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Annual Temperature Curves in Twelve Regions of the Gulf of Maine

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Abstract

Annual temperature functions have been constructed from hydrographic and expendable bathythermograph (XBT) temperature data collected in the Gulf of Maine since 1912 and compiled by the National Oceanographic Data Center (NODC). The Gulf of Maine is divided into 12 regions so that annual temperature variability may be compared among coastal regions, banks and basins. For each of the 12 regions, annual temperature functions which are truncated Fourier series, are constructed for a surface layer of 0–30 m and an intermediate layer of 31–70 m. The temperature functions are presented to suggest a process by which future warming and cooling trends in the Gulf of Maine may be identified and compared with a standard temperature curve based on the historical data of that region. Comparisons of temperature functions are illustrated for a cool period 1963–67 and a warm period 1973–77 in two of the regions. Tables are presented from which the temperature functions may be examined, including the days of the year at which the temperatures are at a maximum and minimum so that the lengths of the warming and cooling cycles can be compared among the regions.

Introduction

Over the years, numerous efforts have been made to identify seasonal and long term temperature cycles at selected depths in the Gulf of Maine and adjacent waters. Using a data set of surface water temperature readings taken twice daily at St. Andrews, New Brunswick, Lauzier (1965) observed a warming trend from the 1920s to the 1950s (with a secondary maximum and minimum centered in the mid-1930s and beginning of the 1940s respectively), followed by a cooling trend from the 1950s to 1965. Similar trends occurred with bottom temperatures on the Scotian Shelf and in the Bay of Fundy area.

Surface water temperatures at Boothbay Harbor, Maine from 1905 to 1980 also showed considerable annual variability (Welch, 1967, 1981). Lauzier (1965) showed that warming and cooling periods of water temperature at St. Andrews and Boothbay Harbor were found to be highly correlated with air temperature records taken at Halifax and Sable Island, Nova Scotia.

Colton (1968a) reported a warming trend of sea surface temperatures along the coast of New England and the Maritime Provinces which began in the early-1940s and reached a maximum during 1952–53, followed by a general cooling trend that continued into the late 1960s. Subsurface temperatures at a depth of 200 m in the periods 1955–60 and 1961–66 in the major basins of the Gulf of Maine and the slope regions south and east of Georges Bank were also found to be lower during the latter period, which parallels observations of the surface layer (Colton, 1968b).

Efforts have also been made to relate temperature changes observed along the coast to similar results offshore. For example, surface temperatures at Boothbay Harbor rose considerably in 1968, marking the end of a 15 year cooling period. Colton (1969) suggested that the Boothbay Harbor temperatures provide a good index to offshore surface and subsurface temperature conditions. He observed that in 1968, the slope water had shifted inward toward the 200 m isobath on the edge of the continental shelf, closer than its position in 1965–66.

Commercial fishing yields have also been tied to the year to year temperature variability. Flowers and Saila (1972) have linked annual temperature variations to the yield of the American lobster (*Homarus americanus*) along the coasts of Maine and Nova Scotia using multiple regression equations. The resulting equations were designed to estimate the lobster yield in a given year based on the previous annual yields and previous mean annual temperatures. The temperature records of bottom waters produced better estimates than surface temperatures. Dow (1977a) showed a highly significant correlation between sea-surface temperature data at Boothbay Harbor and landings of lobsters in Maine 4–6 years later during 1950–72. For the period 1939–67, the sea-surface temperature at Boothbay Harbor experienced the second coldest and the warmest years on record from 1905 to 1977. Dow (1977b) used this 20 year subcycle to establish a high correlation between sea-surface temperature and the number and abundance of commercial marine species in the annual catch on the Maine Coast. Sutcliffe *et al.* (1977) used fish catch records containing 40 years of data in the

Gulf of Maine to establish statistically significant correlations between catches of 10 commercial marine species with sea temperatures at St. Andrews and Boothbay Harbor. Bottom temperature data taken from 1955 to 1965 was used by Schopf (1967) to establish average annual temperature cycles of the Scotian Shelf, Gulf of Maine interior, Georges Bank, and Nantucket Shoals and to relate the distribution of benthic organisms with temperature trends.

