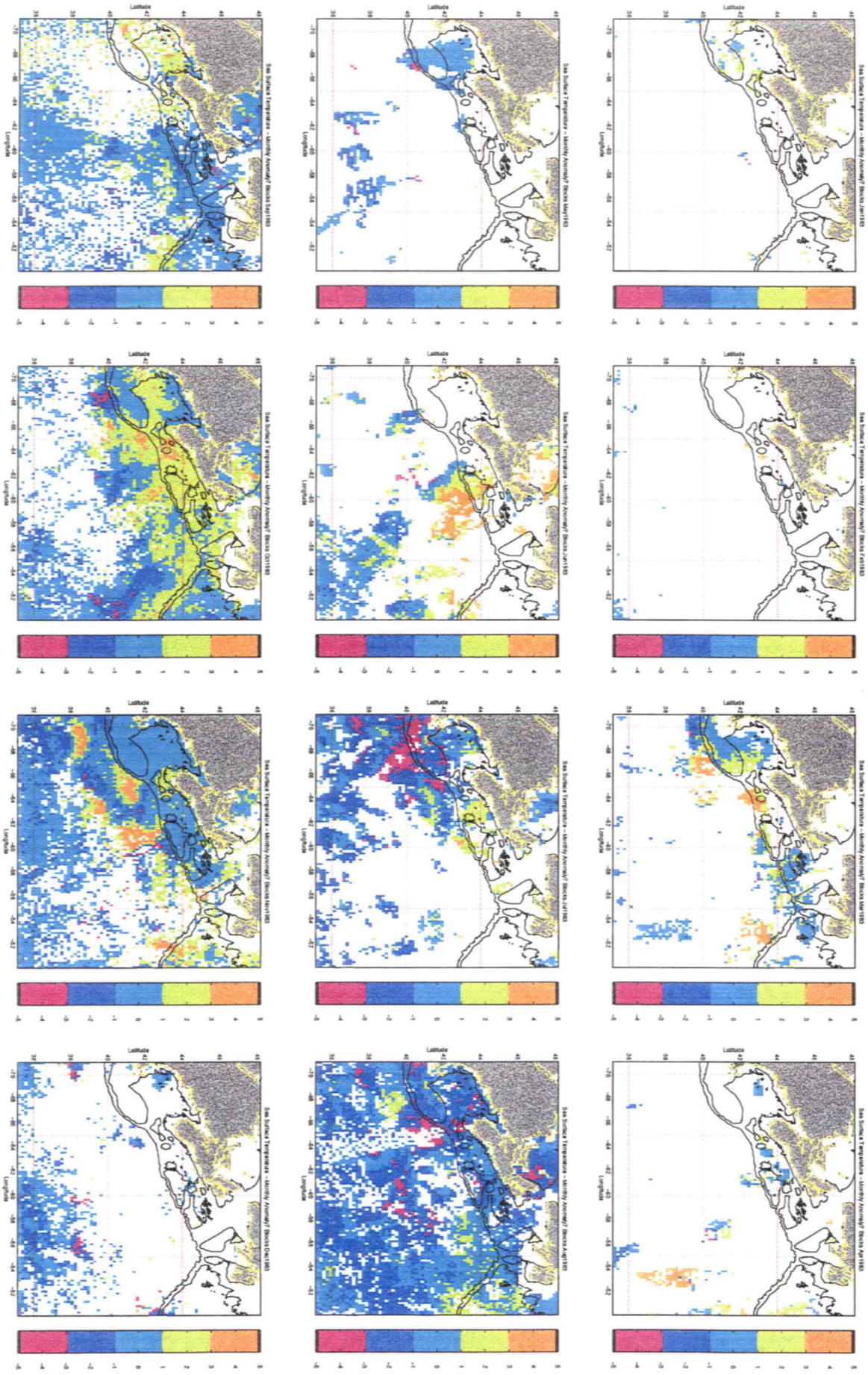
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1984

Average Values must occur in at least 7 years ('81-'96)

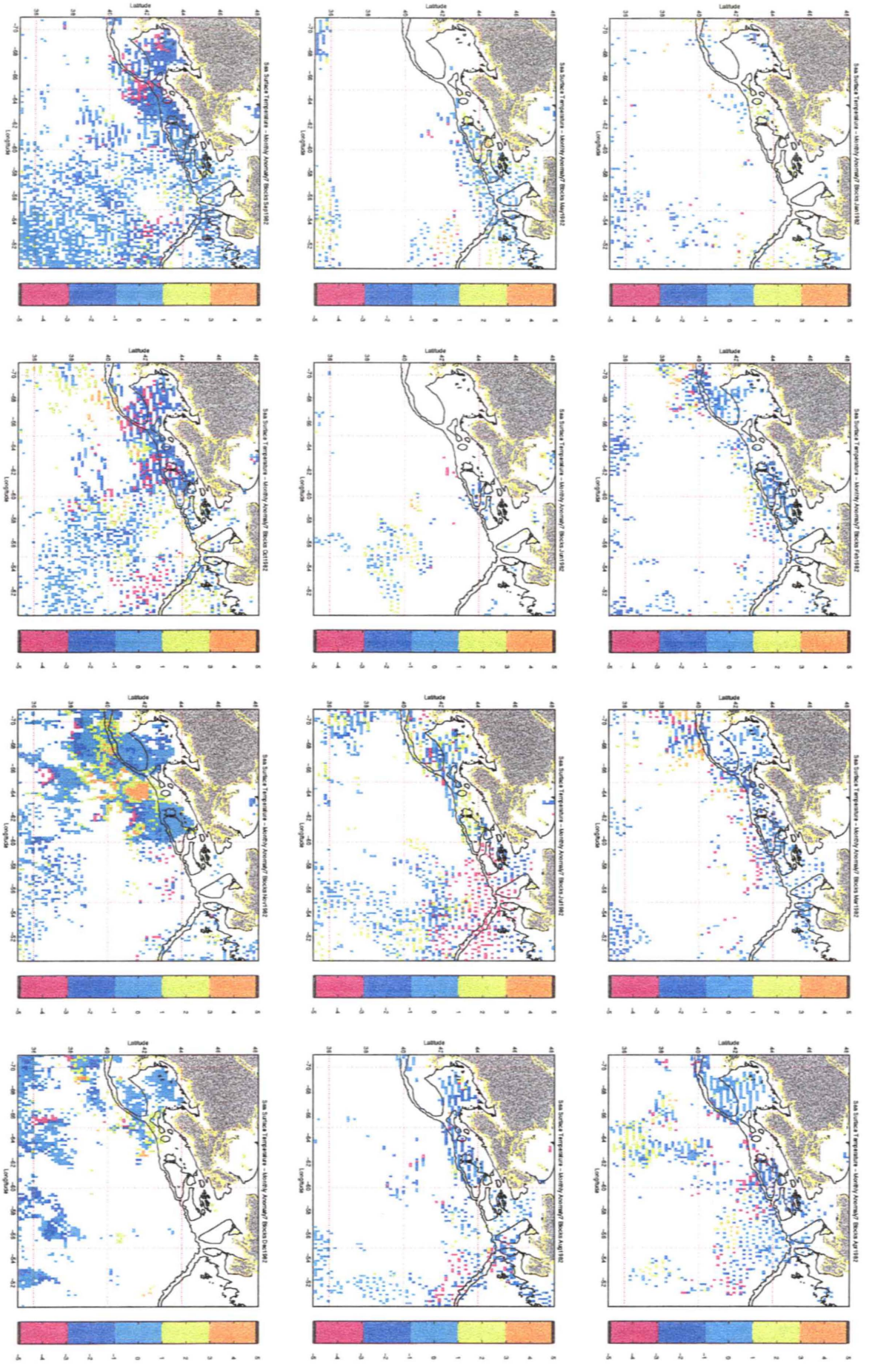
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1983

Average Values must occur in at least 7 years ('81-'96)

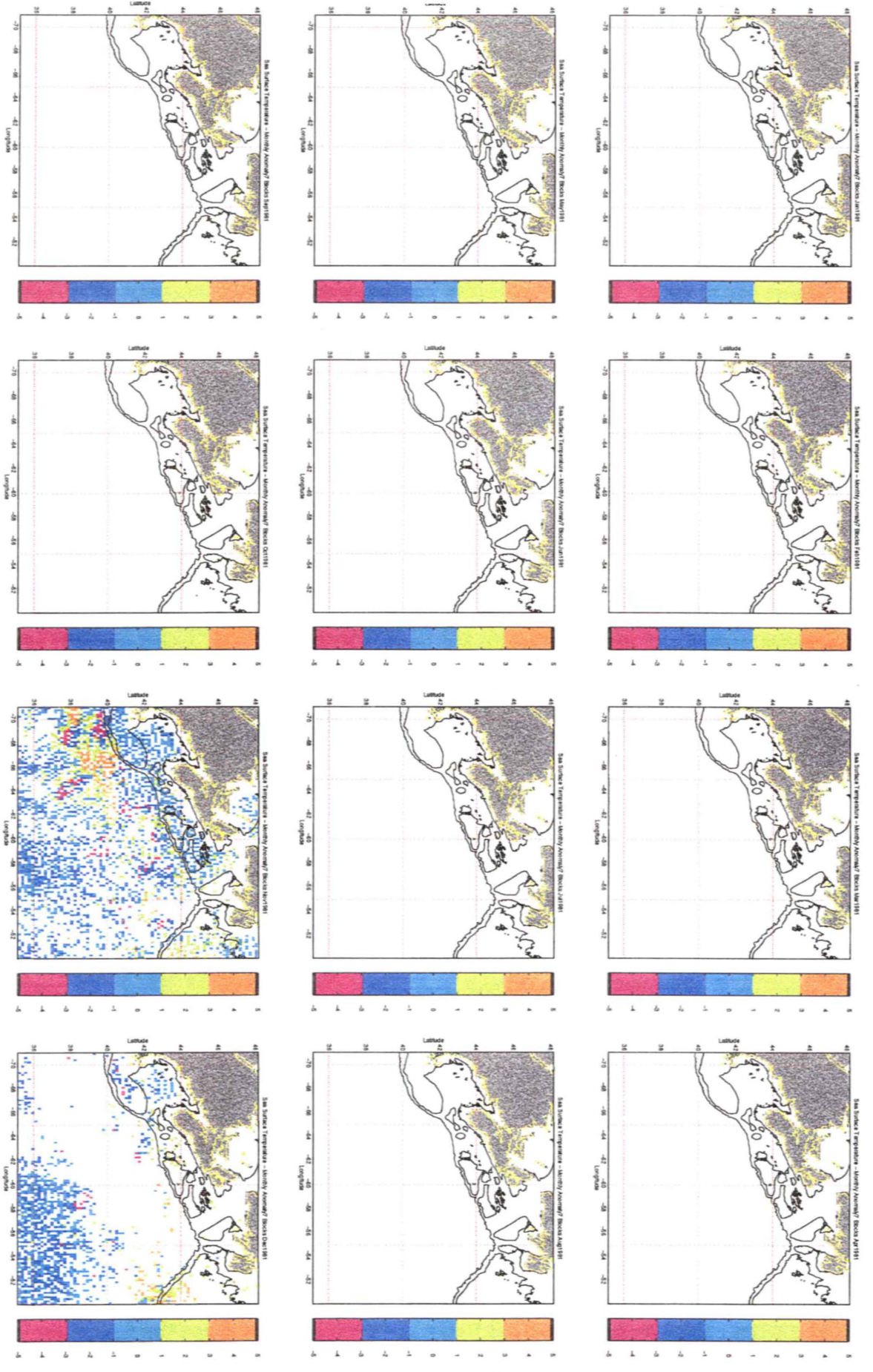
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1982

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1981

Average Values must occur in at least 7 years ('81-'96)

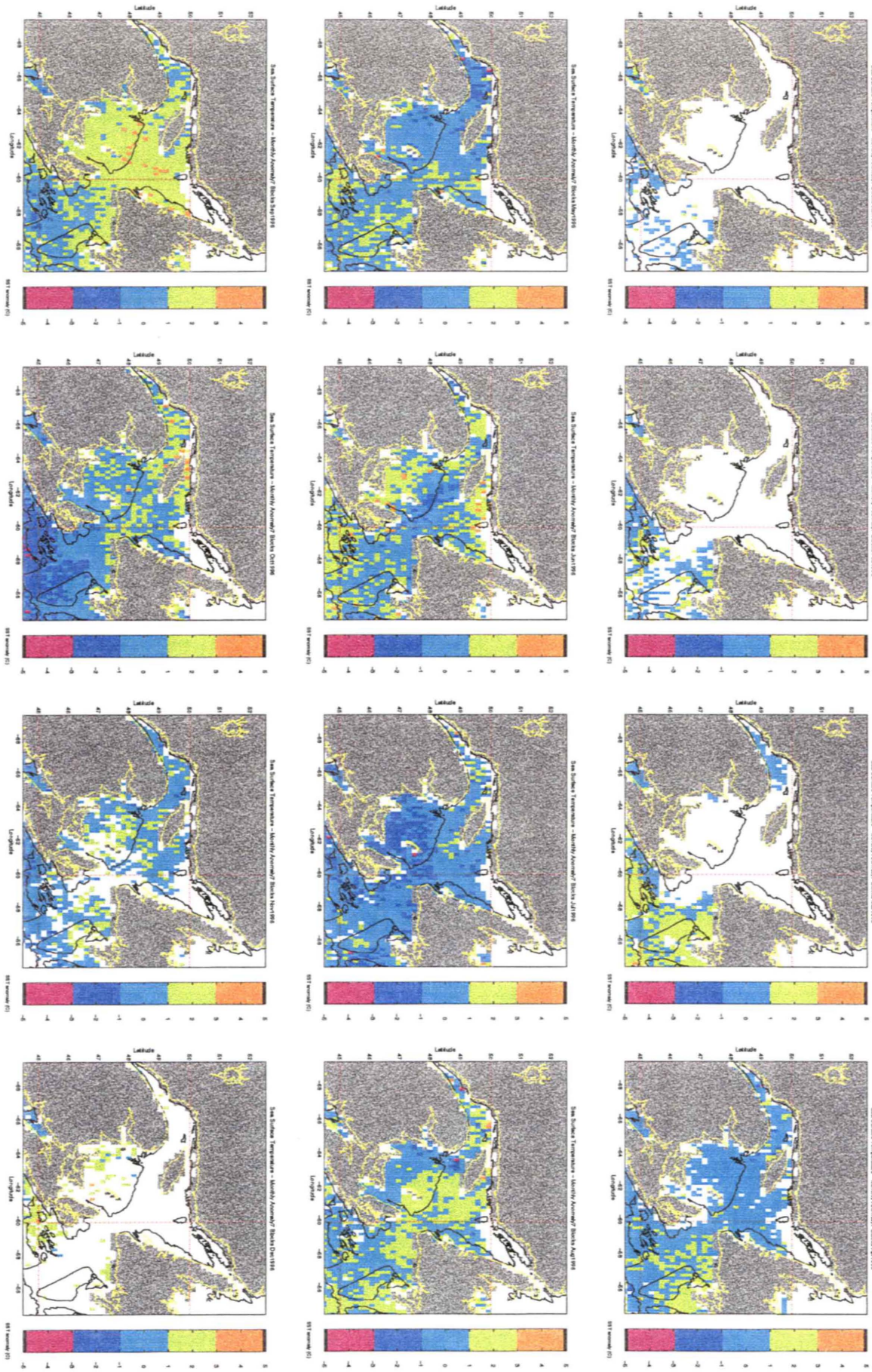
Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map B 16