Prior to the 1960s, the amount of temperature data throughout the Gulf of Maine was limited. There were very few surveys which collected hydrographic or temperature data in all regions of the Gulf. Since 1961, there has been a considerable accumulation of temperature data from hydrographic surveys throughout the Gulf. When these data are combined with numerous expendable bathythermograph (XBT) casts beginning in 1967, the result is a fairly comprehensive temperature data set. In order to continue the study of seasonal and long-term temperature variability in the Gulf of Maine, it seems appropriate to make use of the existing historical temperature data to establish a standard or bench mark of annual temperature curves in various topographical regions of the Gulf . In a manner similar to that used by the National Weather Service, these temperature standards might be used to compare future temperature data to help identify cooling and warming cycles which may affect primary production and commercial fishing yields. Future temperature data would be added to existing data as a continual effort to improve the standard. The purpose of this paper is to offer an approach to provide relatively simple annual integrated temperature curves in 12 regions of the Gulf of Maine.

Methods

Description of data

The data set used in this study is the historical hydrographic station data and XBT data compiled by the National Oceanographic Data Center (NODC). The temperature data represents work by numerous oceanographers over the years whose data collecting surveys have been carried out with different objectives in mind. Much of the data used in earlier reports on seasonal and long-term temperature trends are included in this data set. The quality control and processing of all NODC data is described in the "User's Guide to NODC's Data Services". The station data covers the period from 1912 to 1983, while the XBT data covers the period from 1967 to 1984.

Description of regions

The Gulf of Maine is partitioned into 12 regions (Fig. 1), based on the topography, previous work and areas used for biological studies. Regions 1 through 3 and 12 cover the New England coastal regions and are similar to those used by the Maine State Department of Marine Resources. The Bay of Fundy is designated a coastal area as region 4 and region 5 includes the coastal waters off Nova Scotia from Yarmouth to Barrington Bay. Region 5 bordered by the offshore areas on the west by Jordan Basin (region 6) and on the south by the north edge of Browns Bank. Other offshore areas are regions 7, 9 and 10 which cover Georges, Rodgers and Wilkinson Basins, respectively, and region 8 covers Georges Bank primarily within the 80 m isobath, a slightly larger area than the 65 m isobath used by Hopkins and Garfield (1981). The offshore area, region 11, which includes Jeffreys Bank, is made up of small basins, ridges and ledges between Jordan and Wilkinson Basins.

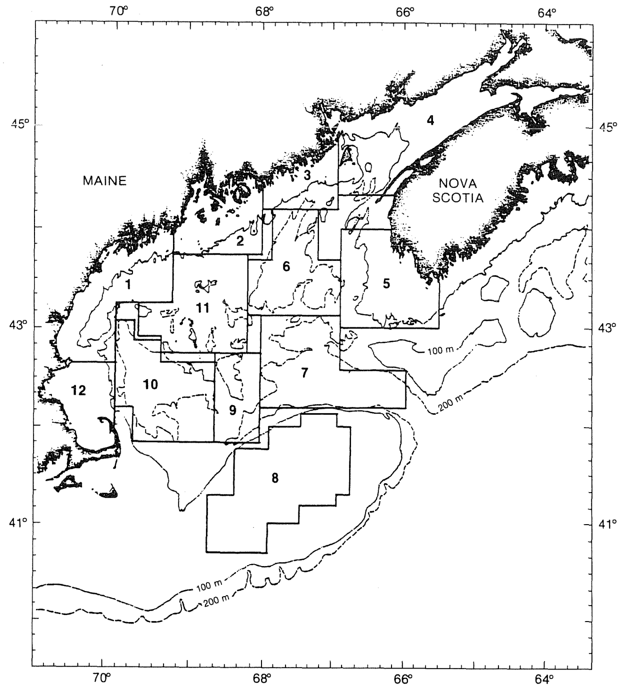

Fig. 1. Twelve regions in the Gulf of Maine in which annual temperature curves are presented.

This particular division of the Gulf of Maine referred to as (Gulf for simplicity) is designed to examine temperature variability separately over basins, banks and strong tidal mixing regions. The seasonal amplitude in temperature differs considerably over the various regions, due in part to topography, tidal mixing, river runoff, intrusions of slope water, and atmospheric forcing.

The total number of hydrographic stations and XBT cast stations for each region is given in Table 1, while Table 2 shows their distribution by month. The data set contains a total of 7,407 hydrographic stations and 10,092 XBT casts representing a total of 17,499 temperature stations contained in the 12 regions.