Annex C

Monthly Anomalies in Sea-Surface Temperature

Gulf

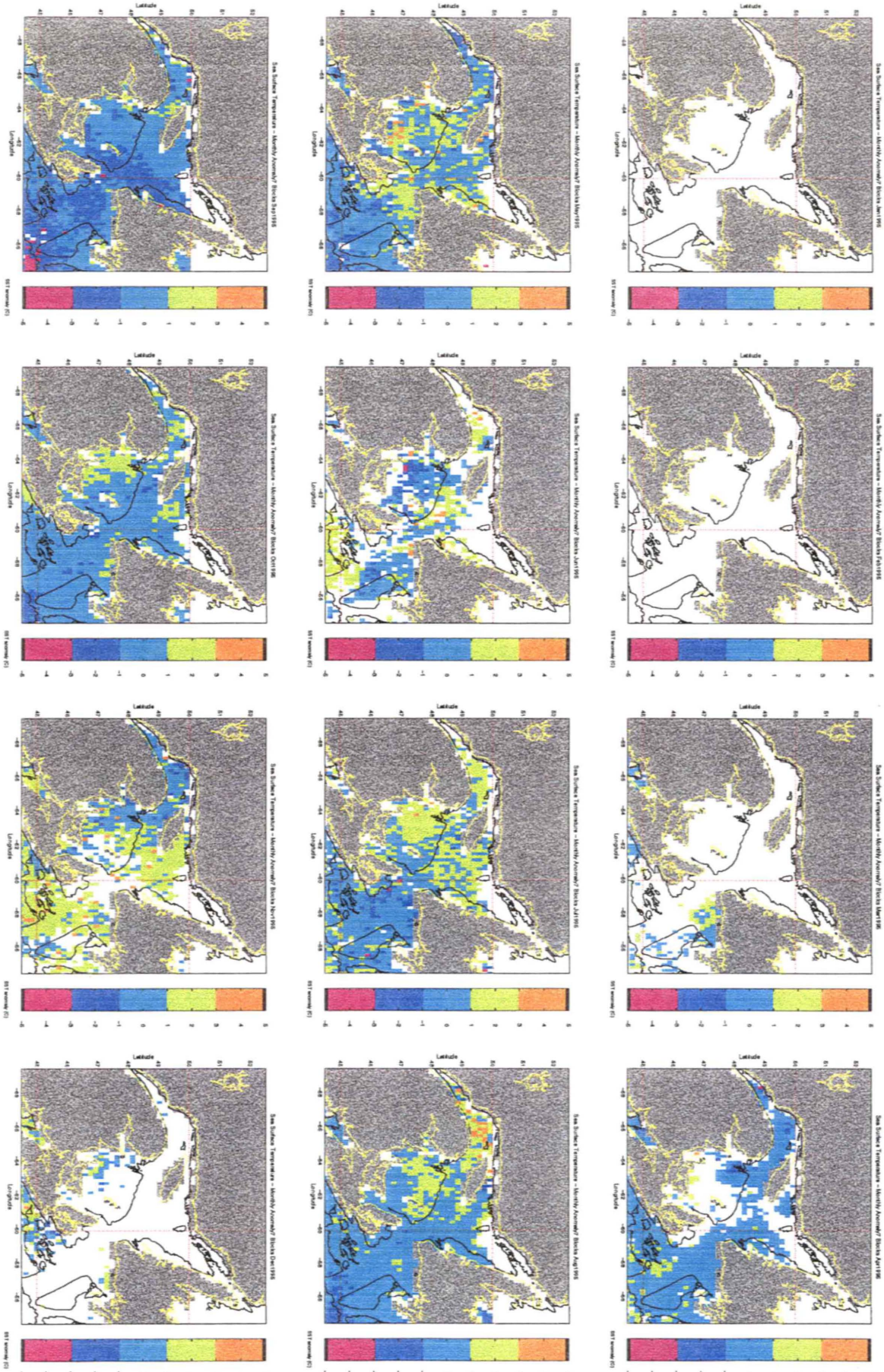


Monthly Anomalies in Sea-Surface Temperatures 1996

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 01

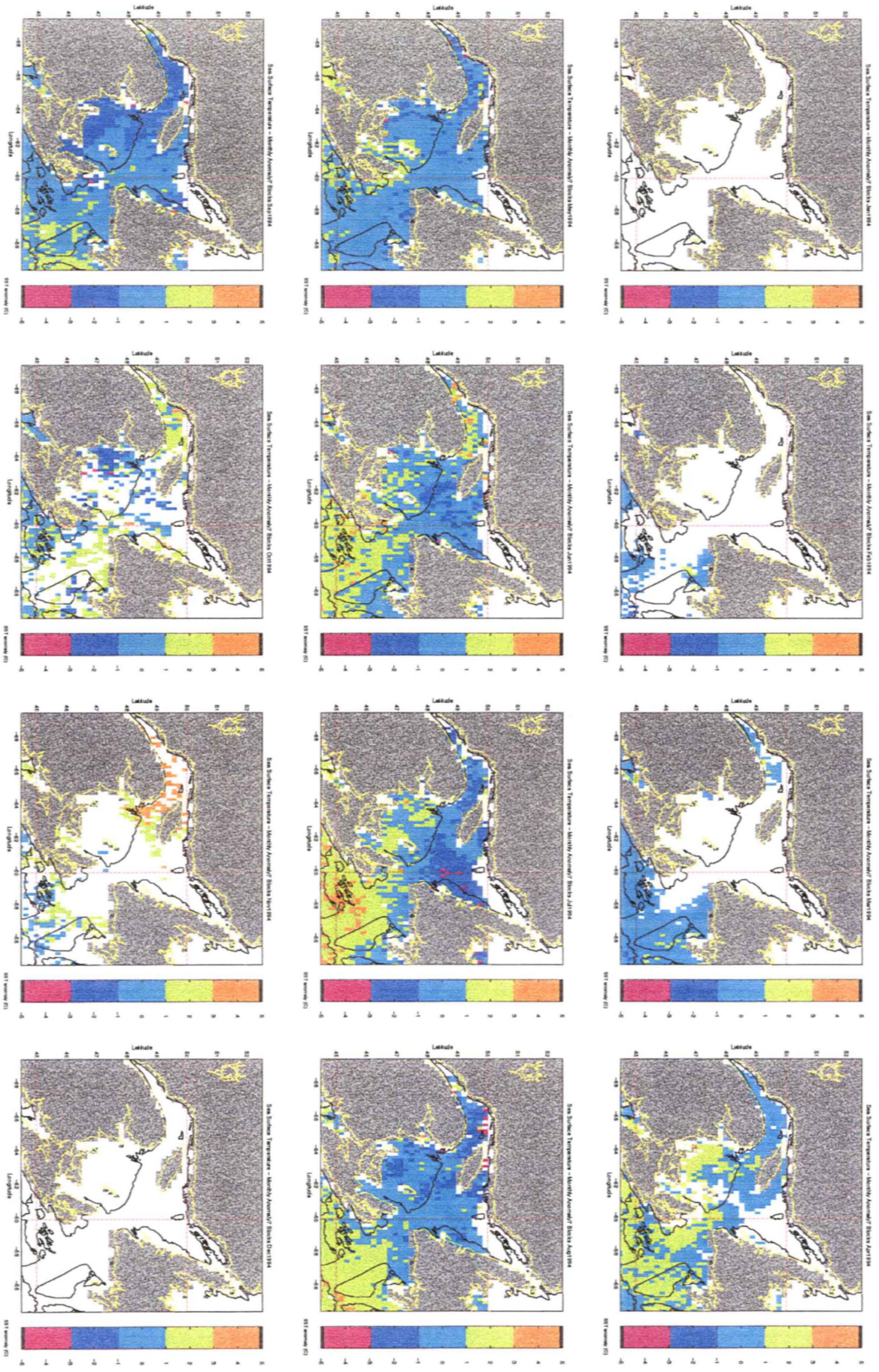


Monthly Anomalies in Sea-Surface Temperatures 1995

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 02

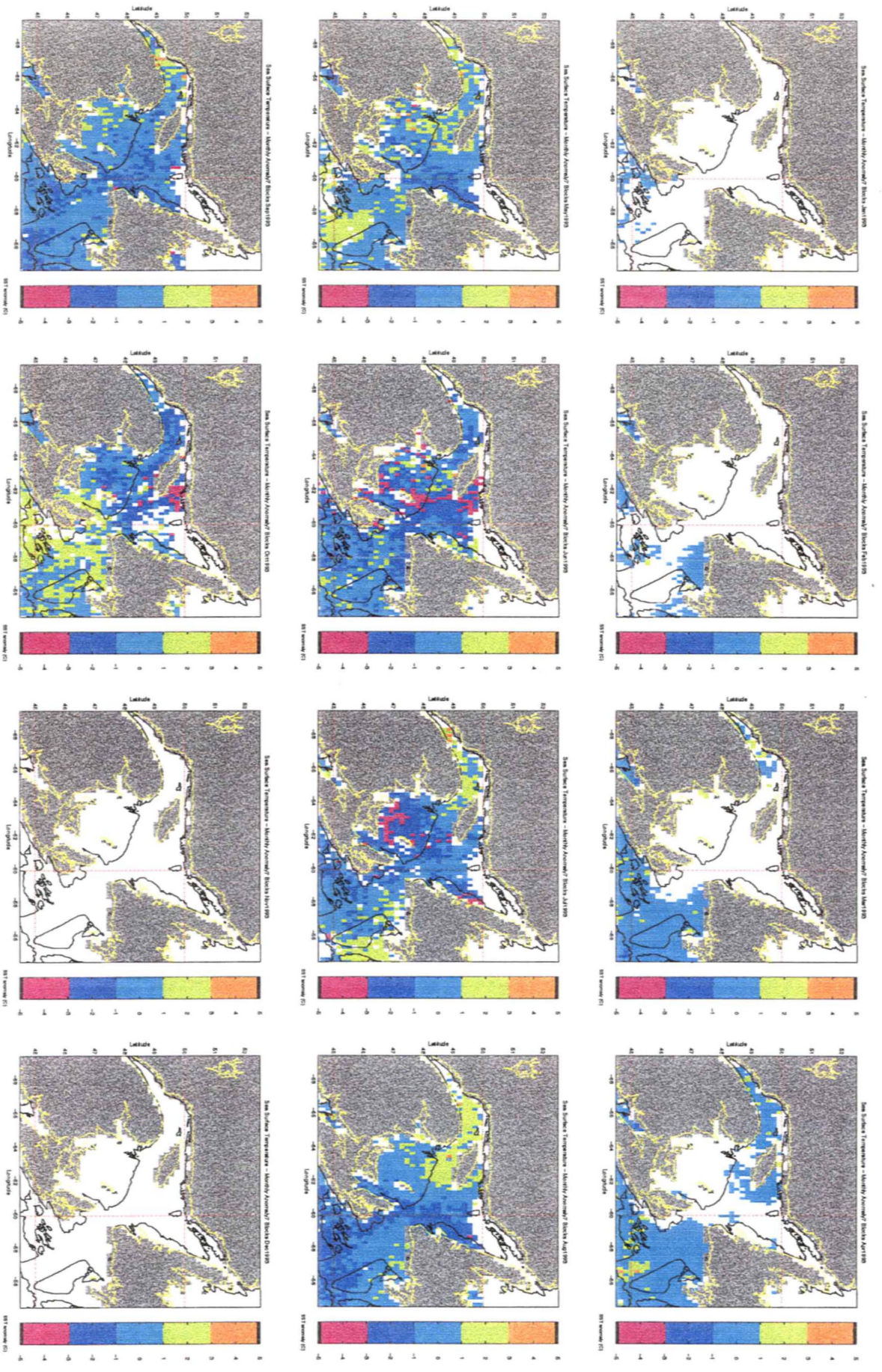


Monthly Anomalies in Sea-Surface Temperatures 1994

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 03

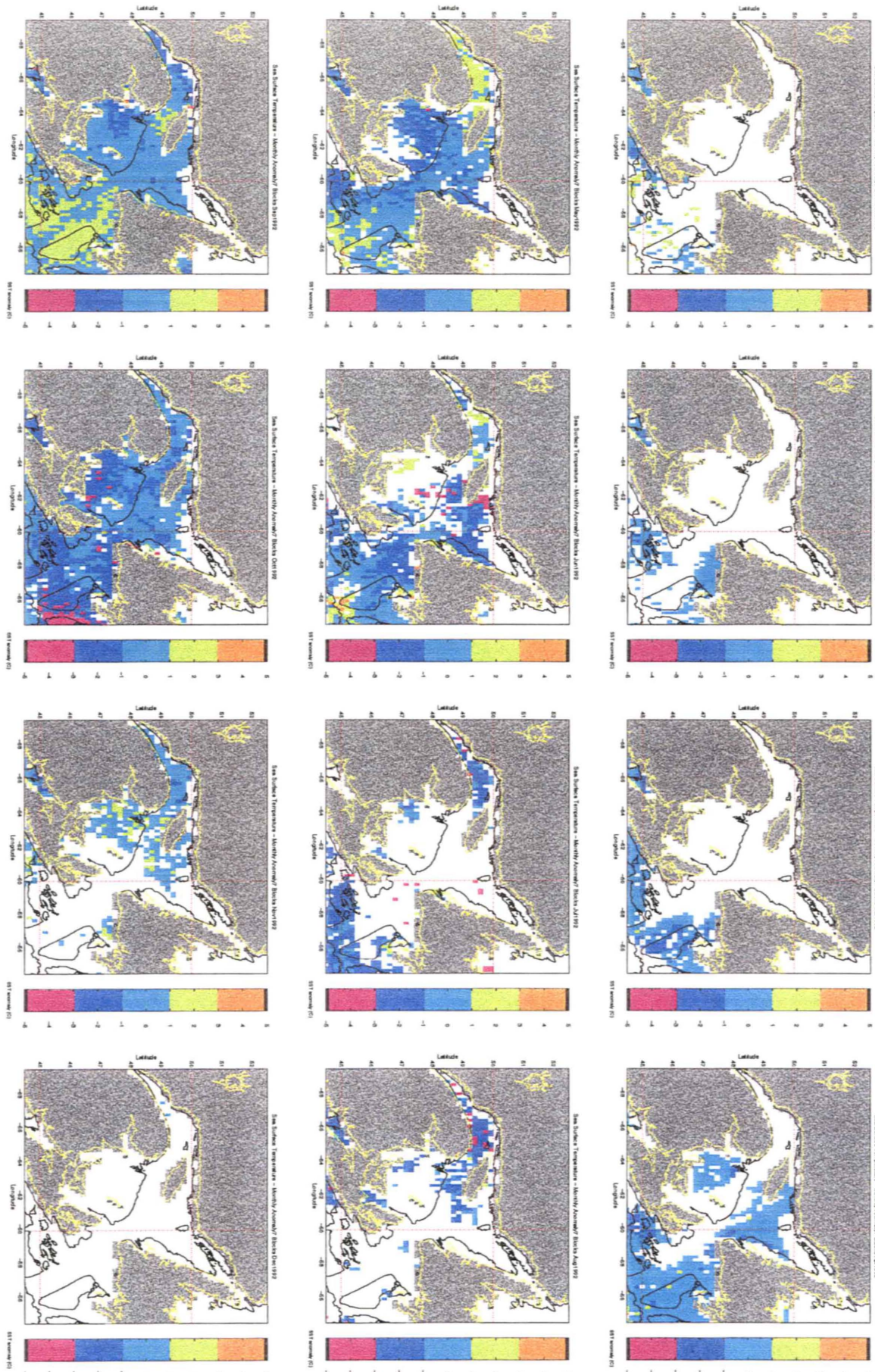


Monthly Anomalies in Sea-Surface Temperatures 1993

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 04

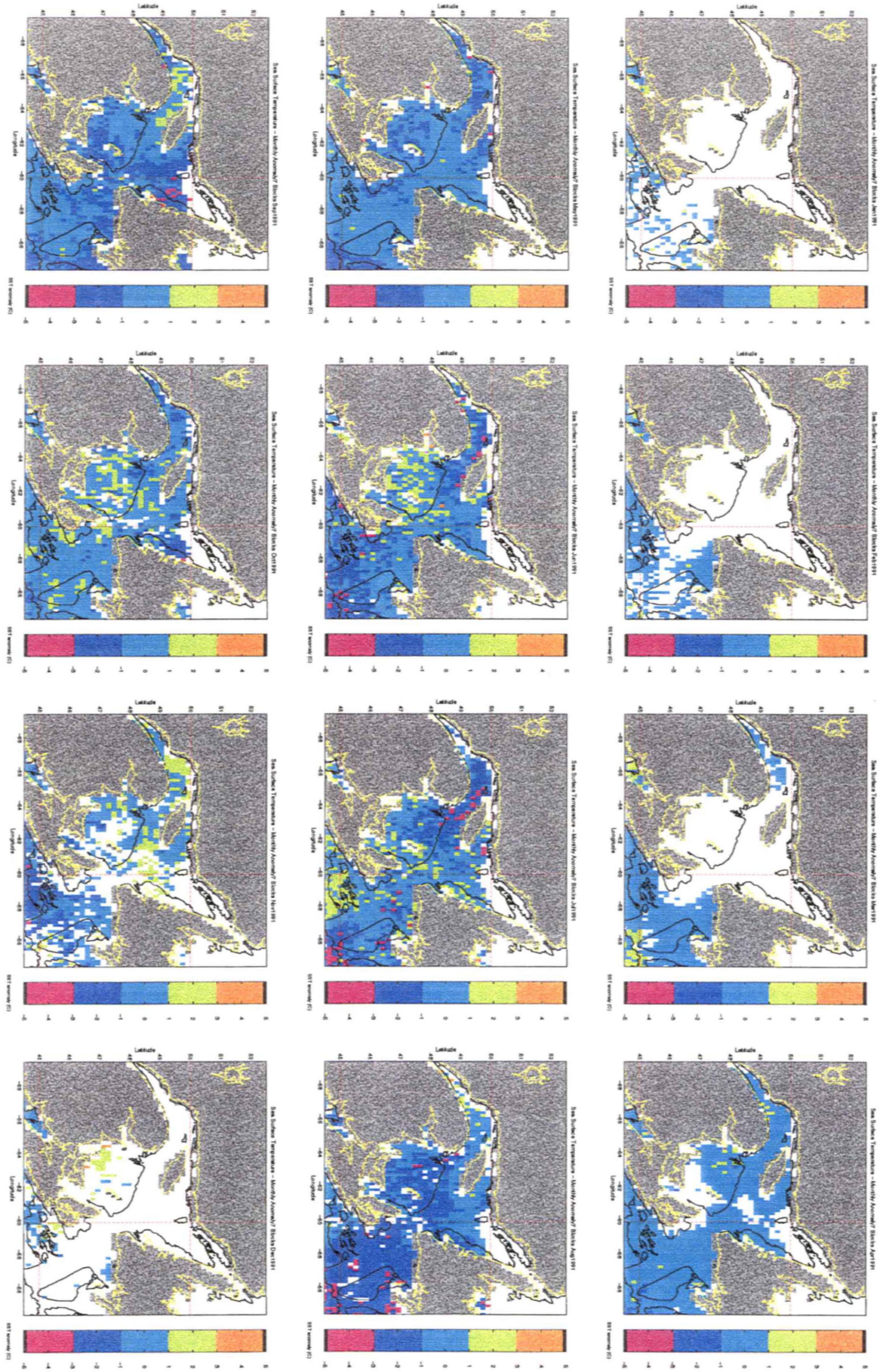


Monthly Anomalies in Sea-Surface Temperatures 1992

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 05

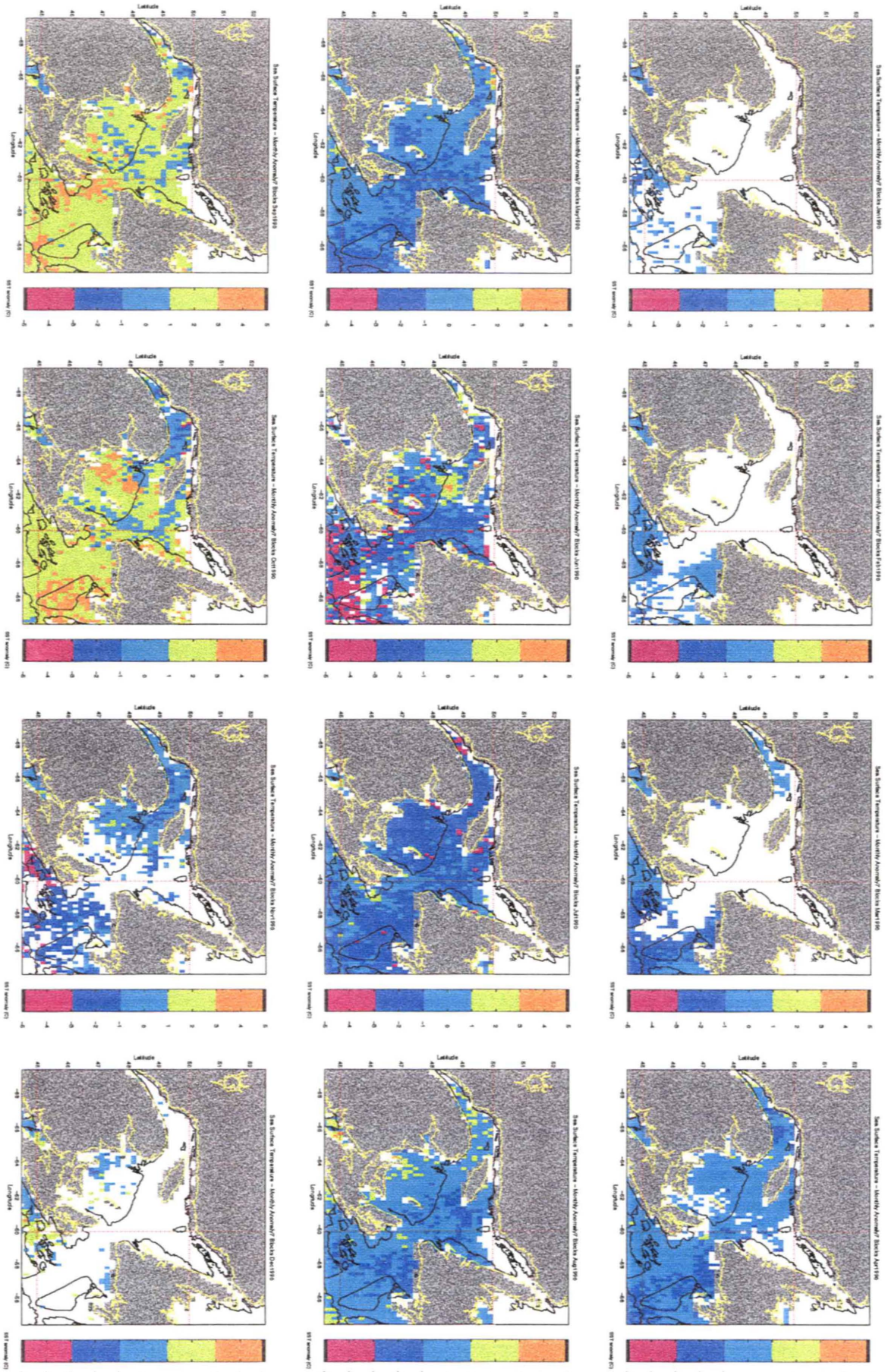


Monthly Anomalies in Sea-Surface Temperatures 1991

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 06

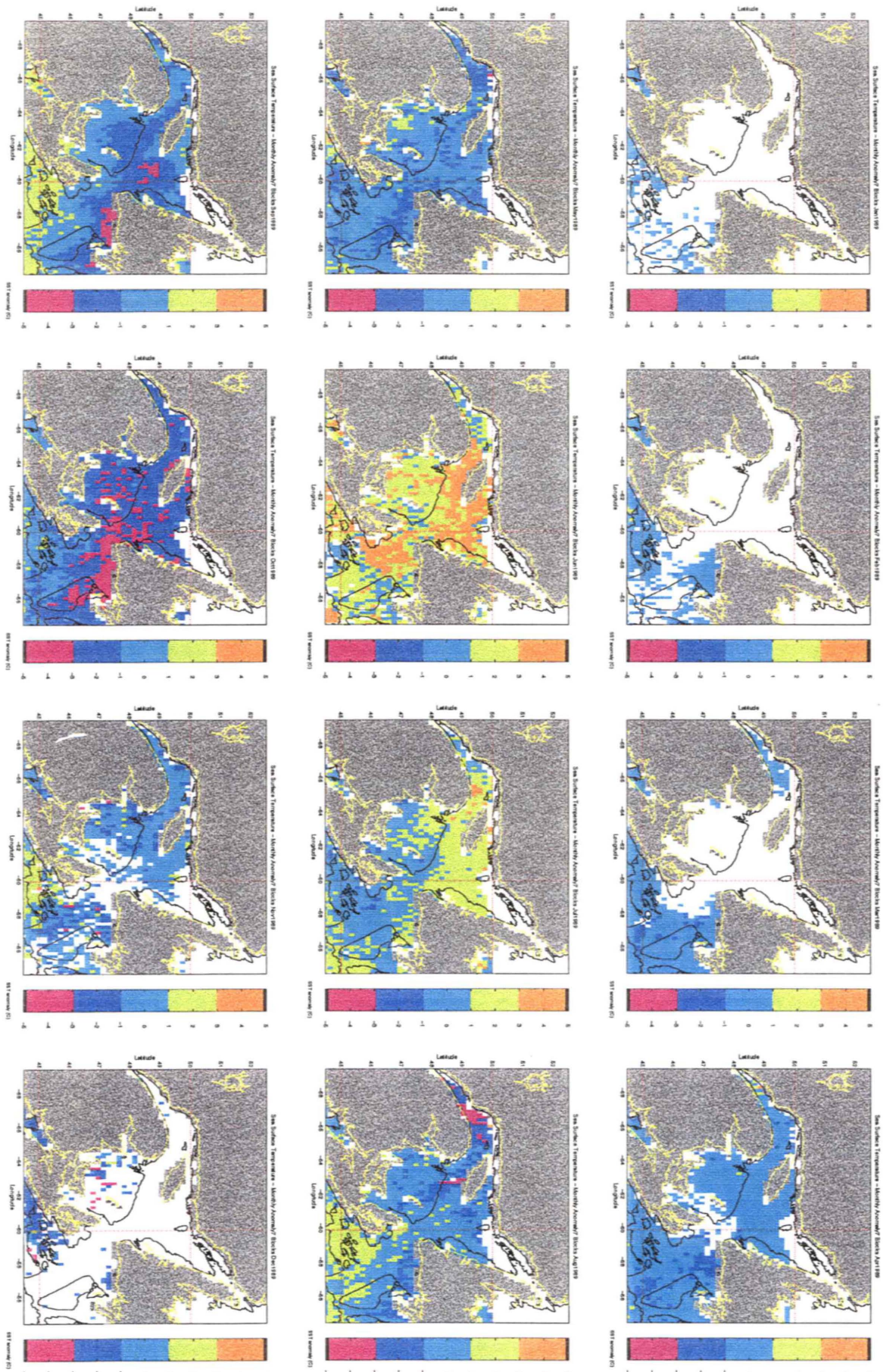


Monthly Anomalies in Sea-Surface Temperatures 1990

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 07

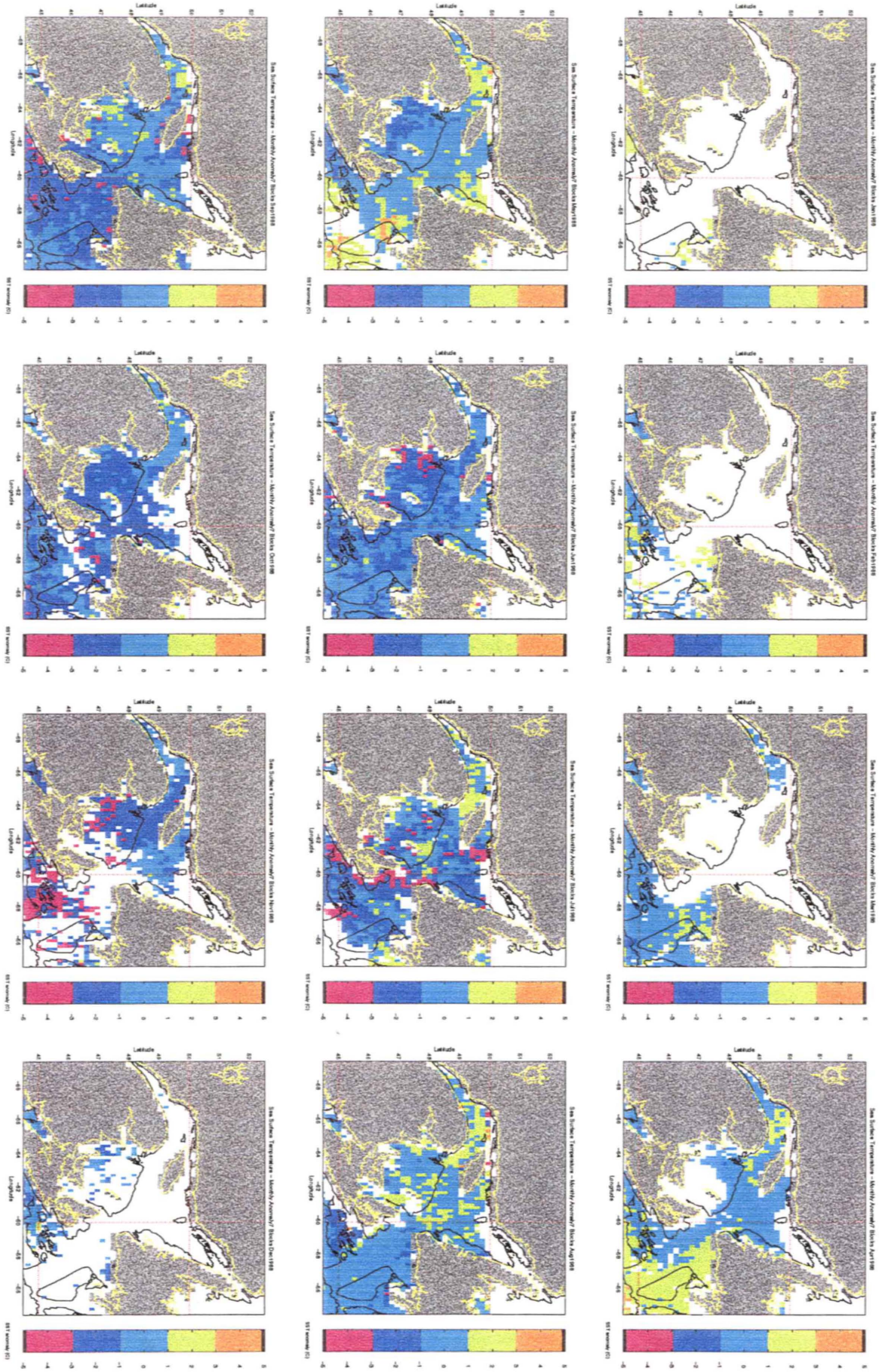


Monthly Anomalies in Sea-Surface Temperatures 1989