Annual temperature curves

For each of the 12 regions, annual temperature curves for the surface layer (upper 30 m) and an intermediate layer (31–70 m) were constructed. For each station in a given region, the temperatures were integrated over a given depth interval to obtain a weighted mean temperature. Only those stations in the NODC file with three or more temperature readings in the given depth interval were used. Next, for each day of the year in which more than one reading occurred, the integrated temperatures were averaged to produce a single mean temperature for that particular day. The reason for this averaging for each day was to distribute the data more evenly throughout the year and reduce the weighting for the curve fitting scheme which was to follow. The resulting mean temperature could then be plotted for the day of the year in which the station data was obtained. Figure 2 shows a scatter plot of the mean temperatures over the upper 30 m for the 235 days of the year in which at least one temperature station was recorded in region 1.

A regression scheme was then used to fit a continuous annual temperature function to the integrated temperature data using the method of least-squares. The result for each of the 12 regions is an annual temperature function of the form:

$$T(X) = M+A1 \sin(0.0172X+B1) + A2\sin(0.0344X+B2) + A3\sin(0.0516X+B3) \quad \text{.... (1)}$$

where X is the day number of the year and M, A1, A2, A3, B1, B2, B3 are parameters which are computed through the regression scheme. The three sine functions are calculated in radians and the temperature T(X) is given in degrees centigrade. The temperature function chosen here is similar to the first seven terms of the truncated Fourier series:

$$T(X) = M + \sum_{n=1}^{3} \left[a_n \sin\left(\frac{n\pi X}{p}\right) + b_n \cos\left(\frac{n\pi X}{p}\right) \right] \quad \text{... (2)}$$

with period 2p = 365 days. Equation 1 is derived from equation 2 by combining sine and cosine terms of the same period into sine terms with lag angles B1, B2 and B3. The identity used to combine a sine and cosine term of the same period into a single sine term is:

$$C_1\sin(\theta) + C_2\cos(\theta) = \sqrt{C_1^2 + C_2^2}\,\sin(\theta+K) \quad \text{...(3)}$$

where arctan (K) = C_2/C_1.

The coefficients and lag angles are computed by the least squares method rather than through the use of the Fourier Integral. The reason for this is due in part to the fact that the temperature data are not equally spaced in time and can lead to poor approximations in the integration for computing some of the Fourier coefficients. The use of least squares coefficients in place of Fourier coefficients is further explained by a well

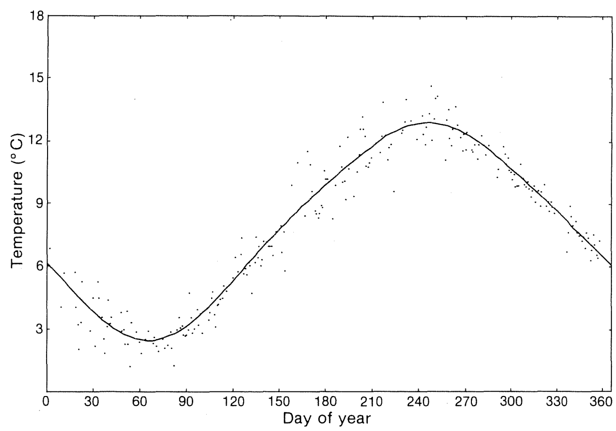

Fig. 2. The annual temperature curve in region 1 in the upper 30 m is compared with integrated temperature data taken from 235 acceptable days of the year.

TABLE 1. Number of hydrographic stations and expendable bathythermograph (XBT) cast stations in each of the 12 regions.

Region	Hydrographic stations	XBT stations	Total
1	573	648	1,221
2	168	167	335
3	320	370	690
4	1,814	1,053	2,867
5	647	1,277	1,924
6	436	646	1,082
7	743	1,385	2,128
8	1,206	1,658	2,864
9	232	417	649
10	520	965	1,485
11	283	772	1,055
12	465	734	1,199
Total	7,407	10,092	17,499

TABLE 2. Number of hydrographic stations and expendable bathythermograph (XBT) casts appearing in all 12 regions by month.

	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hydrographic stations													
	312	422	703	679	817	547	678	712	649	545	783	560	7,407
XBT casts													
	221	364	891	1,179	1,168	506	586	1,161	481	1,197	1,755	583	10,092
Total	533	786	1,594	1,858	1,985	1,053	1,264	1,873	1,130	1,742	2,538	1,143	17,499

known result that Fourier coefficients give the best least-squares fit for the orthogonal expansion of the type of function described here. Hence, Fourier coefficients and least squares coefficients are closely bound together.