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 08

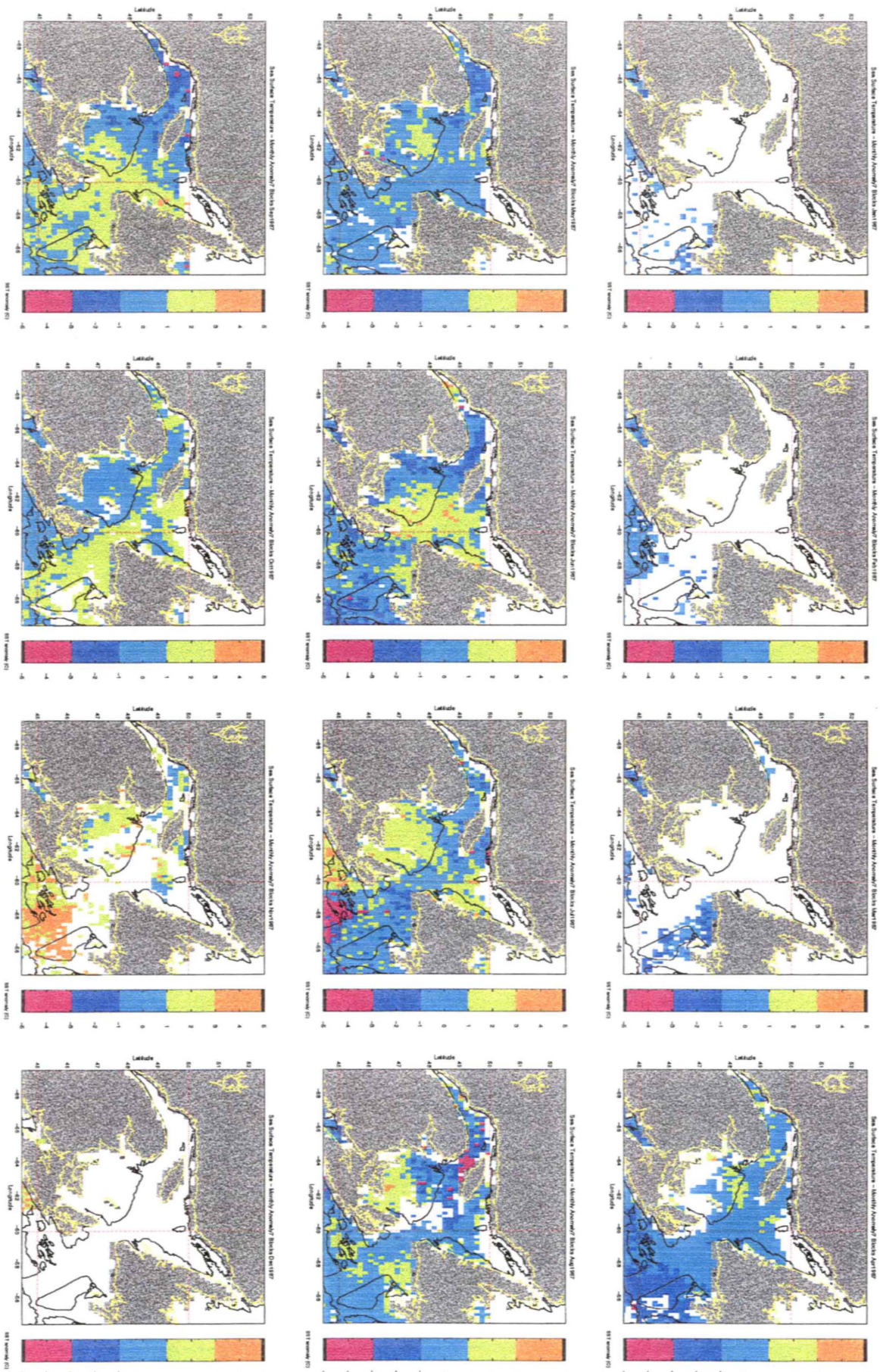


Monthly Anomalies in Sea-Surface Temperatures 1988

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 09

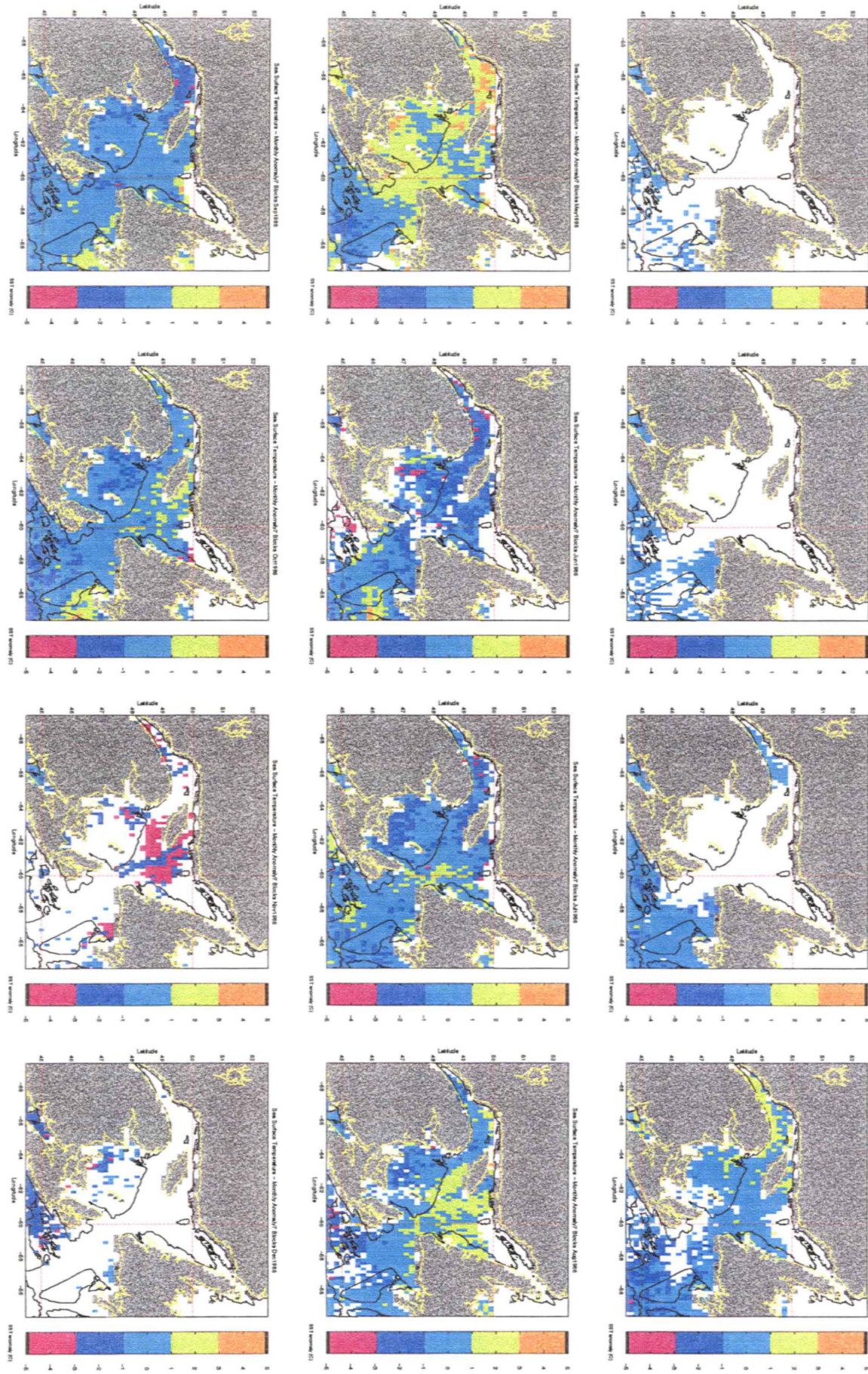


Monthly Anomalies in Sea-Surface Temperatures 1987

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 10

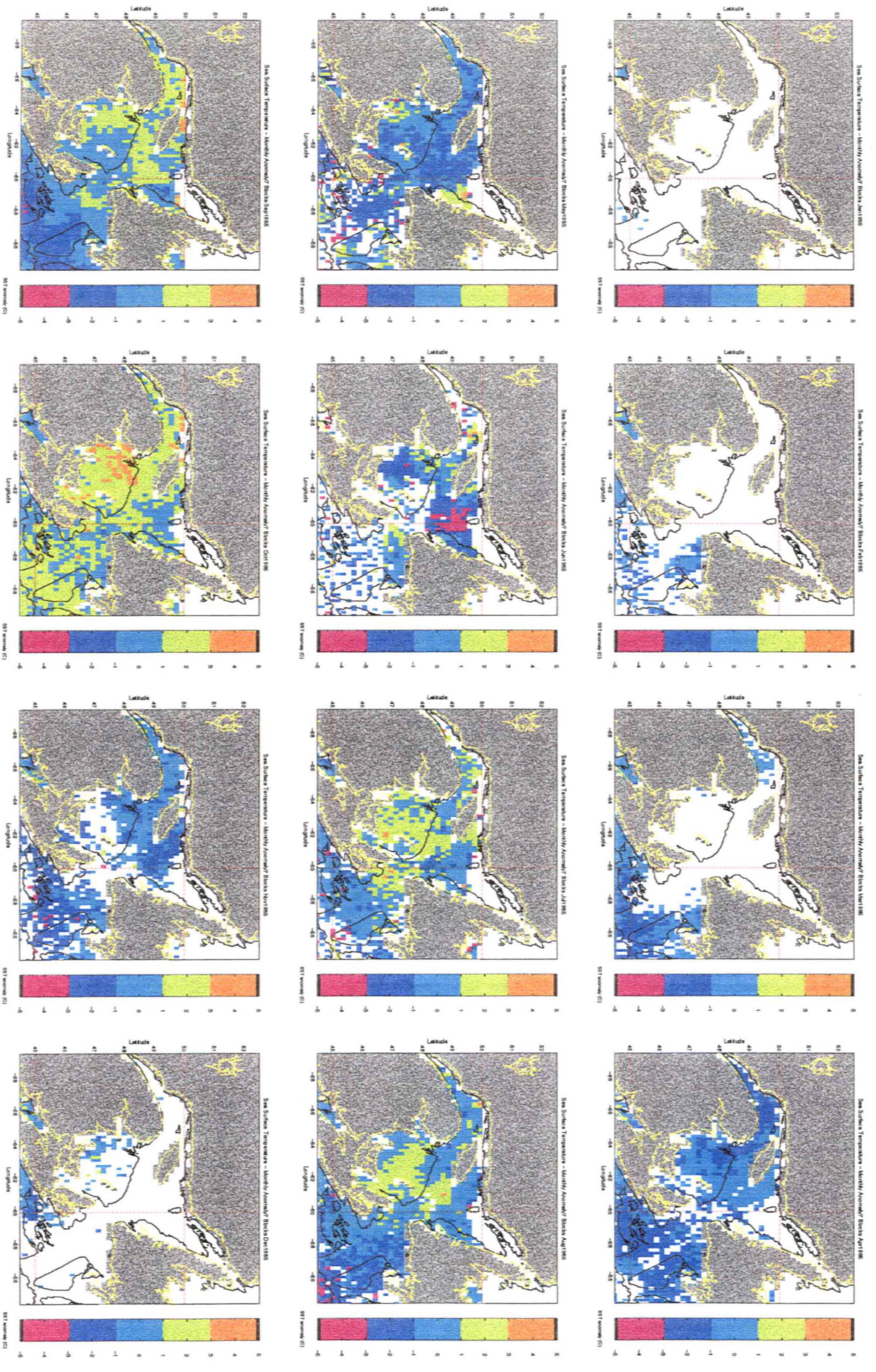


Monthly Anomalies in Sea-Surface Temperatures 1986

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 11

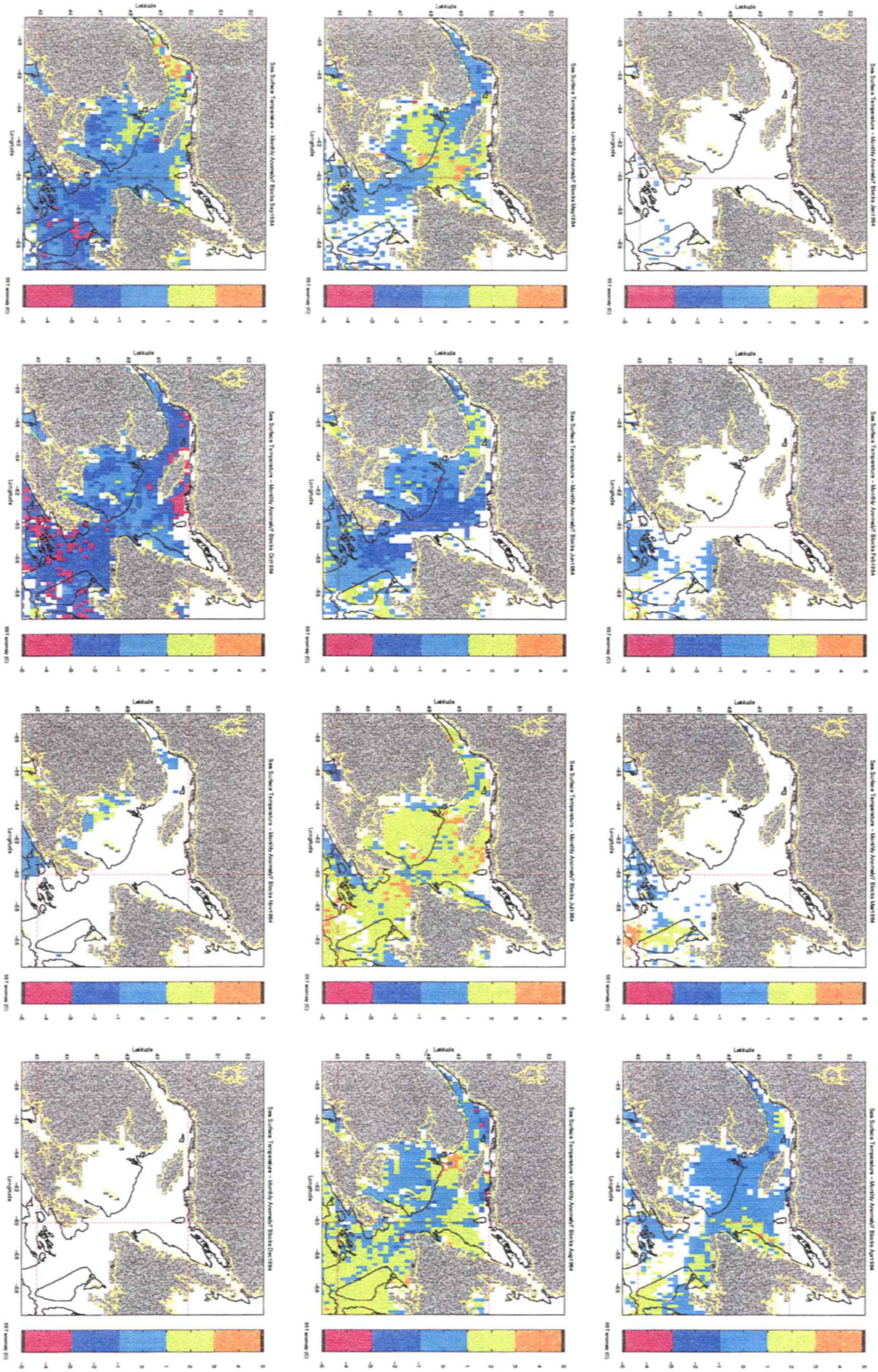


Monthly Anomalies in Sea-Surface Temperatures 1985

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

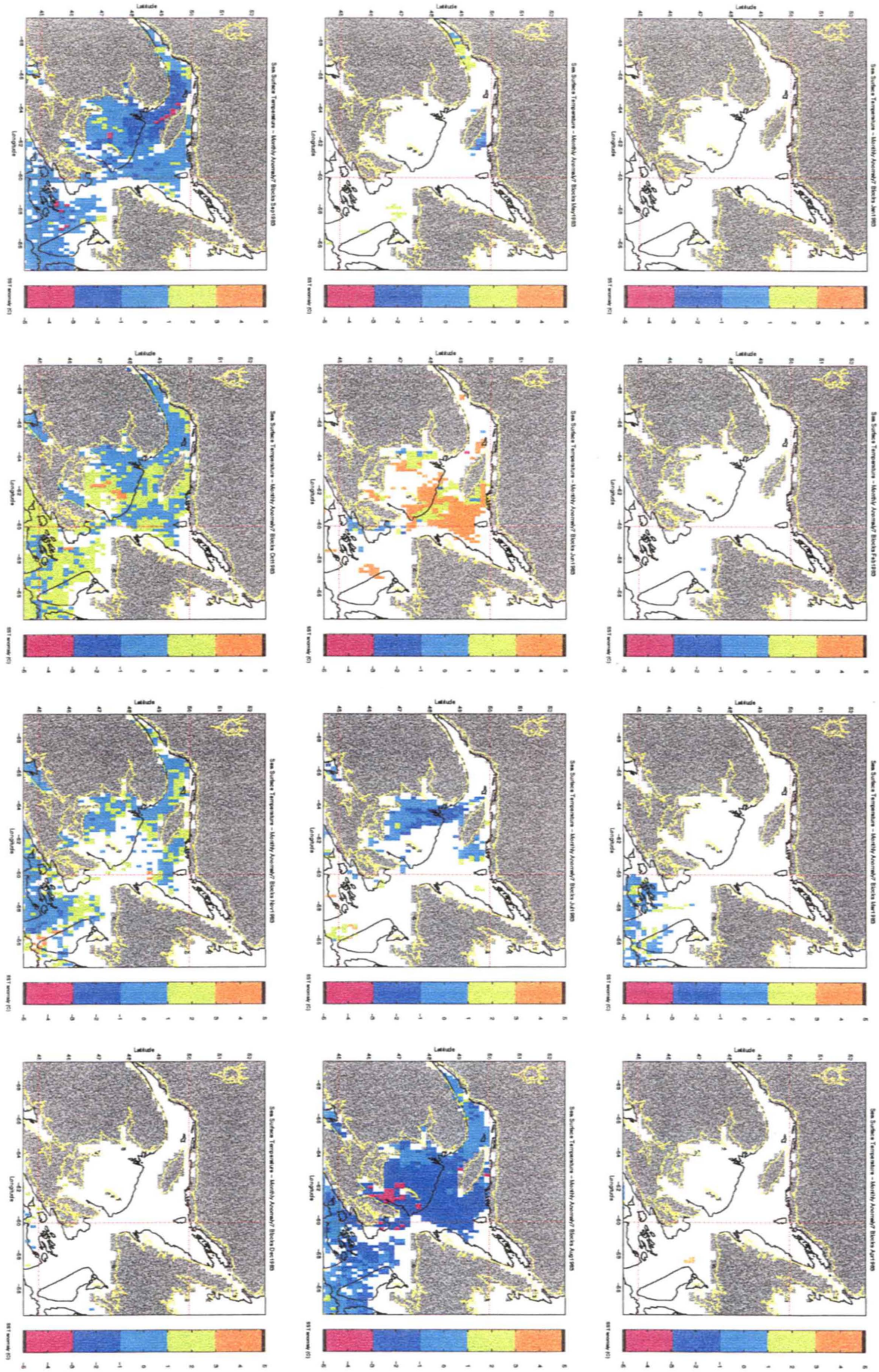
Map C 12



Monthly Anomalies in Sea-Surface Temperatures 1984

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

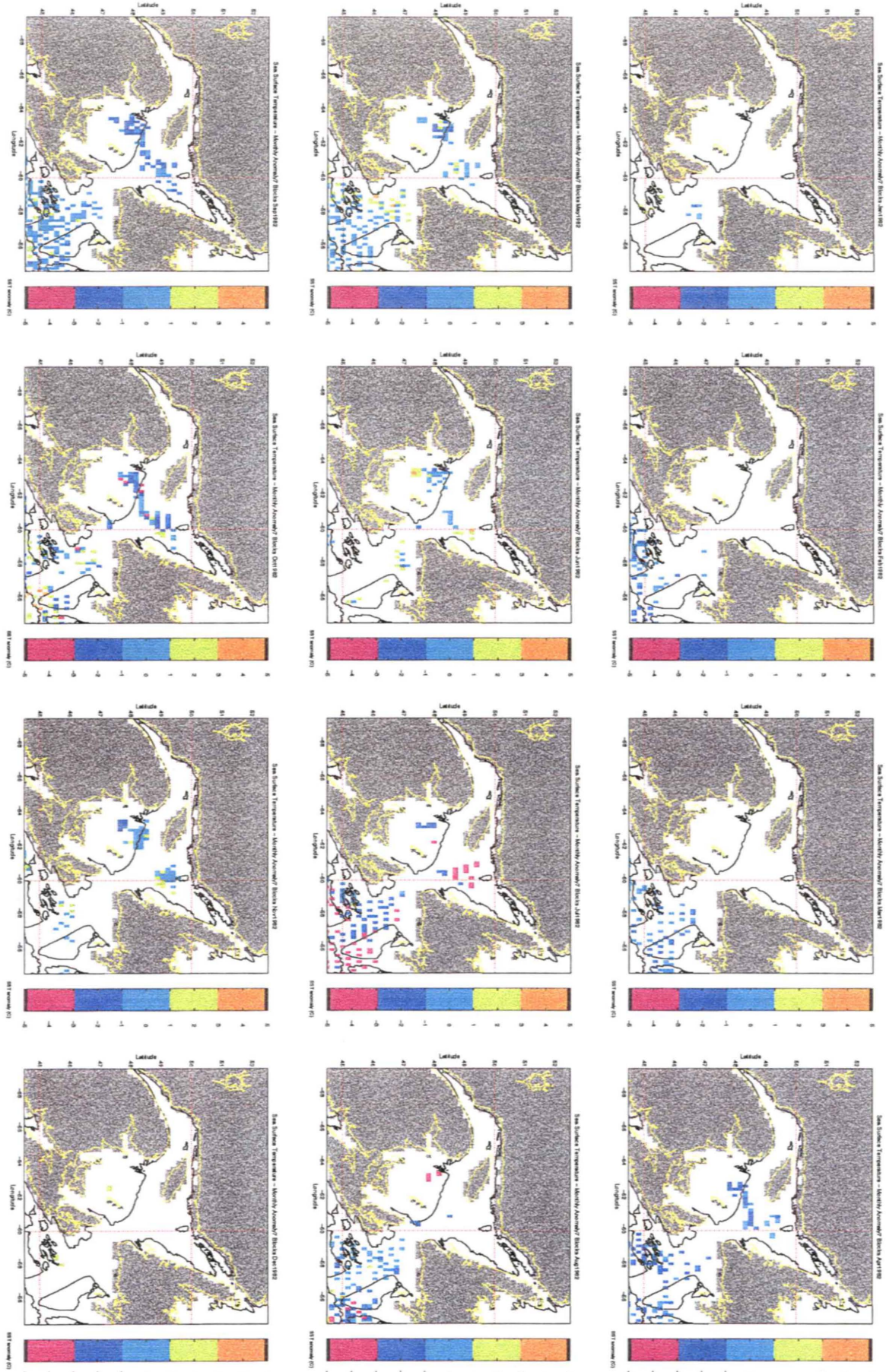


Monthly Anomalies in Sea-Surface Temperatures 1983

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 14

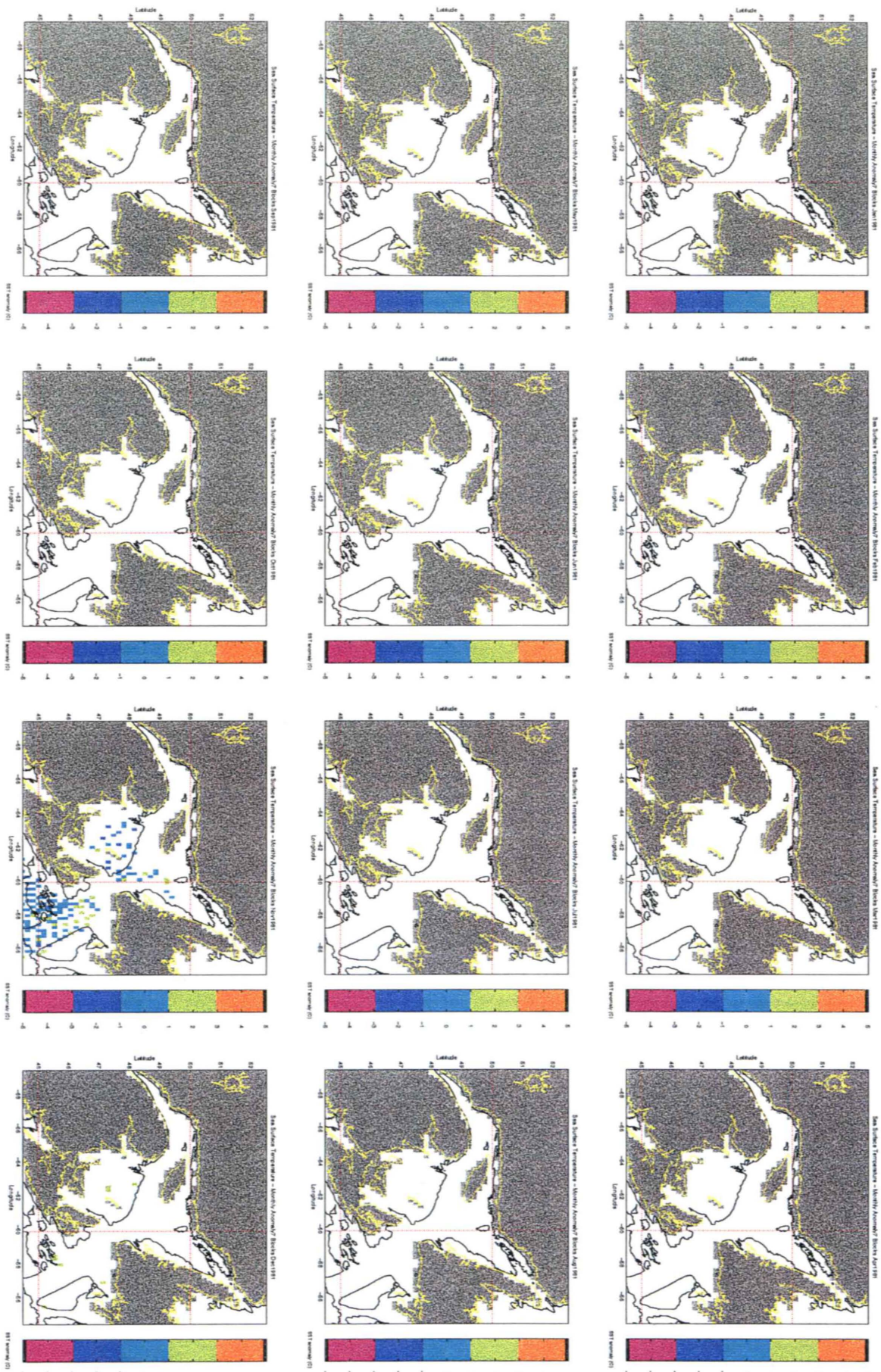


Monthly Anomalies in Sea-Surface Temperatures 1982

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 15



Monthly Anomalies in Sea-Surface Temperatures 1981

Average Values must occur in at least 7 years ('81-'96)