The decision to express T(X) in terms of the first three harmonics was based on several factors. For the purpose of comparisons among regions and ease of application, such as in computer modelling, it is desirable to have a single function type which produces equally accurate results for each season in each of the 12 regions. The temperature function should accurately describe early spring data, when vernal surface warming initiates vertical mixing and surface turnover, as well as the autumn data when surface and intermediate layers begin to cool. The length of the warming and cooling cycles, which vary among regions, should be reflected in the temperature function as well. To achieve these objectives, the temperature data for a given region was first regressed using only the sine term of the first harmonic,

$$T(X) = M + C1\ SIN(0.0172X) \quad \ldots (4)$$

The coefficient C1 was then examined, using the null hypothesis that $C1 = 0$ against the hypothesis that $C1 \neq 0$. At the 95% confidence interval, C1 was found to be significant and the cosine term for the first harmonic was then added and the same data was then regressed on the function:

$$T(X) = M + C1 \sin(0.0172X) + C2 \cos(0.0172X). (5)$$

Again, C2 was found to be significant and included in the temperature function. The identity in equation 3 can be used to express equation 5 in the form:

$$T(X) = M + A1 \sin(0.0172X + B1) \quad \ldots (6)$$

The first harmonic, with a period of 365 days, is the dominant harmonic in equation 1. It may be regarded as a first approximation to the annual fluctuation in temperature about the mean, M. In the surface layer of each of the 12 regions, equation 6 has a correlation coefficient which exceeds 0.90, and a standard deviation of 1.40°C or less. However, the first harmonic alone would show the length of the warming and cooling periods each to be 6 months in every region. Moreover, equation 6 provides a less accurate fit in the spring and autumn data. When the terms of the second harmonic were added to equation 6, a similar analysis was applied to its coefficients, which were also found to be significant at the 95% level. The addition of the second harmonic also provides the necessary adjustment to compensate for the difference in time periods associated with the annual warming and cooling cycles. Although the addition of this second harmonic also improves the predicted temperature values in the spring and autumn, the sum of squares due to the error for these two harmonics is most prevalent in the spring data in some of the 12 regions. The addition of the third harmonic improves the overall fit, especially in the spring data in the coastal regions. Although the third harmonic contributes less than 0.4° C in the computation of any of the temperature functions, it is statistically significant in some regions, such as the Bay of Fundy, and can contribute more to the mean than the second harmonic.

When additional harmonic terms are appended to the first 3 harmonics, an analysis of their coefficients leads to their rejection at the 95% confidence interval. In addition to constructing the temperature function in equation 1 by testing the significance of each term added separately, an alternative procedure was also performed. A fourth harmonic was included, giving a total of 4 sine and 4 cosine terms. The data in a given region was then regressed on this set of 8 functions, first regressing on 1 function at a time, then 2, and so on up to all 8 functions, thereby eliminating the preference to the order in which each predictor is included. The results of this procedure illustrate that there is more than one combination of these functions which produce statistically acceptable temperature functions.

From a purely statistical viewpoint, there is no single "best" function of the types examined in this work. When this analysis was applied to the data in various regions, the temperature function chosen in equation 1 was included as one of the best. As an illustration, Fig. 2 shows the fitted temperature function over the upper 30 m corresponding to the averaged temperature data for region 1. The temperature function shown in Fig. 2 is:

$$T(X) = 7.92 - 4.97\sin(0.0172X + 0.47) - 0.25 \sin(0.0344X - 0.91) + 0.25 \sin(0.0516X + 1.31). \quad \ldots (7)$$

The information in Table 3 gives the parameters M, A1, A2, A3, B1, B2 and B3 which are used in the temperature function T(X) for each of the 12 regions for the upper 30 m. The table also includes the number of days in the year in which at least one suitable temperature station was recorded, the standard deviation about T(X), the correlation coefficient and the days when the temperature function shows its annual minimum and maximum temperature in the given region. Table 4 gives the same results for temperature functions in the intermediate layer from 31 to 70 m.

Since the sine function of any number cannot exceed 1 numerically, the maximum contribution of any harmonic to T(X) is equal to its amplitude (A1, A2 or A3 in Tables 3 and 4). For example in equation 7, the inclusion of the second harmonic (and third harmonic in this case) contributes no more than 0.25° C in the computation of T(X) for any given day of the year.

TABLE 3. Annual temperature functions integrated over the depth interval 0–30 m. (The function: T(X) = M + A1 SIN(0.0172X + B1) + A2 SIN(0.0344X + B2) + A3 SIN(0.0516X + B3) where X = day number.)

Region	No. of days	Standard deviation (SD)	Correlation coefficient (R)	Parameters							Minimum temp. (°C)	Day number	Maximum temp. (°C)	Day number
				M	A1	B1	A2	B2	A3	B3				
1	235	0.81	0.98	7.92	−4.97	0.47	−0.25	−0.91	0.25	1.31	2.46	66	12.90	246
2	127	0.98	0.96	7.02	−4.60	0.40	−0.39	−0.11	−0.21	0.07	2.10	58	11.23	249
3	146	0.79	0.97	7.09	−4.15	0.26	−0.26	0.18	−0.20	−0.23	2.84	63	11.05	259
4	254	0.75	0.98	6.80	−4.75	0.32	0.09	−1.26	−0.32	0.81	2.44	65	11.32	253
5	262	0.97	0.96	7.03	−4.51	0.26	−0.34	0.38	0.28	−1.35	2.62	76	11.58	277
6	226	1.00	0.96	8.15	−4.88	0.42	0.22	0.21	0.08	1.44	3.31	71	13.25	246
7	299	1.10	0.96	8.75	−5.35	0.41	0.33	−0.31	0.07	−1.46	3.74	73	14.34	248
8	307	0.91	0.98	9.22	−5.83	0.41	−0.57	1.31	−0.19	0.78	3.63	50	15.20	258
9	197	1.28	0.95	9.67	−5.50	0.49	0.82	0.19	0.15	−0.64	4.50	84	15.72	239
10	273	0.84	0.98	9.46	−5.56	0.52	0.70	0.19	0.26	0.07	4.10	80	15.57	242
11	233	1.05	0.95	8.53	−4.79	0.43	0.48	0.58	0.24	1.40	3.58	74	13.76	241
12	226	1.05	0.96	8.24	−5.22	0.50	−0.38	0.84	0.29	0.39	2.83	62	13.70	257

TABLE 4. Annual temperature functions integrated over the depth interval 31–70 m. (The function: T(X) = M + A1 SIN(0.0172X + B1) + A2 SIN(0.0344X + B2) + A3 SIN(0.0516X + B3) where X = day number.)

Region	No. of days	Standard deviation (SD)	Correlation coefficient (R)	Parameters							Minimum temp. (°C)	Day number	Maximum temp. (°C)	Day number
				M	A1	B1	A2	B2	A3	B3				
1	203	0.73	0.96	6.33	−3.14	−0.07	−0.76	0.00	−0.04	−1.37	2.95	71	9.81	298
2	96	0.79	0.96	6.76	−3.80	0.18	−0.60	0.07	−0.15	0.96	2.80	65	10.56	287
3	120	0.72	0.97	7.04	−3.77	0.18	−0.38	0.20	−0.16	−0.67	3.10	65	10.71	270
4	143	0.69	0.98	6.83	−4.16	0.23	−0.34	0.44	−0.37	0.66	2.87	57	10.77	281
5	244	0.96	0.94	6.82	−3.70	0.11	−0.47	0.07	−0.28	0.83	3.22	69	10.55	292
6	190	0.90	0.92	6.92	−2.84	−0.06	−0.62	0.36	−0.09	−1.43	4.03	68	10.11	290
7	276	1.03	0.90	7.21	−2.88	−0.06	−0.49	0.20	−0.10	0.70	4.42	75	10.37	296
8	269	1.22	0.95	8.85	−4.91	0.29	−0.63	1.05	−0.33	0.26	4.05	49	13.82	266
9	177	1.44	0.80	7.13	−2.31	−0.27	−0.61	0.11	0.22	−0.97	4.85	90	10.12	300
10	257	0.84	0.90	6.57	−2.14	−0.39	−0.80	0.05	0.09	−1.14	4.54	79	9.50	308
11	222	0.79	0.93	6.72	−2.67	−0.13	−0.66	−0.11	0.08	1.52	3.79	73	9.64	300
12	193	0.94	0.92	6.14	−2.76	−0.24	−0.93	0.18	0.11	1.08	3.28	70	9.58	301