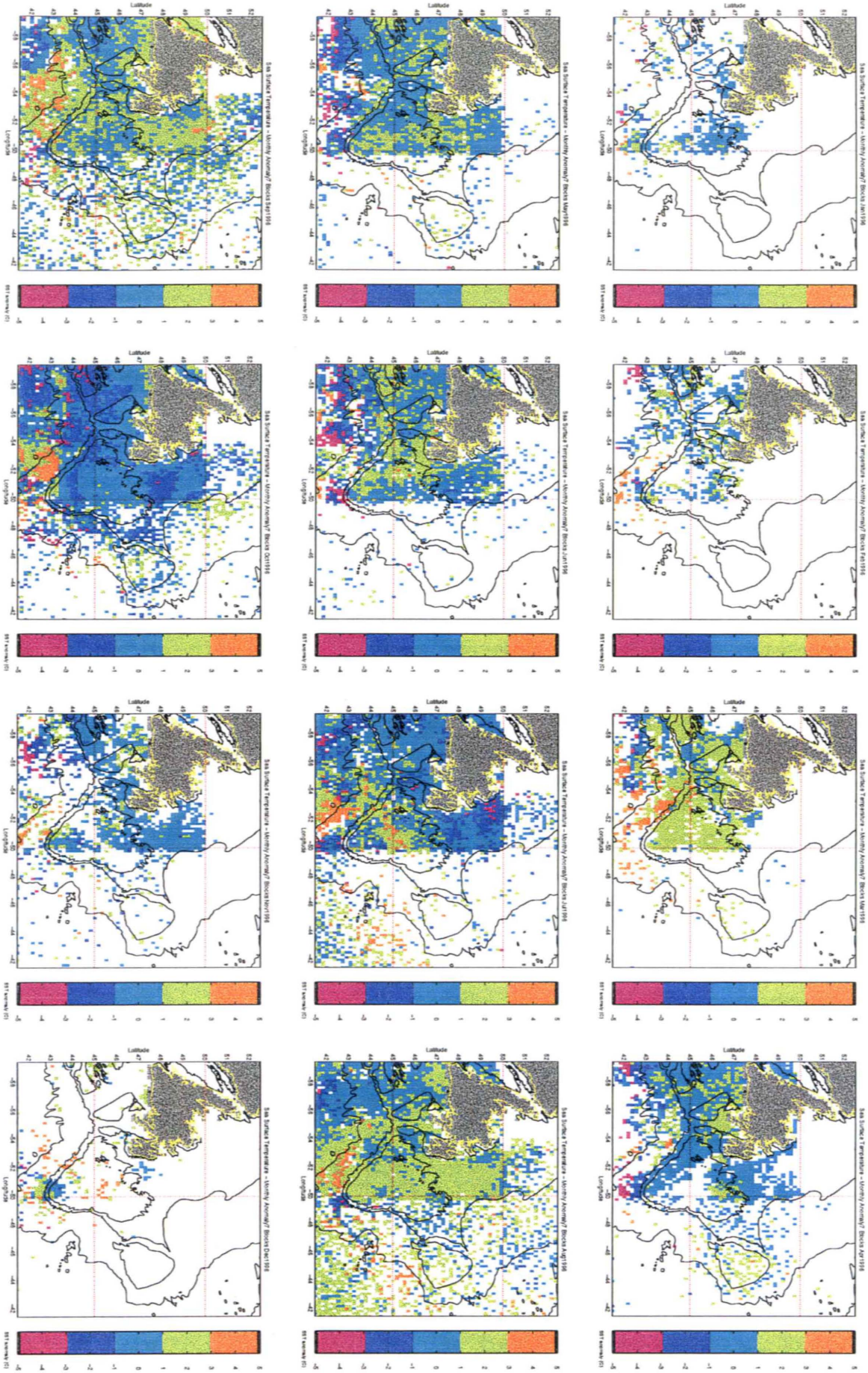
Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map C 16

Annex D

Monthly Anomalies in Sea-Surface Temperature

Newfoundland

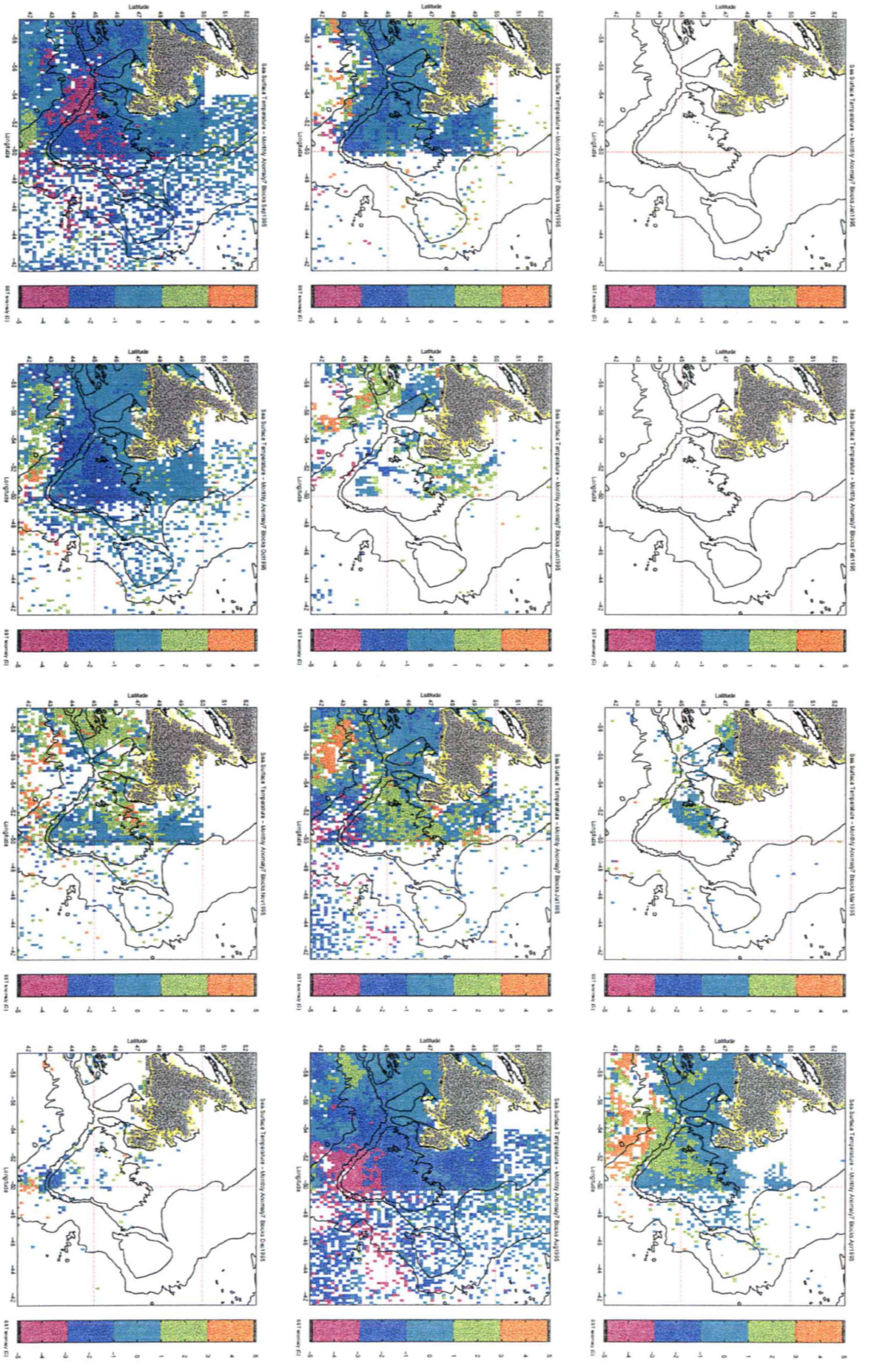


Monthly Anomalies in Sea-Surface Temperatures 1996

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map D 01

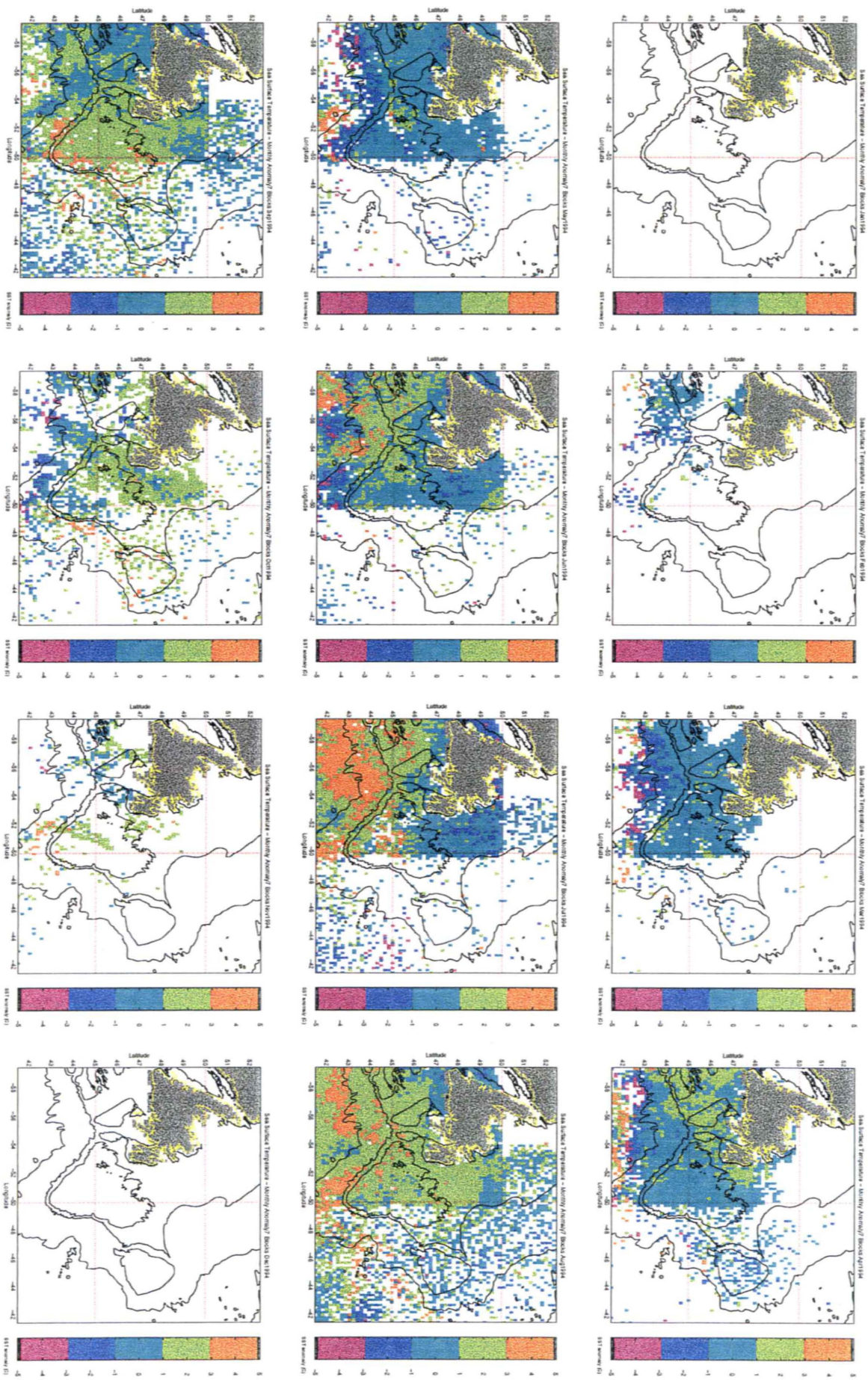


Monthly Anomalies in Sea-Surface Temperatures 1995

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map D 02

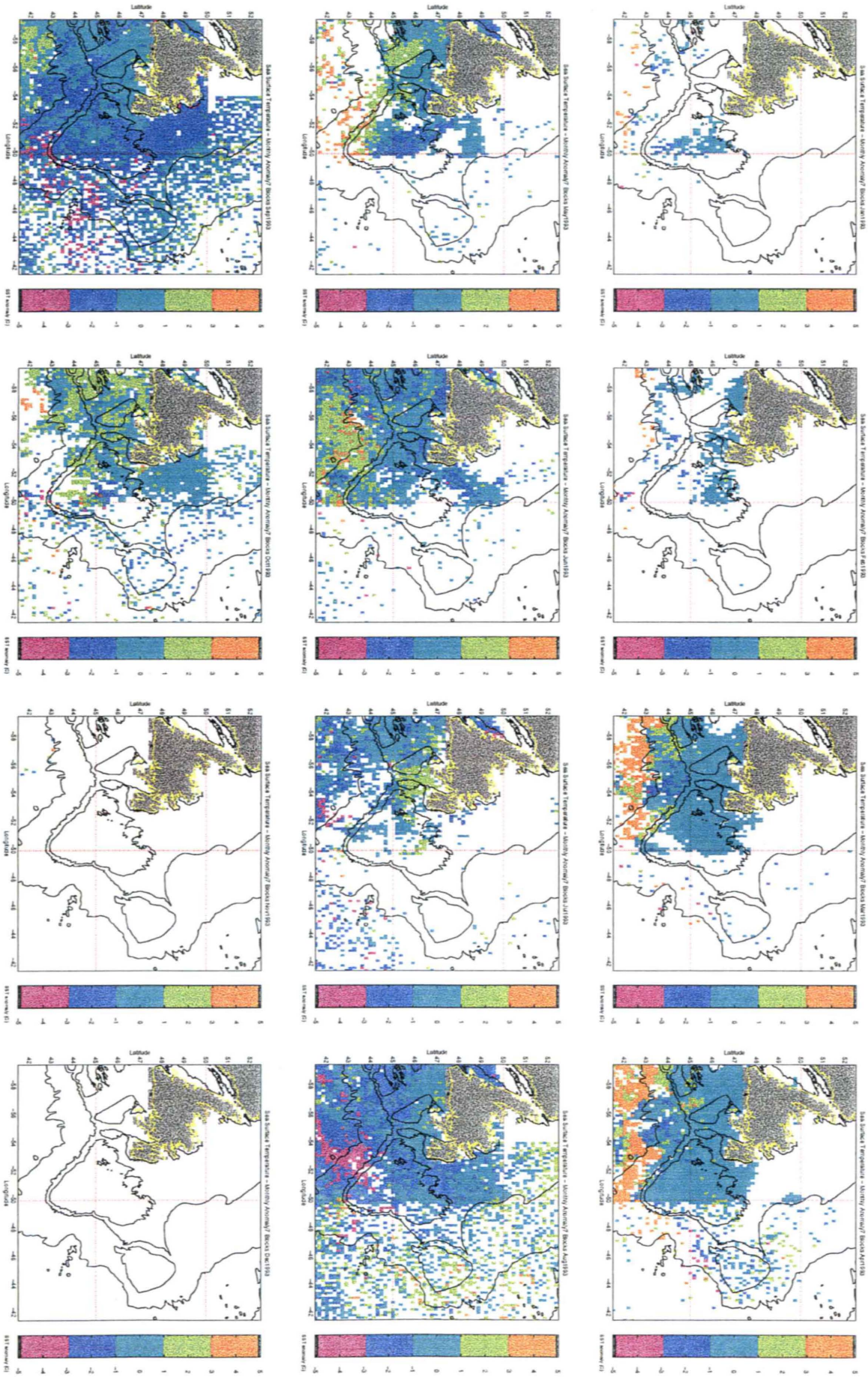


Monthly Anomalies in Sea-Surface Temperatures 1994

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map D 03

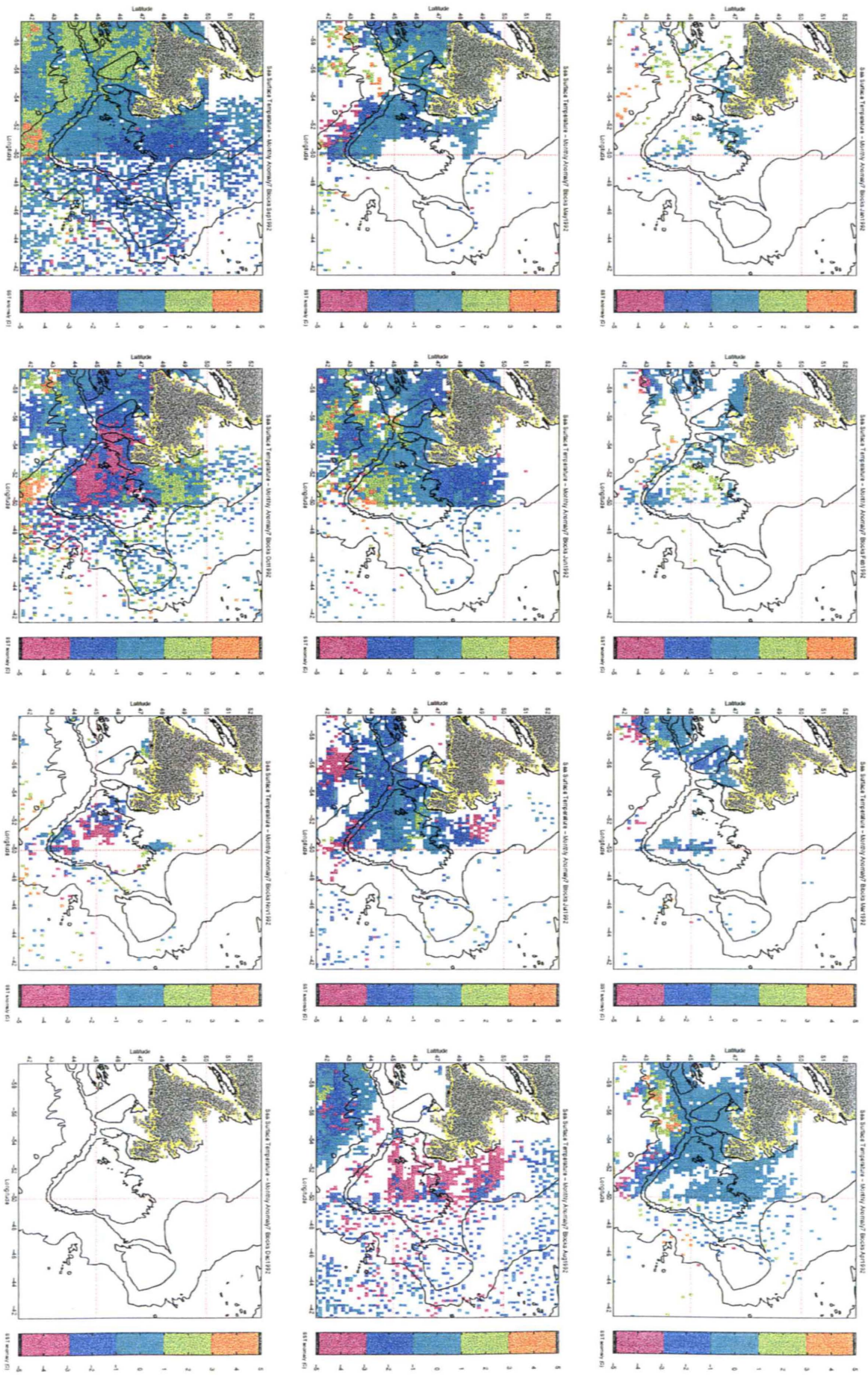


Monthly Anomalies in Sea-Surface Temperatures 1993

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map D 04

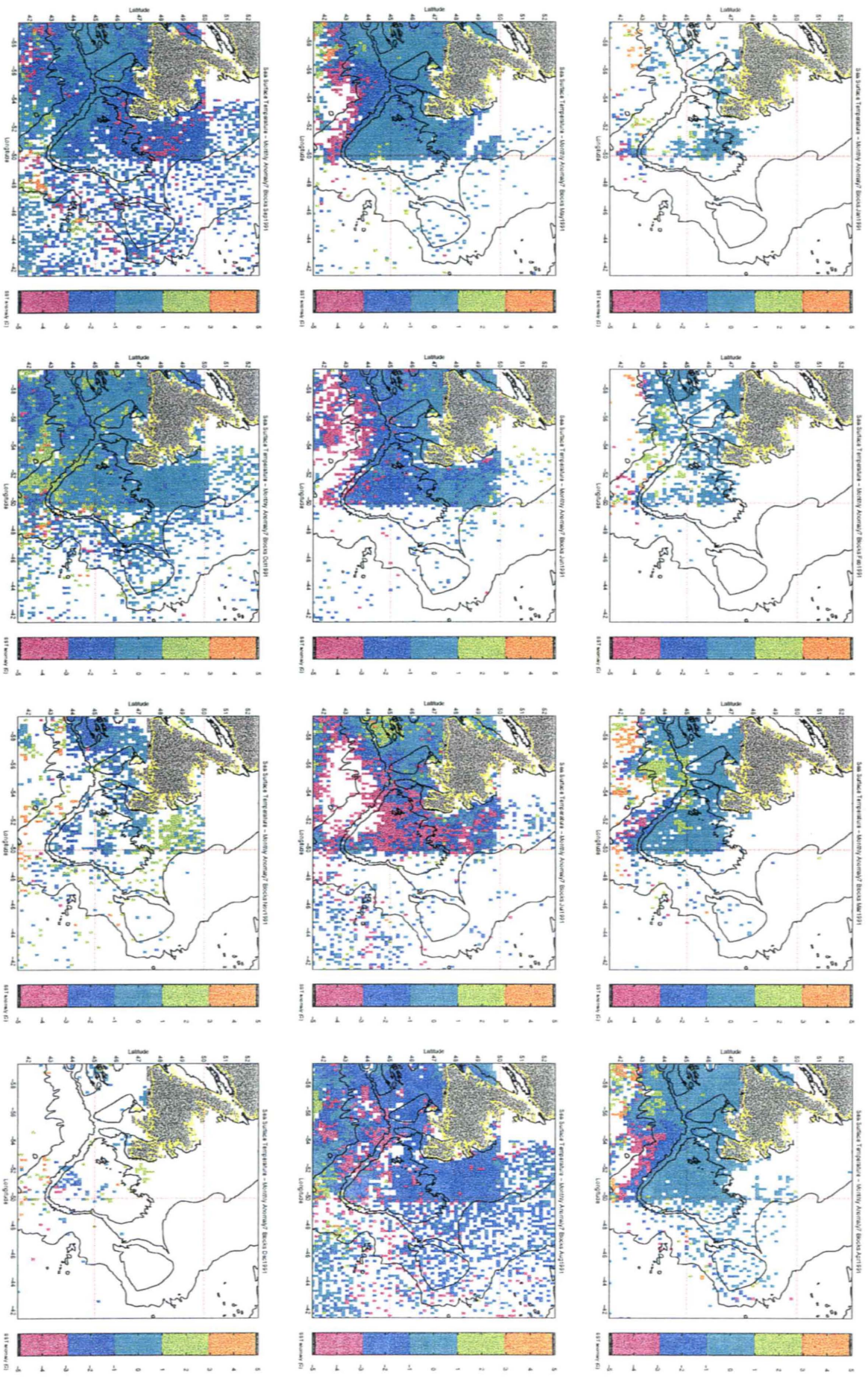


Monthly Anomalies in Sea-Surface Temperatures 1992

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map D 05

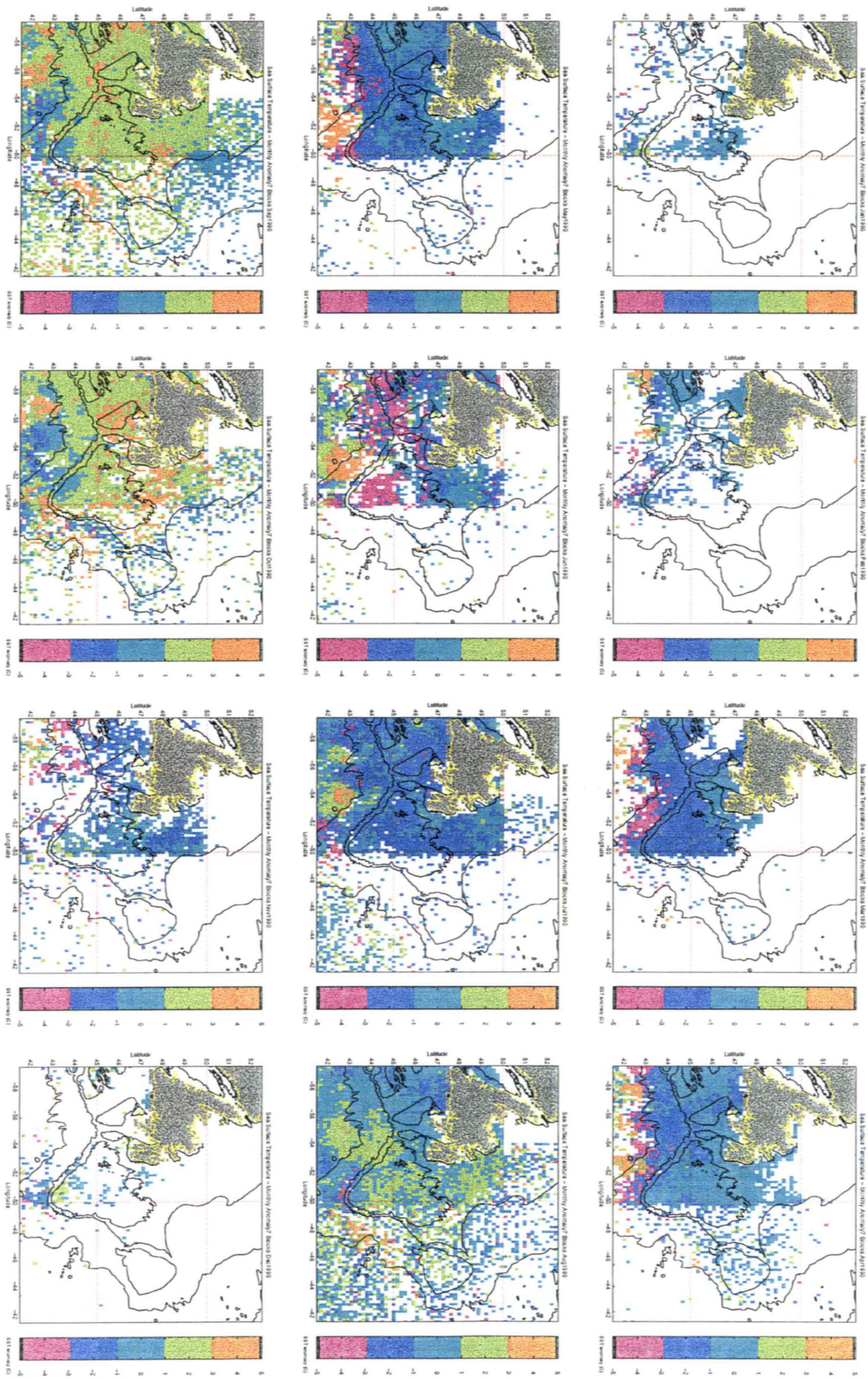


Monthly Anomalies in Sea-Surface Temperatures 1991

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map D 06

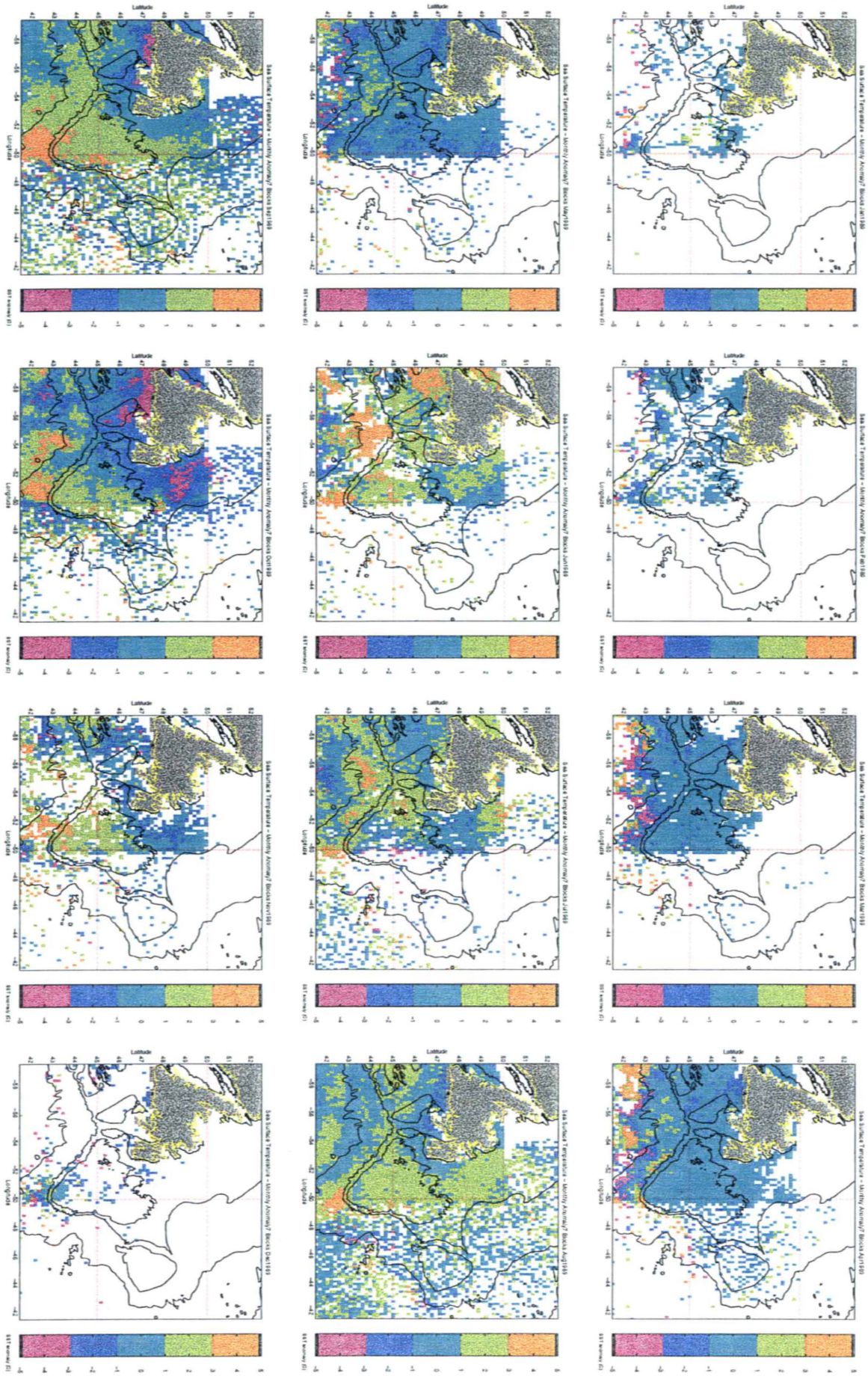


Monthly Anomalies in Sea-Surface Temperatures 1990

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map D 07

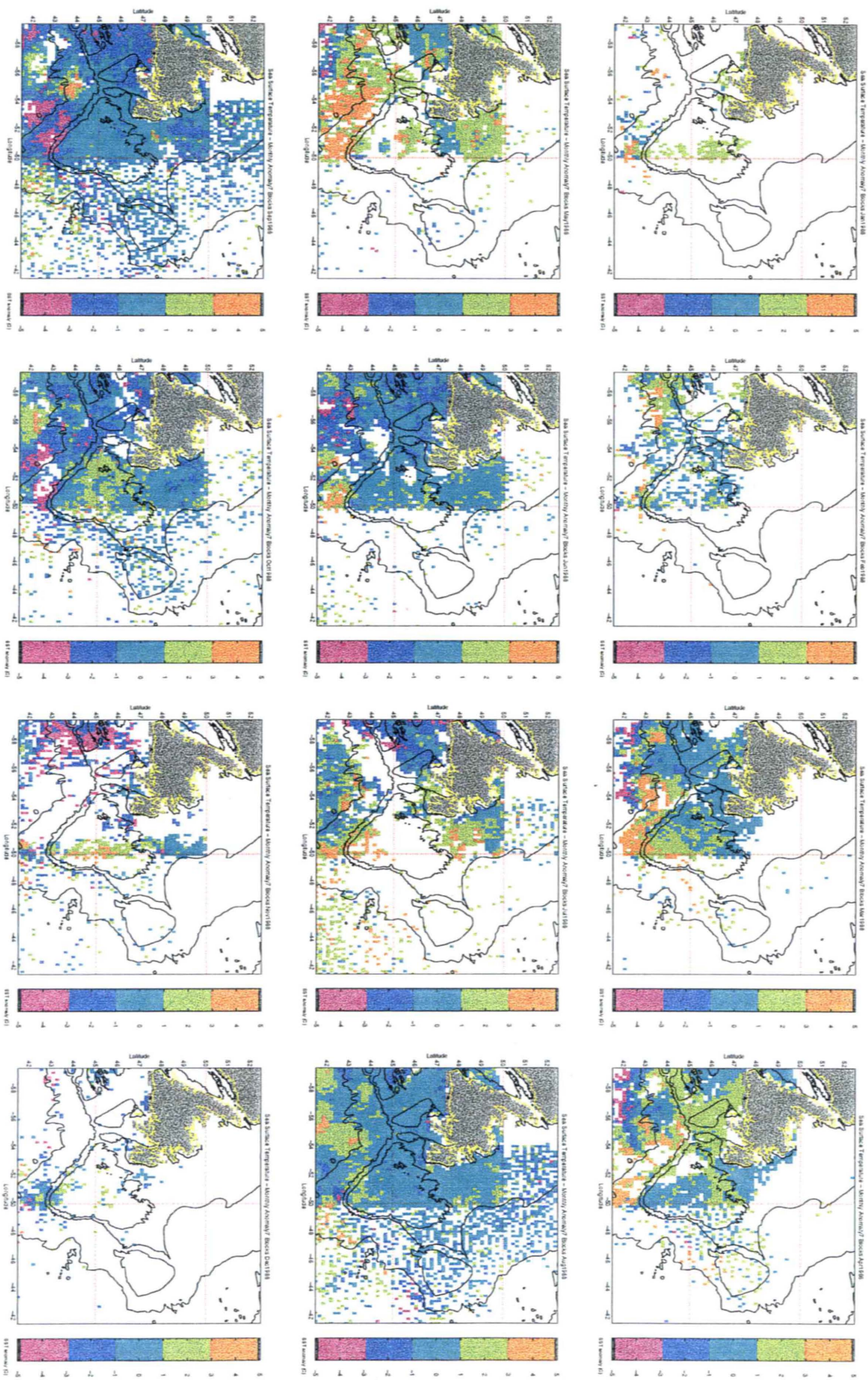


Monthly Anomalies in Sea-Surface Temperatures 1989