Results and Discussion

The primary purpose of this work has been to present a process for comparing future warming and cooling trends in various regions of the Gulf against typical or standard annual temperature curves based on historical data. The temperature functions for different regions may be plotted and compared to illustrate seasonal and geographical variability. They may also be used for comparison with future temperature data surveys to determine warming and cooling anomalies in various topographic regions of the Gulf. The mechanisms responsible for warming and cooling trends include atmospheric variability, the long-term differential between evaporation and precipitation, an excess or deficiency in river runoff, changes in volume transport in and out of the Gulf, the proximity of the slope water boundary as suggested by Colton (1969), and the presence of warm-core rings. A combination of these events may affect annual temperatures in some regions at certain depths, but leave temperatures at other regions unchanged.

Hopkins and Garfield (1979) selected the upper 50 m as the Maine Surface Water, with a temperature-salinity envelope which includes that of the Maine Intermediate Water with a depth range of 50–120 m. In this paper the water column has been further divided into an upper 30 m layer along with an intermediate layer which extends to 70 m. This division was partly influenced by biologists who expressed an interest in temperature variability in a fairly shallow upper layer. In addition, the observed temperature readings at most hydrographic stations in the NODC data set are recorded at depths sufficiently close to allow reasonably accurate integrated temperatures in the 0–30 and 31–70 m layers. Smaller depth intervals would reduce the number of acceptable stations. Below 75 m, the intervals between depths at which observed temperatures were recorded can be quite large, which introduces considerable variability in the curve fitting scheme presented here. Attempts are being made to construct temperature curves for a bottom layer in each of the 12 regions. Many of the hydrographic stations do not contain a sufficient number of temperature readings completely down to the bottom depth at that station. Most XBT casts, however, do contain readings to the bottom along with a bottom depth at the cast location. There appears to be sufficient temperature data to integrate temperature readings from the bottom up to some prescribed depth, but the temperature functions used here for the upper layers may not be suitable for the bottom layer and further analysis of the bottom layer data is being continued.

The results which appear in Tables 3 and 4 show that in each region the correlation coefficient for the temperature function used is high. The results for goodness-of-fit were very encouraging and residuals were generally evenly distributed about the mean, without clustering about a particular season of the year. The standard deviation among the 12 regions varied from 0.75° to 1.28° C in the upper layer, and from 0.69° to 1.44° C in the intermediate layer. The column labelled M gives the annual mean temperature for the given region. Region 4 (Bay of Fundy area) showed the coldest annual mean temperature of the 12 regions in the upper 30 m (M = 6.80° C), with the other coastal regions 1, 2, 3 and 5 being only slightly warmer. The regions showing the warmest annual mean temperature in the surface layer were the offshore regions 7 and 10 (Georges and Wilkinson Basins) and region 8 (Georges Bank). In the intermediate layer (Table 4), coastal regions 1 and 12 showed the coldest annual mean, while the offshore region 8 was more than 1° C warmer than any other region.

The minimum and maximum temperature columns in Tables 3 and 4 showed the amplitude of the annual variability for each region. In the surface layer, annual variability extended from 8.21° C in coastal region 3 to 11.57° C on Georges Bank. In the intermediate layer, the annual variability was between 4.96° C in Wilkinson Basin and 9.77° C on Georges Bank.

Also, the days at which the fitted temperature functions obtained their maximum and minimum values can be used to determine the length of the warming and cooling cycles for each region. The warming cycles in the upper 30 m varied from 155 days in Georges Basin to 208 days on Georges Bank in the offshore area, while in the intermediate layer, the warming cycle only varied from 205 days in region 3 to 231 days in region 12. Both region 3 and 12 are coastal regions. With the exception of Georges Bank, the warming cycle in the surface layer was generally shorter offshore and over basins, where tidal mixing was reduced. It should be pointed out that the uneven distribution of data over the year in any region can slightly affect the curvature of the fitted temperature functions, and hence the length of the warming cycle by a few days.

In every region, the temperature of the surface layer was colder than the intermediate layer during the first 3 to 4 months of the year. In the coastal regions 2, 3, 4 and 5 and the offshore region 8 on Georges Bank where vertical mixing was significant, the temperature of the surface layer exceeded that of the intermediate layer only slightly during the warming cycle. The temperature difference between the surface layer and the intermediate layer in coastal regions 1 and 12 behaved more like that of the offshore regions where the formation of the summer thermocline has a dominant influence. This observation coincided with infrared satellite pictures which showed surface temperatures in coastal regions 1 and 12 more closely related to those of the offshore basin regions in the Gulf.