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map D 08

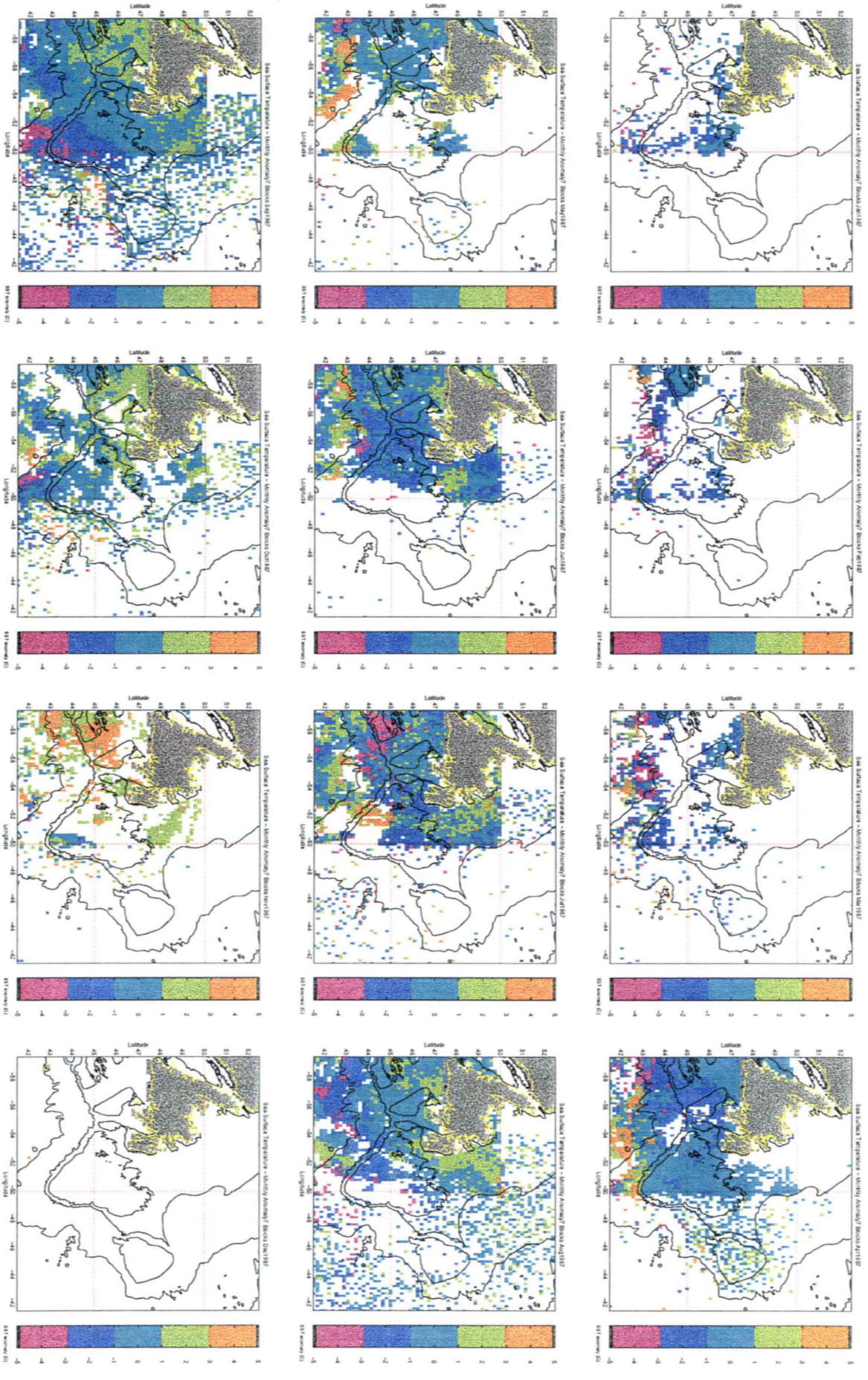


Monthly Anomalies in Sea-Surface Temperatures 1988

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

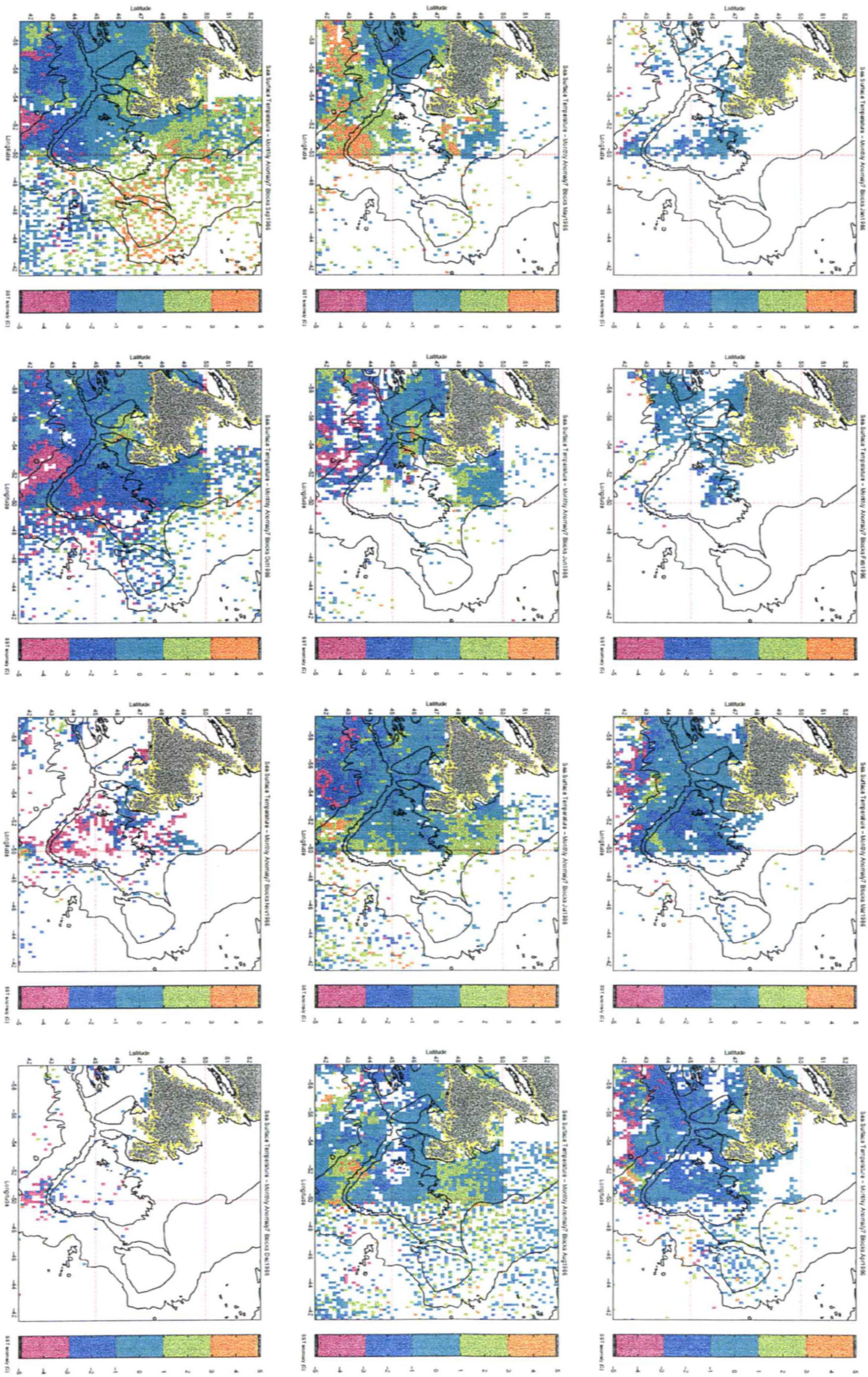
Map D 09



Monthly Anomalies in Sea-Surface Temperatures 1987

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

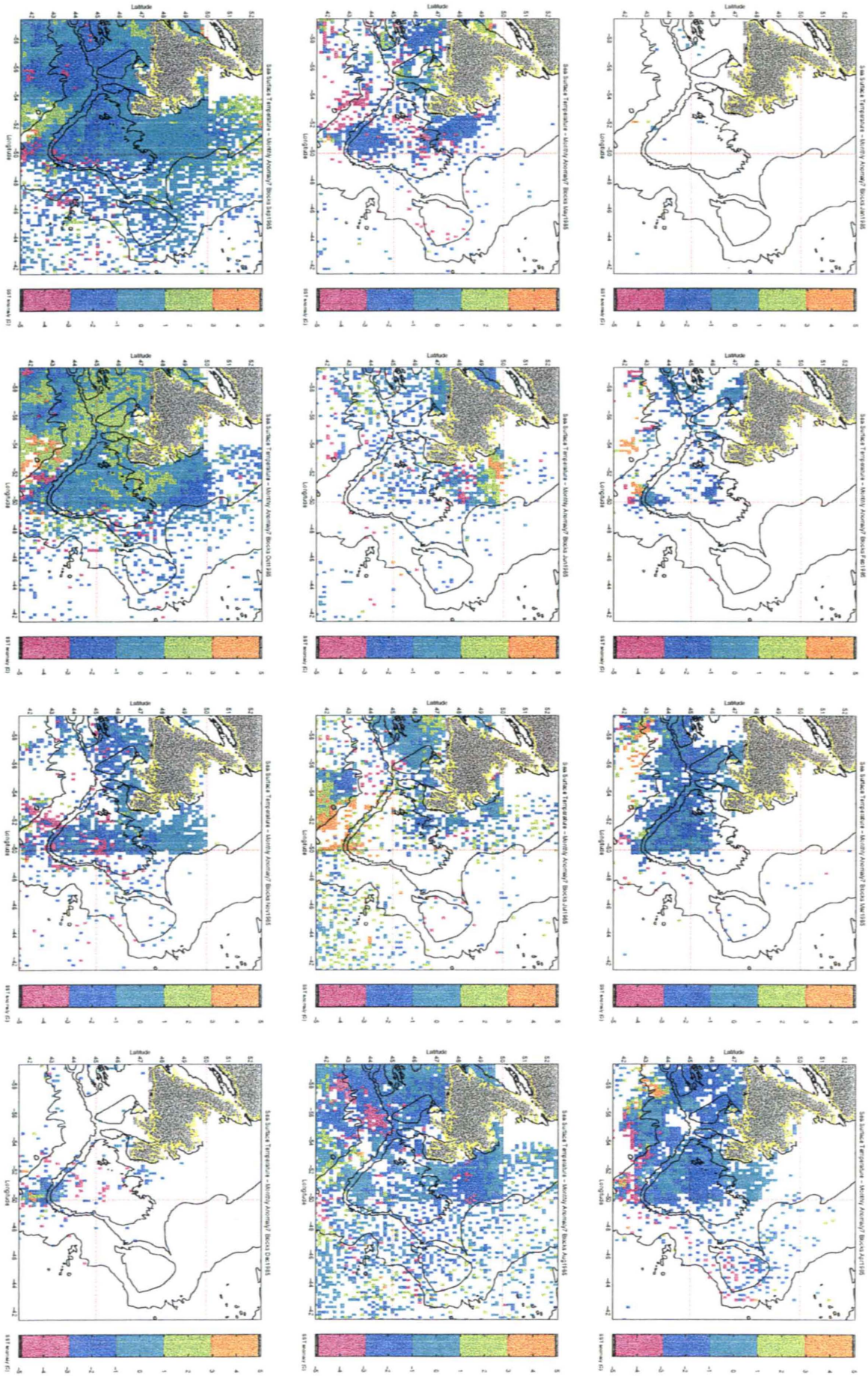


Monthly Anomalies in Sea-Surface Temperatures 1986

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

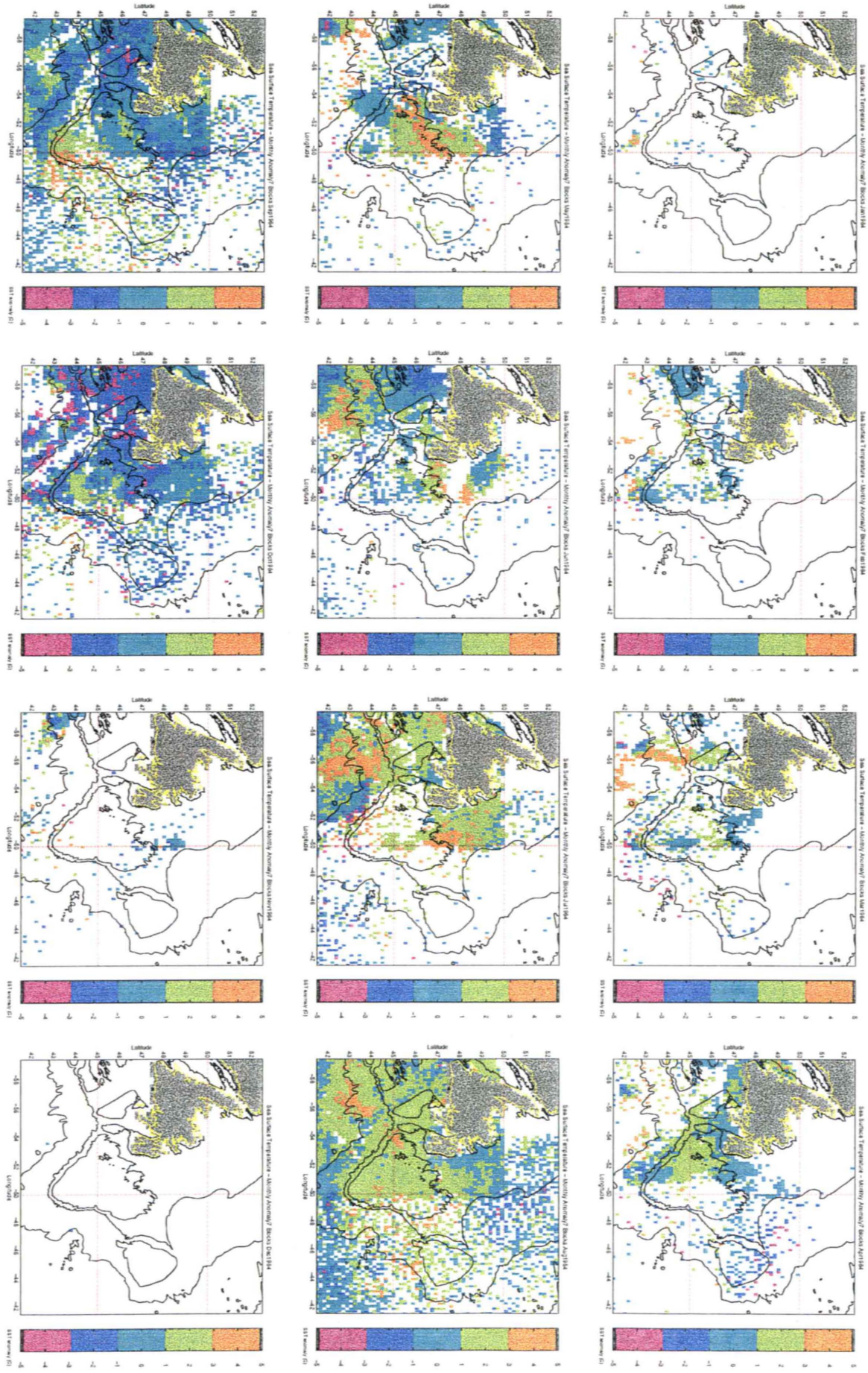
Map D 11



Monthly Anomalies in Sea-Surface Temperatures 1985

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

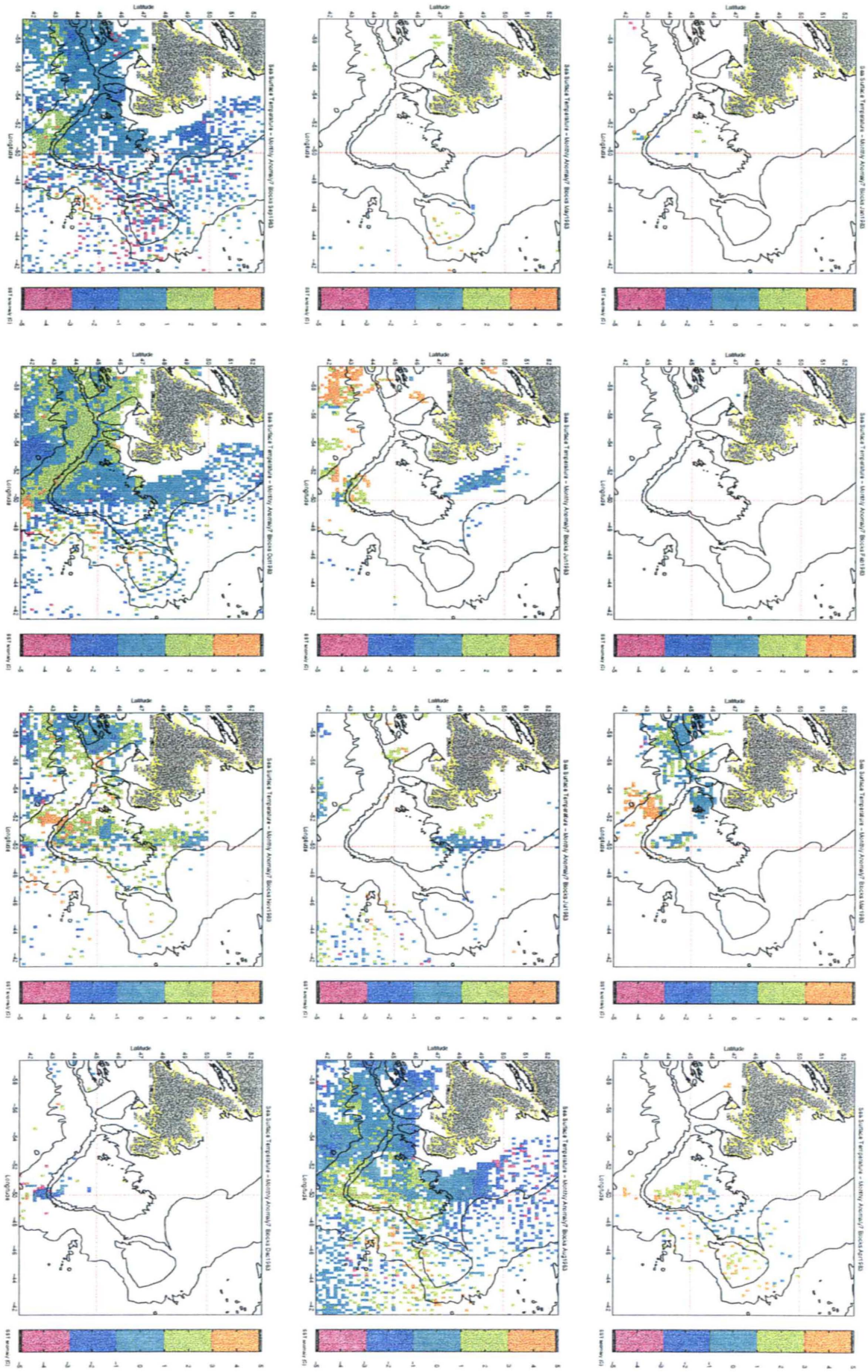


Monthly Anomalies in Sea-Surface Temperatures 1984

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

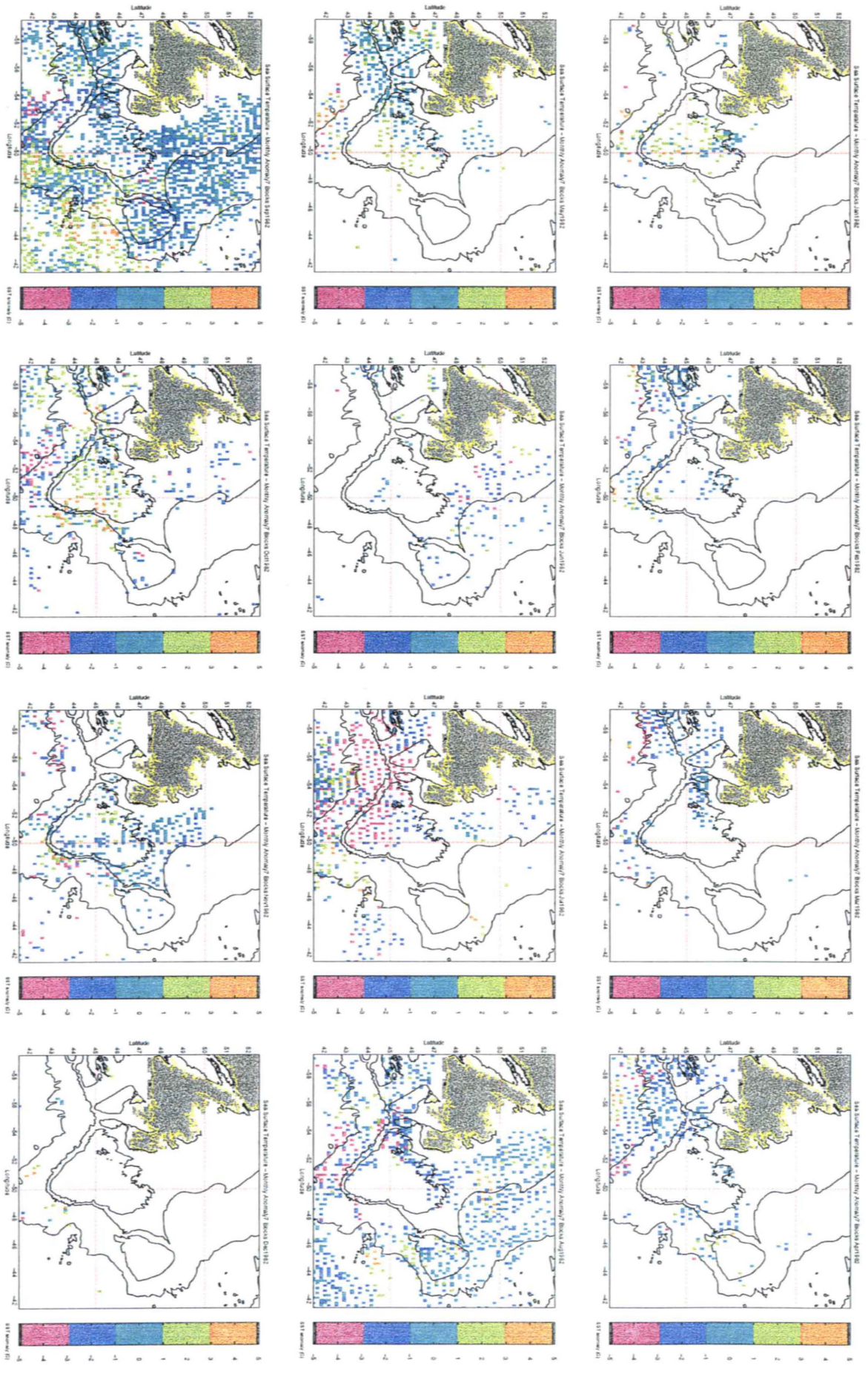
Map D 13



Monthly Anomalies in Sea-Surface Temperatures 1983

Average Values must occur in at least 7 years ('81-'96)

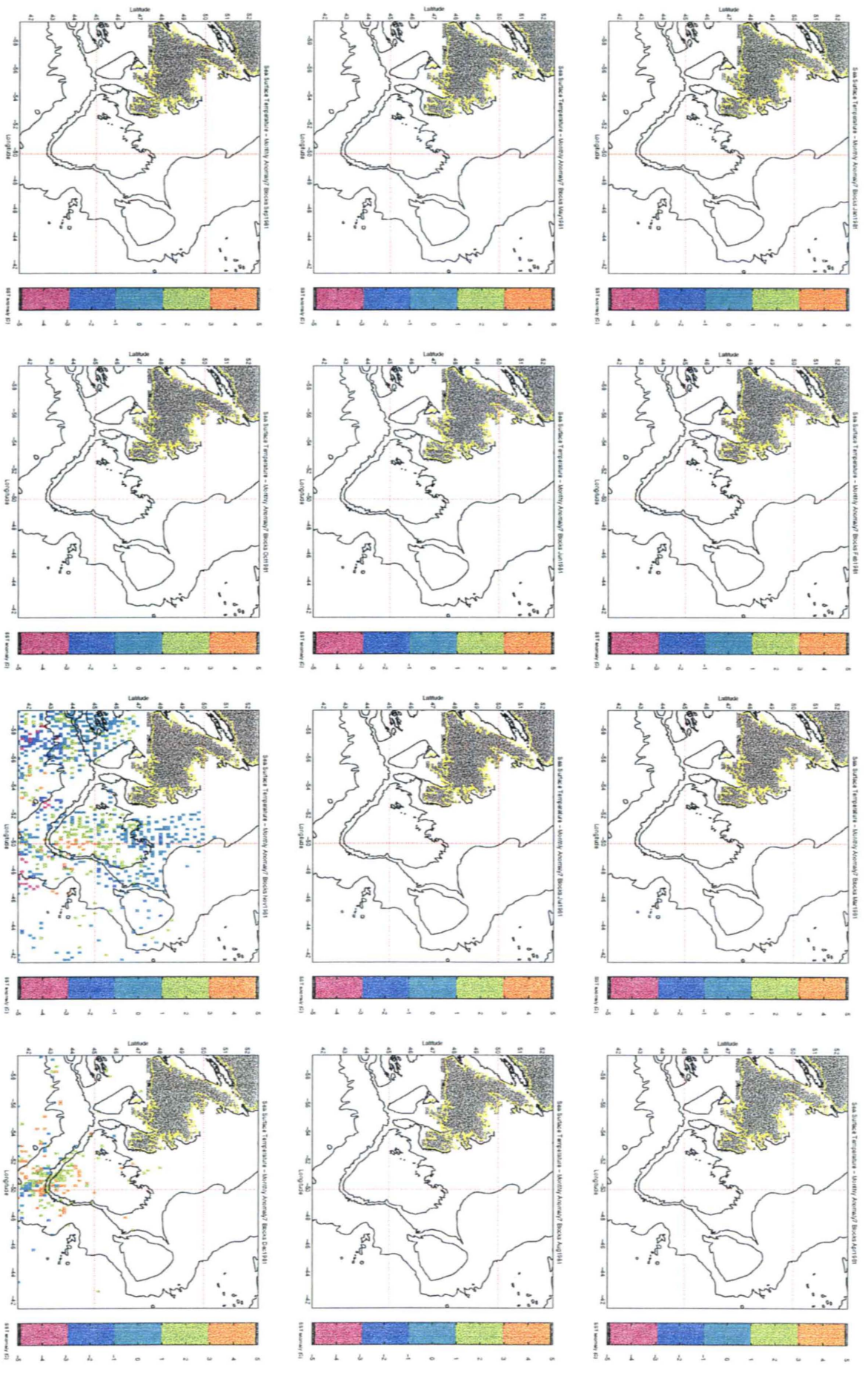
Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1982

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1981

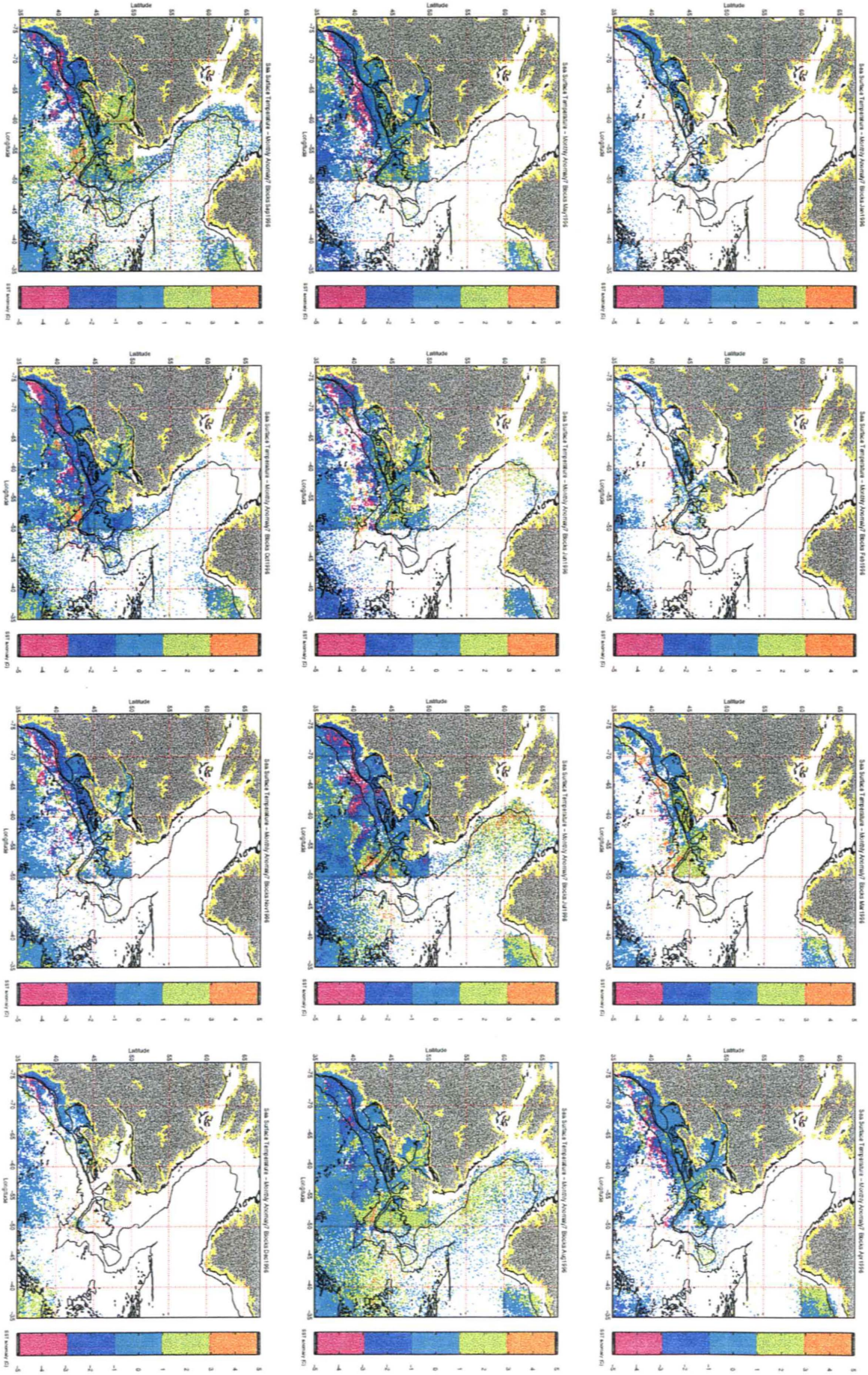
Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Annex E

Monthly Anomalies in Sea-Surface Temperature

WOCE Region

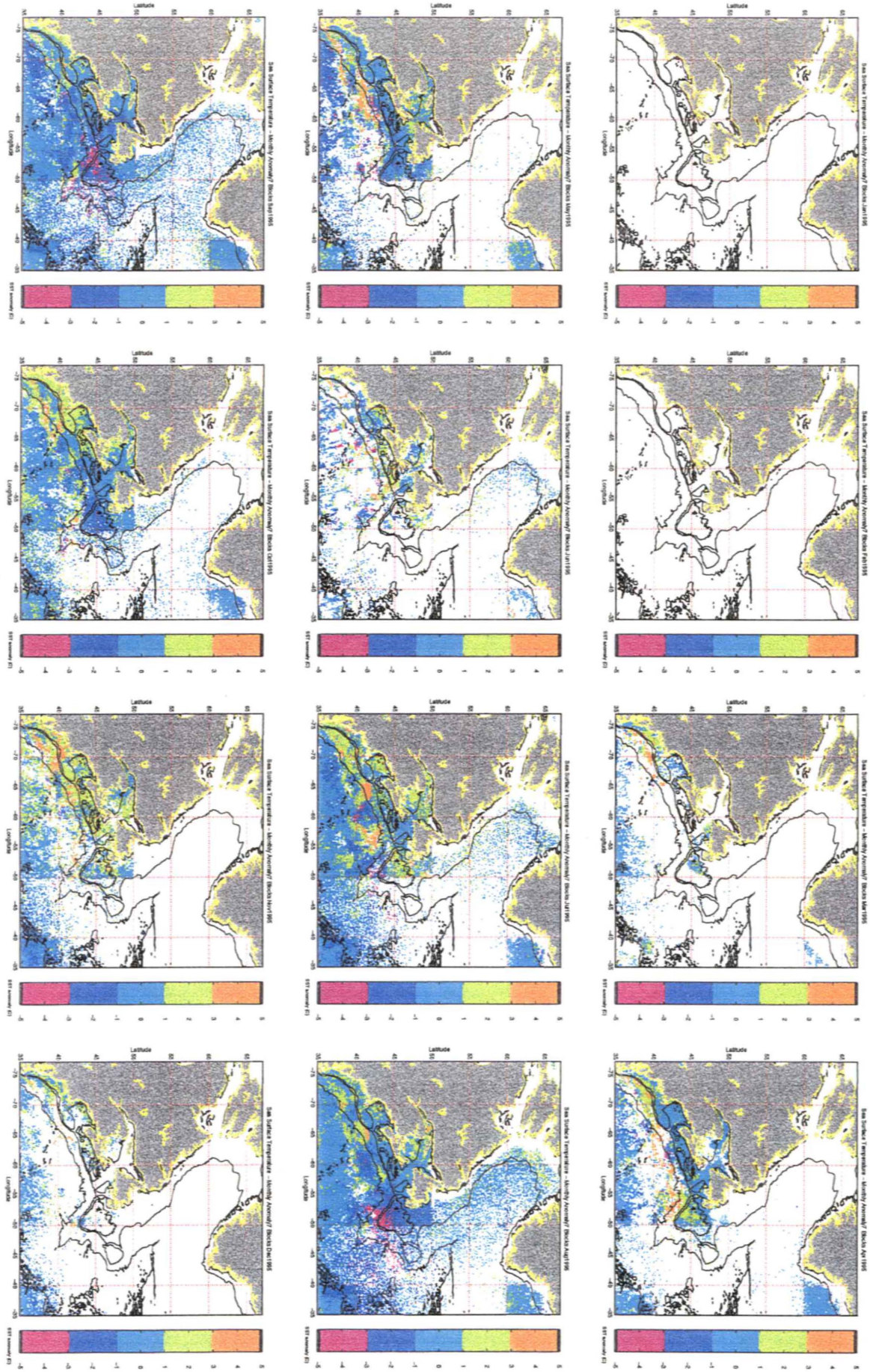


Monthly Anomalies in Sea-Surface Temperatures 1996

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 01

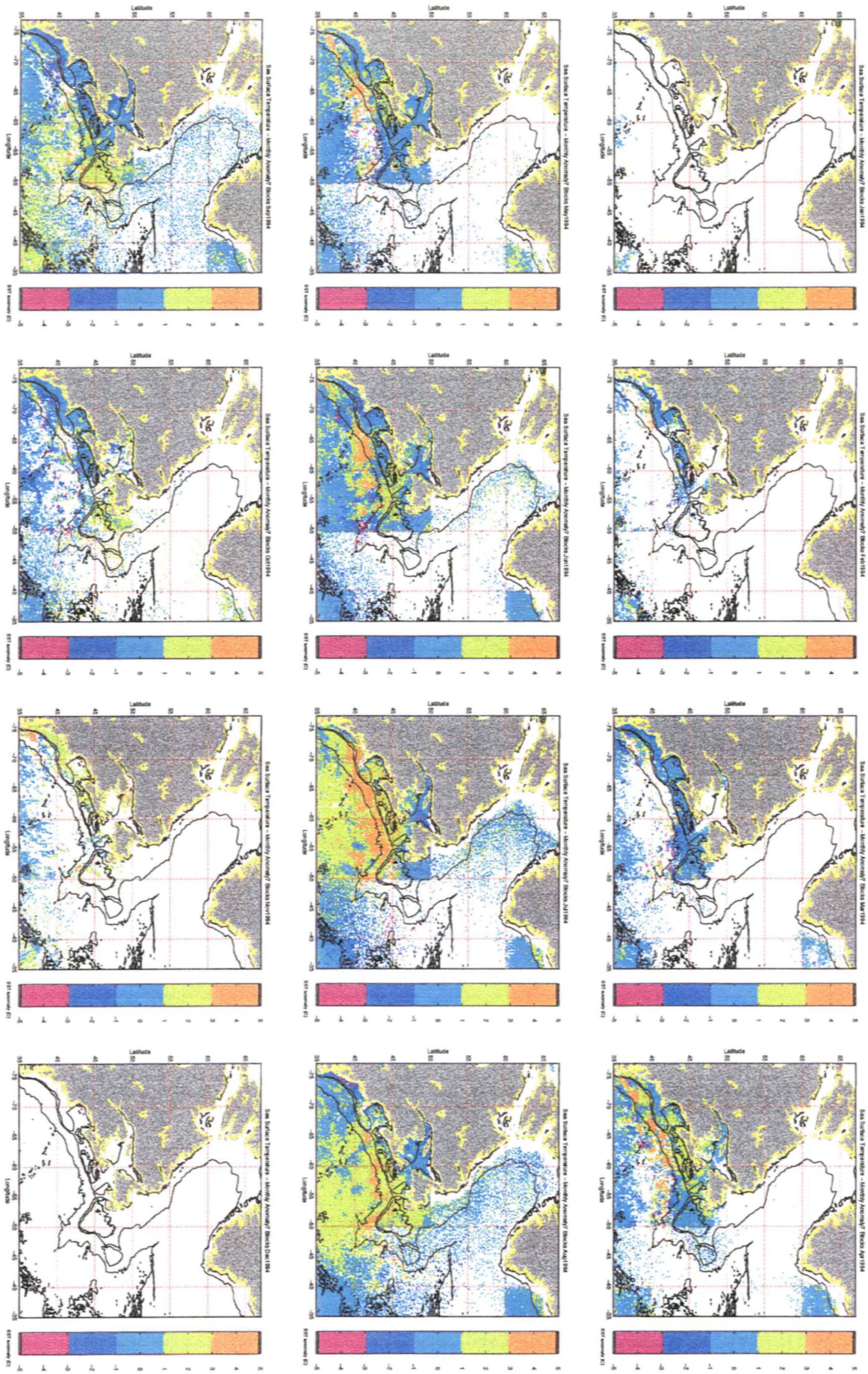


Monthly Anomalies in Sea-Surface Temperatures 1995

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 02

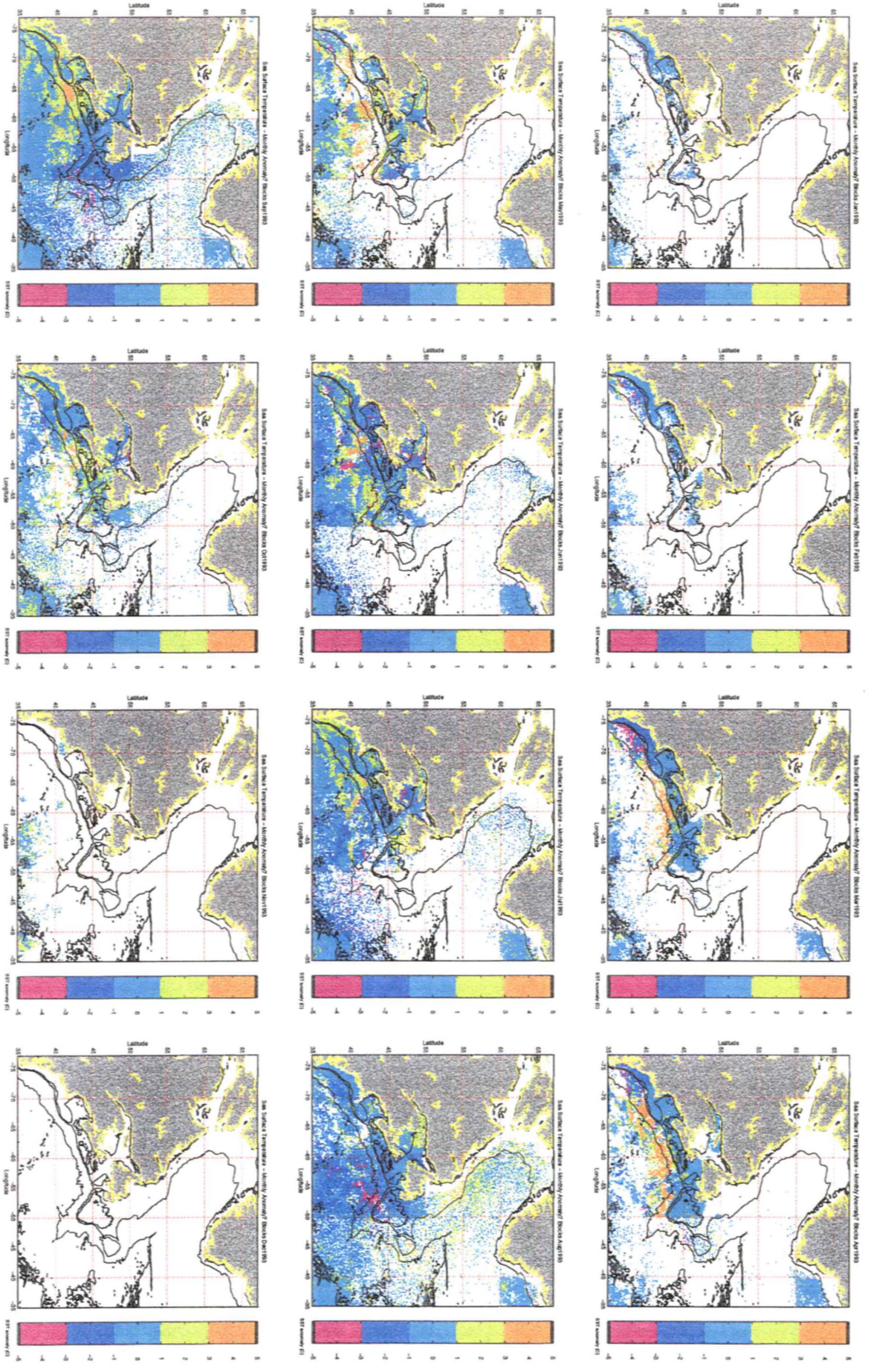


Monthly Anomalies in Sea-Surface Temperatures 1994

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 03

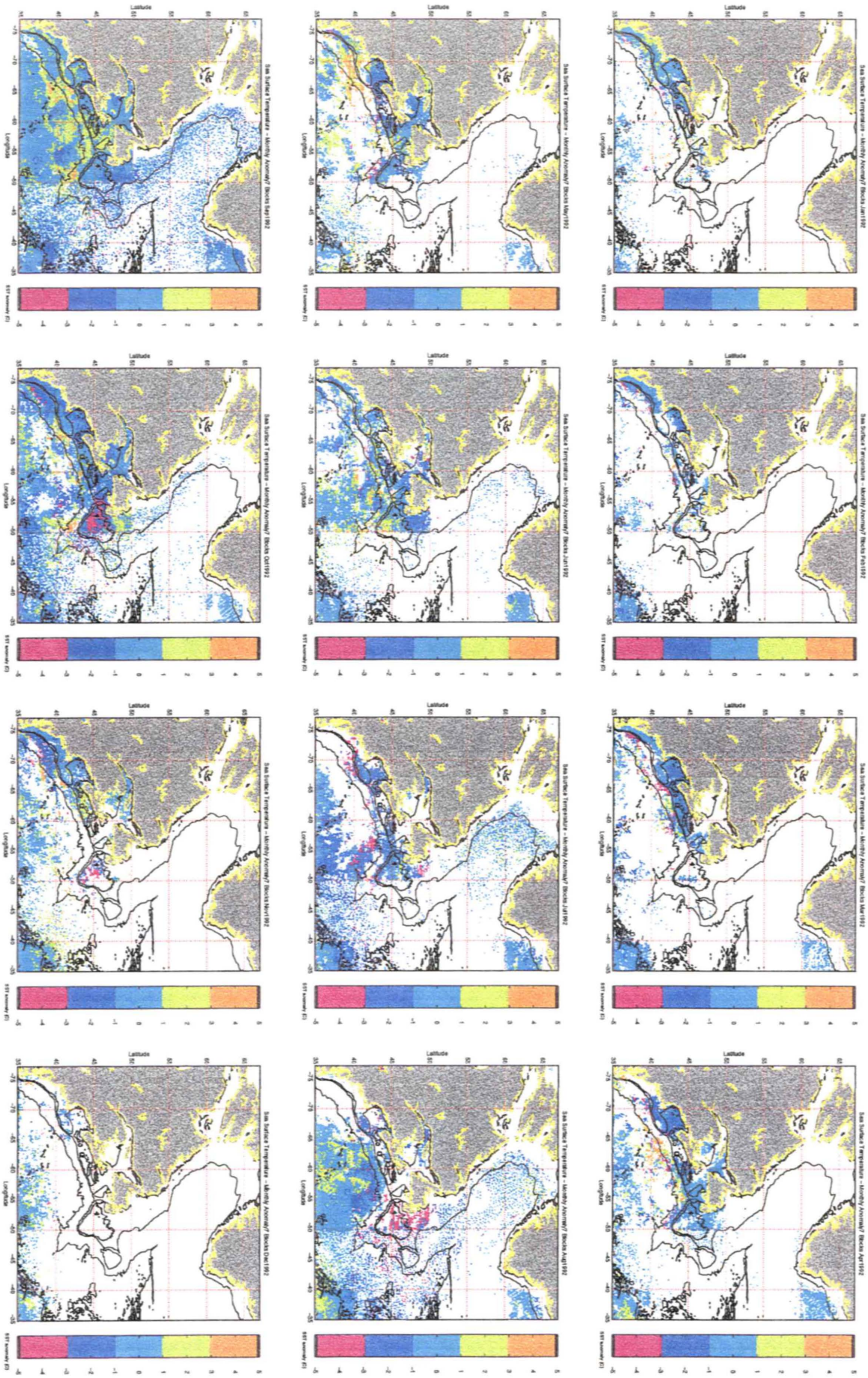


Monthly Anomalies in Sea-Surface Temperatures 1993

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 04

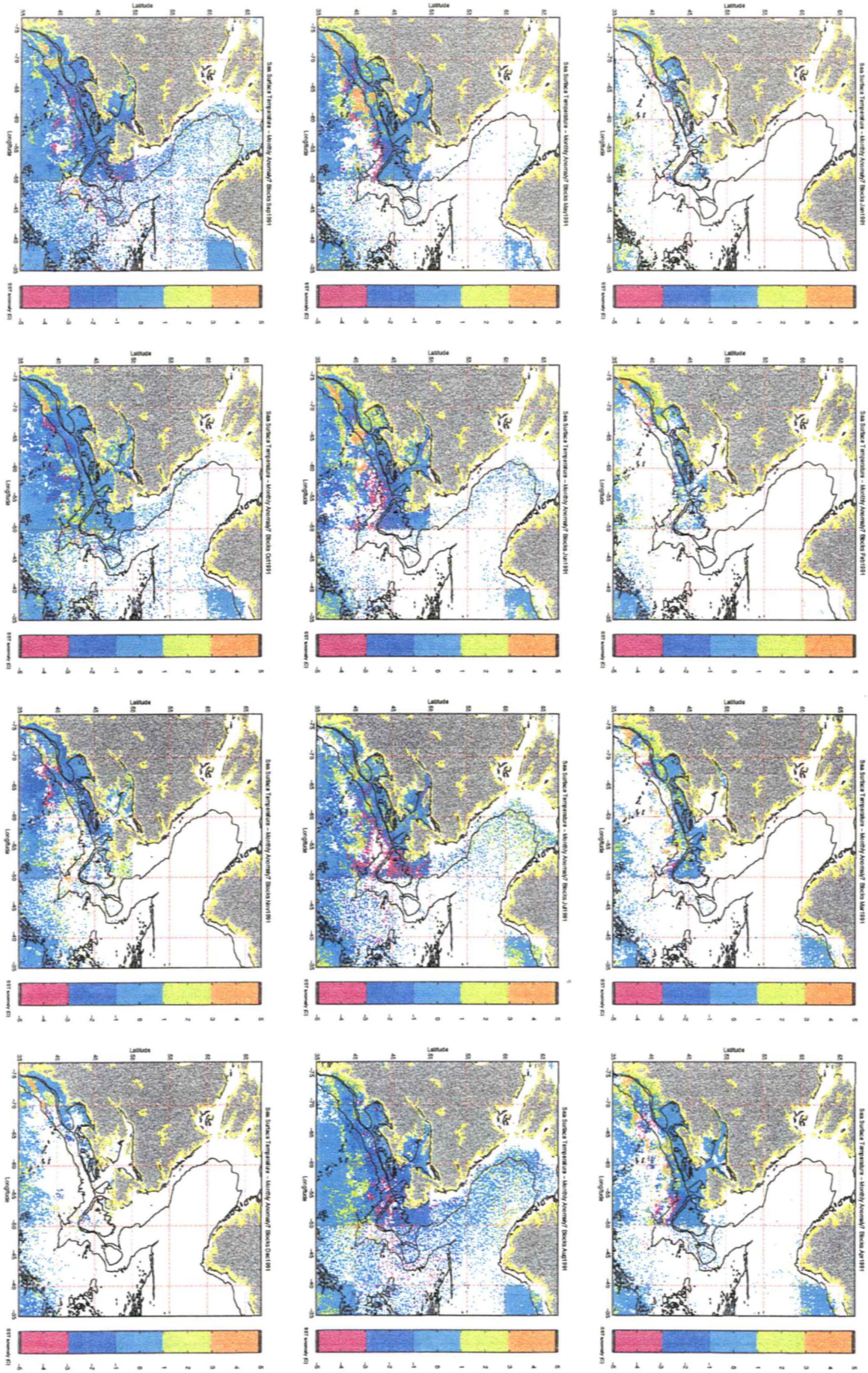


Monthly Anomalies in Sea-Surface Temperatures 1992

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 05

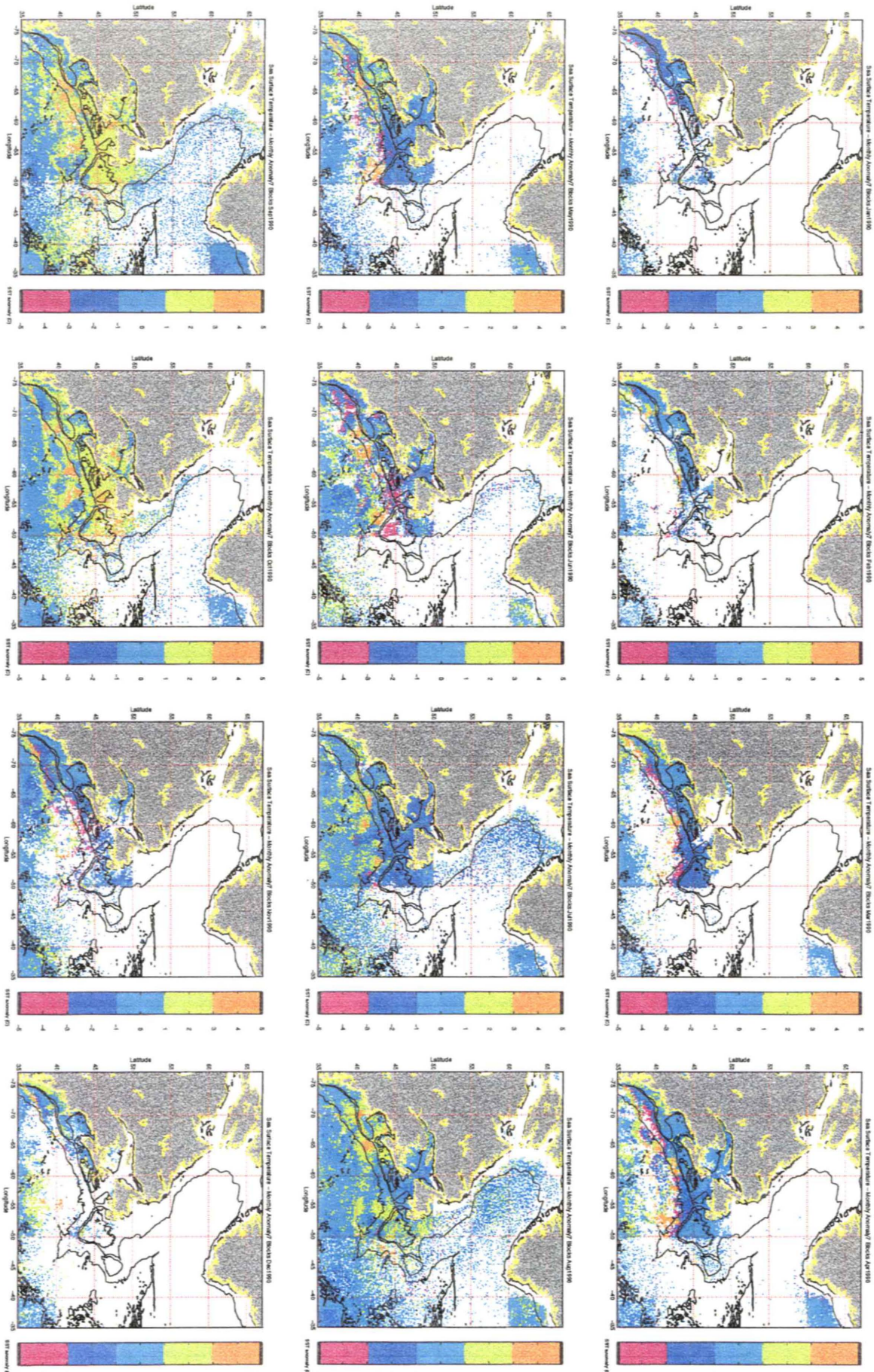


Monthly Anomalies in Sea-Surface Temperatures 1991

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 06

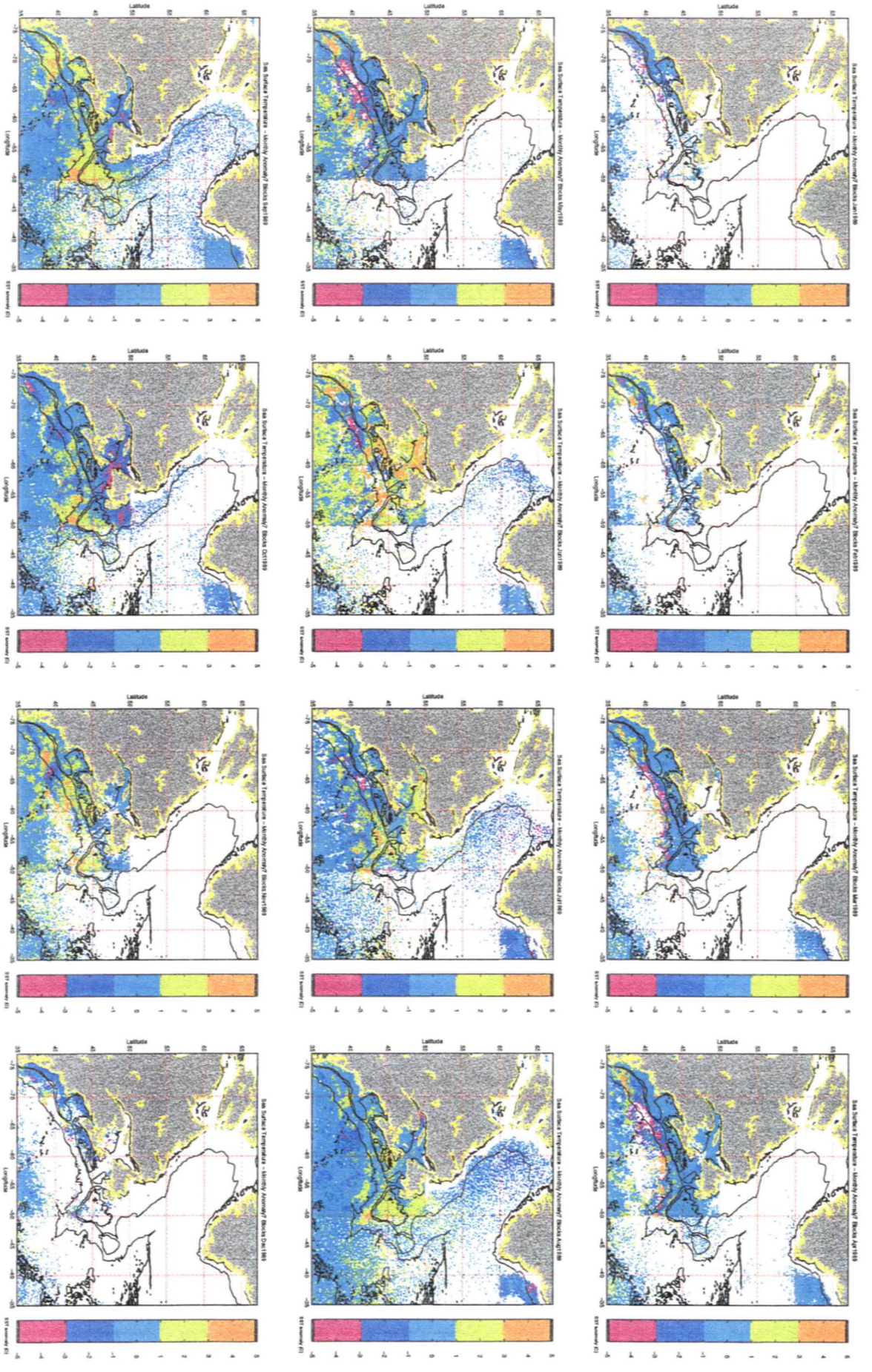


Monthly Anomalies in Sea-Surface Temperatures 1990

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 07

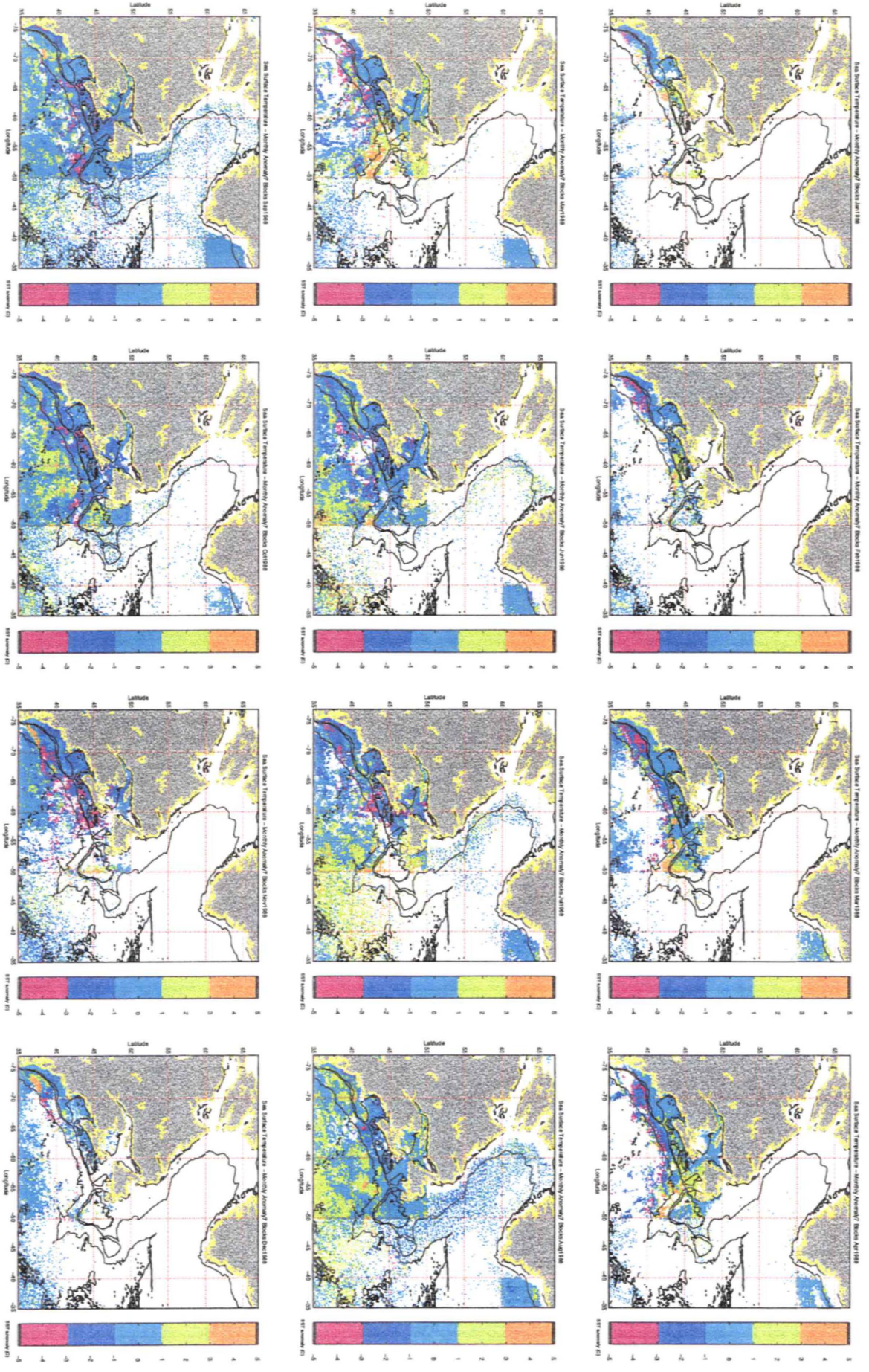


Monthly Anomalies in Sea-Surface Temperatures 1989

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 08

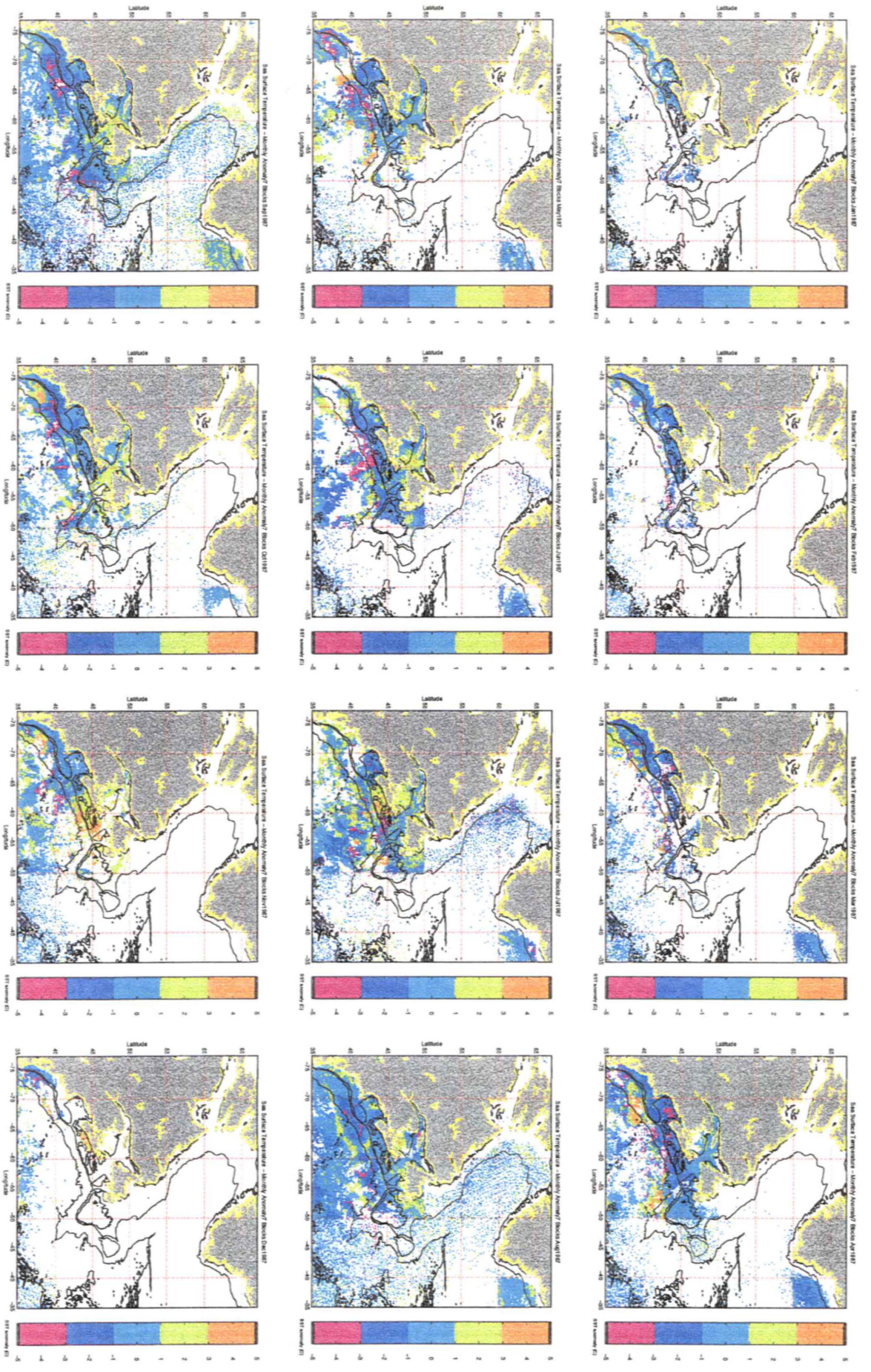


Monthly Anomalies in Sea-Surface Temperatures 1988

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 09

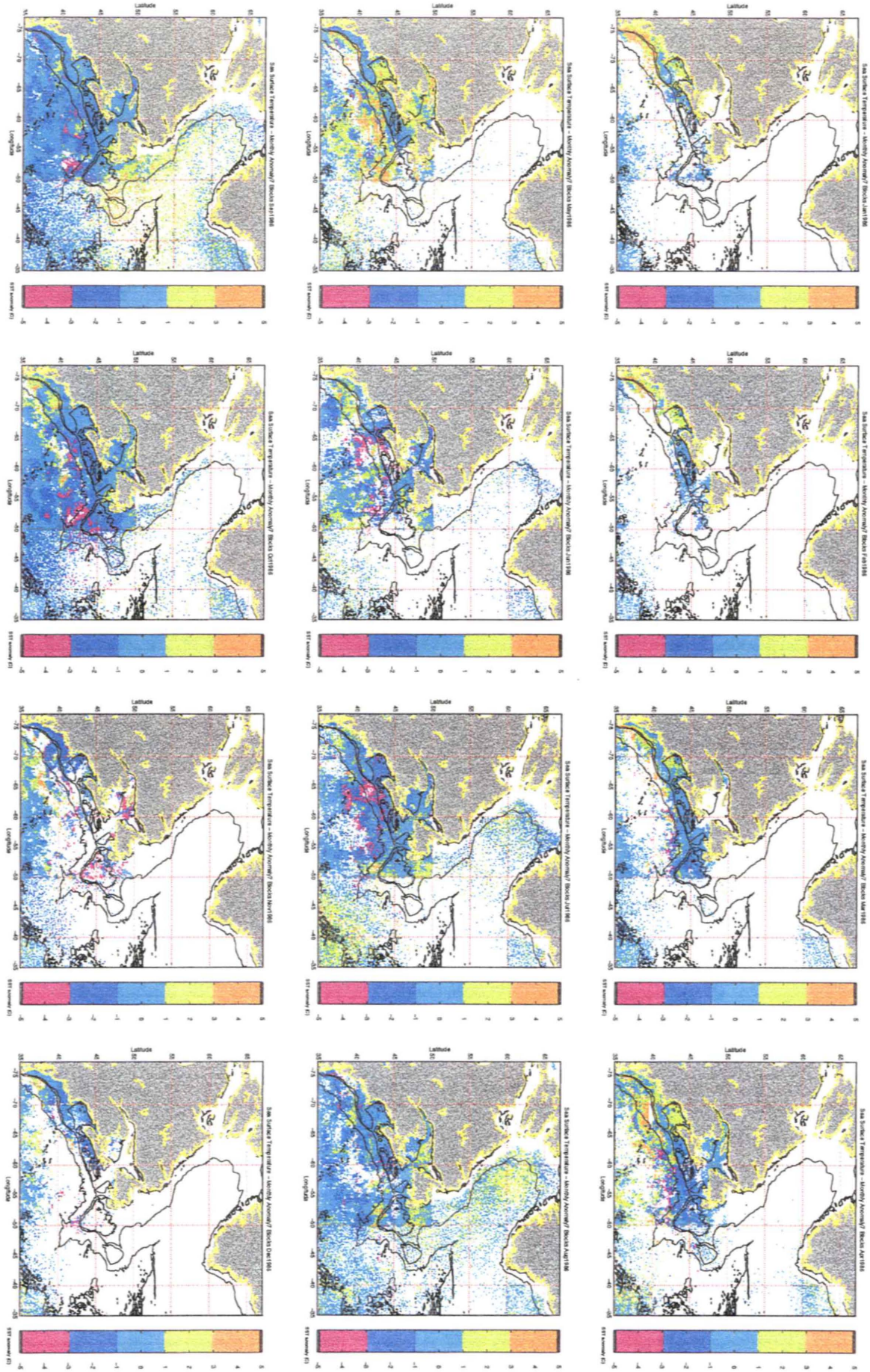


Monthly Anomalies in Sea-Surface Temperatures 1987

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 10

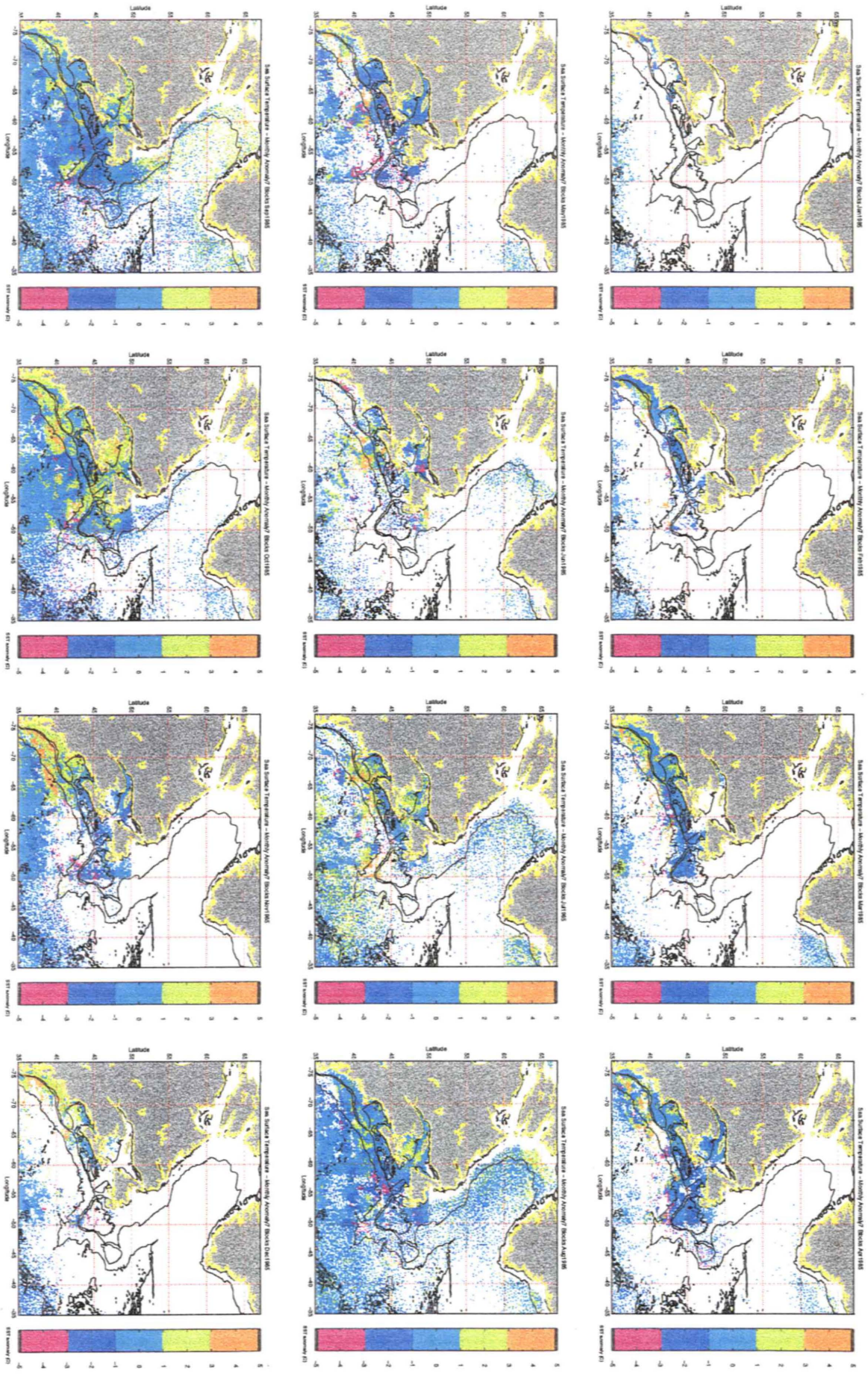


Monthly Anomalies in Sea-Surface Temperatures 1986

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 11

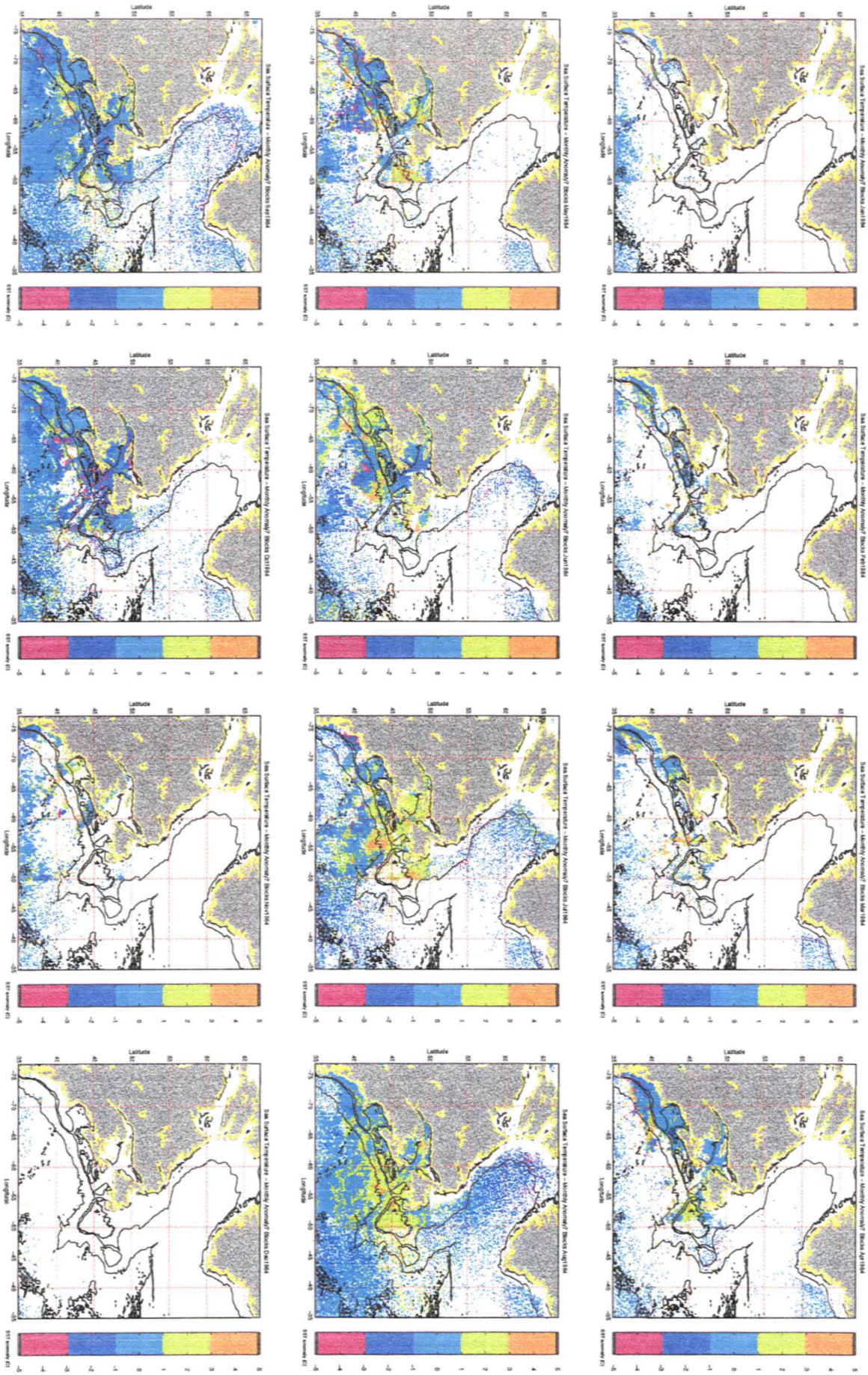


Monthly Anomalies in Sea-Surface Temperatures 1985

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 12

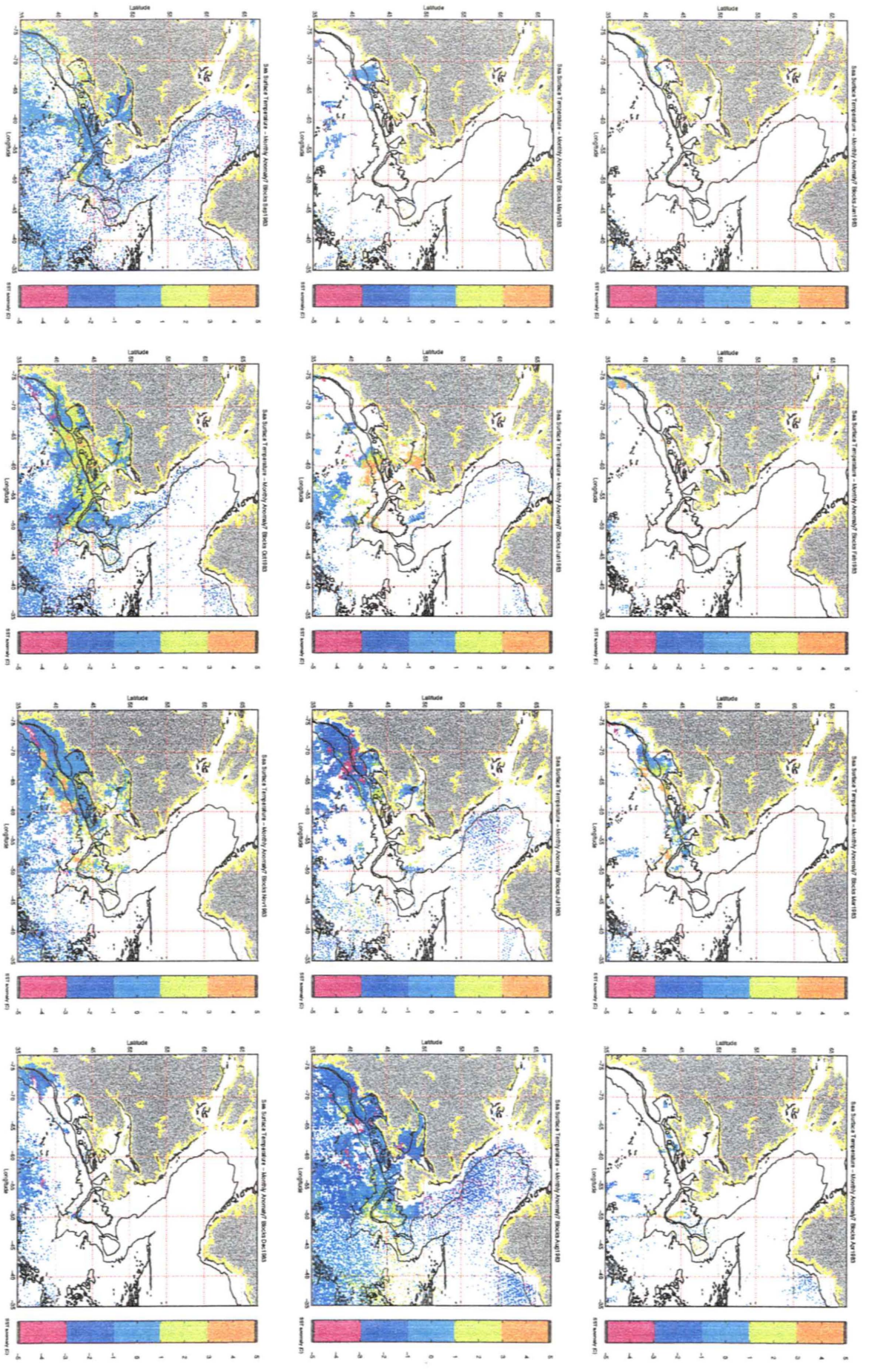


Monthly Anomalies in Sea-Surface Temperatures 1984

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

Map E 13

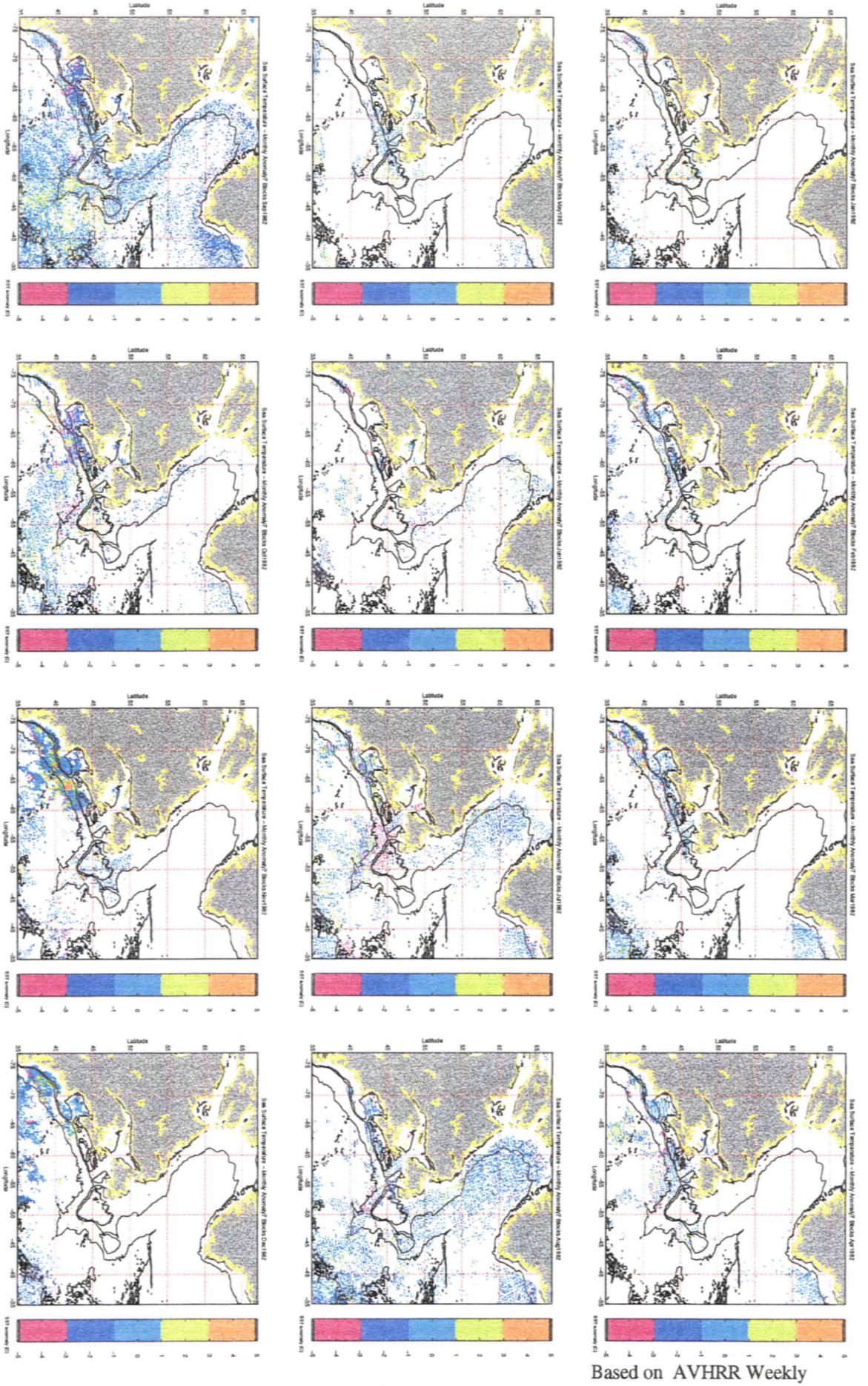


Monthly Anomalies in Sea-Surface Temperatures 1983

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST

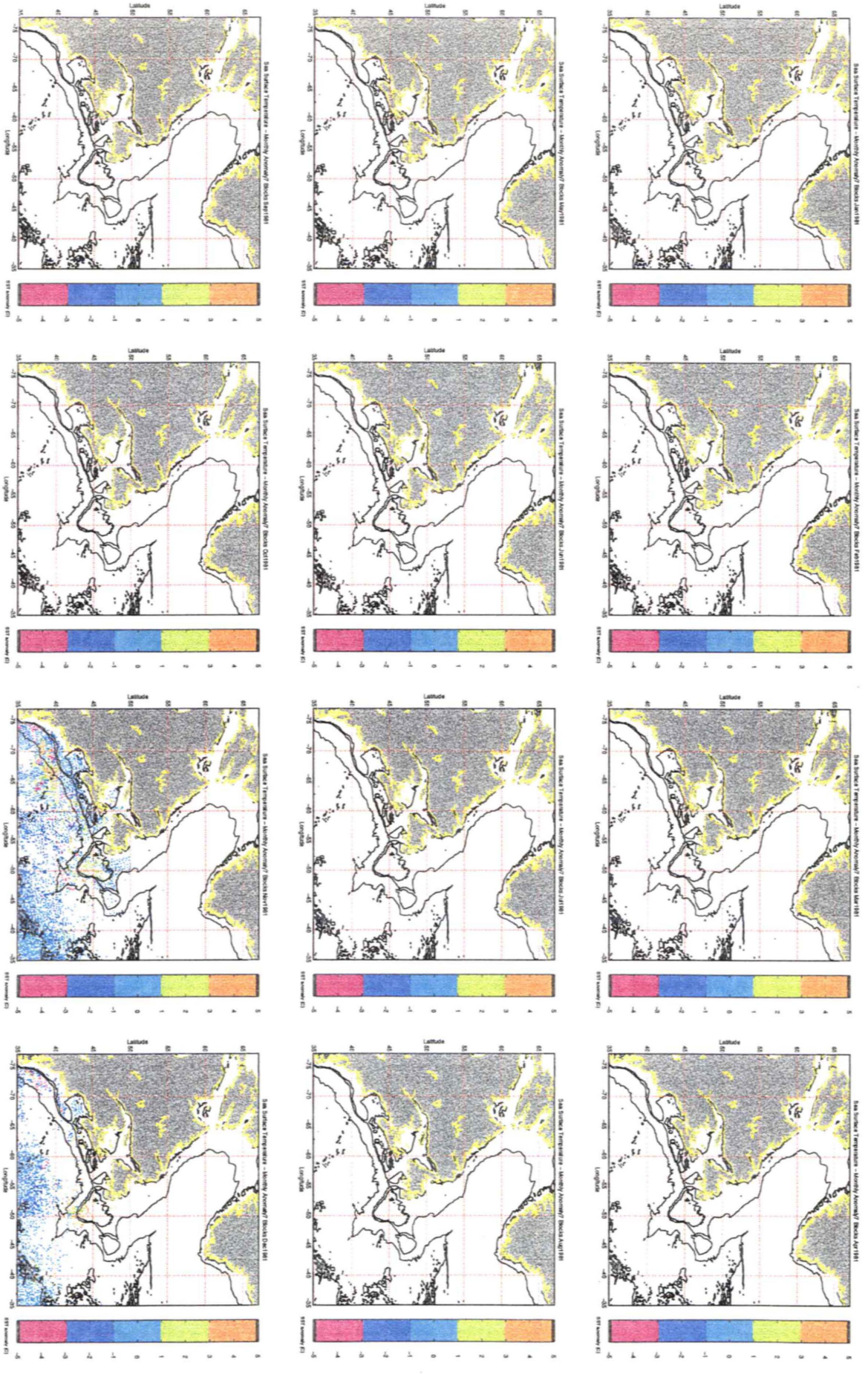
Map E 14



Monthly Anomalies in Sea-Surface Temperatures 1982

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST



Monthly Anomalies in Sea-Surface Temperatures 1981

Average Values must occur in at least 7 years ('81-'96)

Based on AVHRR Weekly Global 18 KM Gridded MCSST