By using the minimum and maximum temperature values in Tables 3 and 4 along with the length of the warming cycle, one can compare the average temperature increase per day among the regions. In the surface layer, the coastal regions 2, 3, 4 and 5 warmed at a slower rate than the offshore basin regions, but in the intermediate layer the rates were slightly larger in the coastal regions, as one would expect from regions of strong vertical mixing. Although a discussion of the heat budget in the Gulf is not the subject of this work, a detailed analysis of the NODC data set does point out some additional difficulties in attempting to determine the annual heat budget for a given region. One difficulty is that of determining the depth of heat convection during the warming cycle, especially within the basin regions. When the minimum-temperature layer is examined in a basin region throughout the year, we find that the temperature of the minimum-temperature layer increases gradually through the warming cycle. Moreover, the depth at which the minimum-temperature layer occurs also increases with time and varies considerably throughout the Gulf, making volume estimates difficult to determine. A rigorous treatment of the annual heat budget for the Gulf continues to be a difficult, but important subject to pursue.

To illustrate one application of the annual temperature functions in Tables 3 and 4, these can be compared with temperature data over shorter time intervals. Colton (1968a) observed a cool period in the years 1963–67 and his data are included in the NODC data set. Also, temperature data in 1973–77 recorded at Boothbay Harbor by Welch (1981) showed temperatures to be warmer than normal, but these data are not part of the NODC data set. However, the temperature data from the NODC data set have been integrated separately in the upper 30 m for the coastal region 1 and offshore region 7 (Georges Basin). In region 1 (Fig. 3), a temperature function similar to that shown in Table 3 was fitted to the data taken in 1963-67 and shows this to be considerably cooler than the standard, as reported by Colton (1968a). For the period 1973-77 the 41 data points were not distributed sufficiently to fit an appropriate temperature function, due to the lack of data during the months from June to October in region 1. However, the integrated temperature data is plotted for 1973-77 and shows most temperature readings to be generally above the standard temperature curve, although the few temperature readings in January and February were well below the standard. In Georges Basin there were sufficient data to fit an annual temperature curve to the surface temperatures for the periods 1963-67 and 1973-77. The curves are shown in Fig. 4 where the standard curve for this offshore region separates the temperature curves for the cool period 1963-67 and the warm period 1973-77. These comparisons, along with similar testing in other time periods, seem to suggest that the annual temperature functions in Tables 3 and 4 are reasonably effective indicators of typical or standard annual temperature curves for the 12 regions represented in the Gulf.

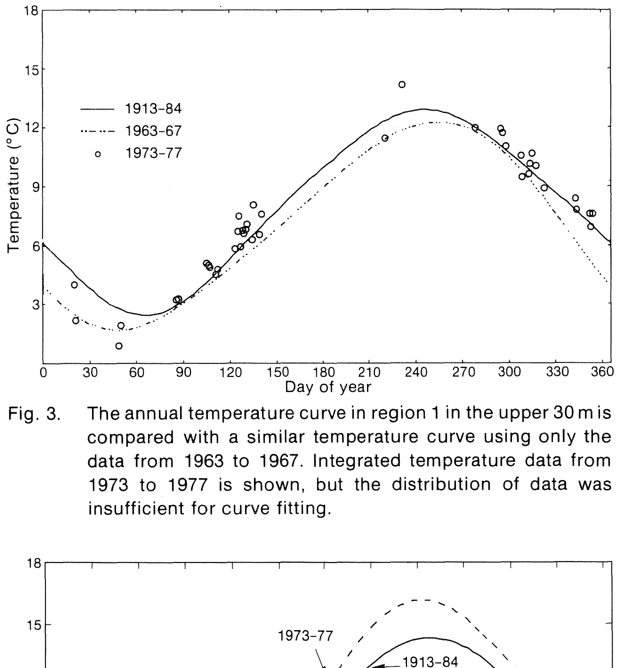

Fig. 3. The annual temperature curve in region 1 in the upper 30 m is compared with a similar temperature curve using only the data from 1963 to 1967. Integrated temperature data from 1973 to 1977 is shown, but the distribution of data was insufficient for curve fitting.

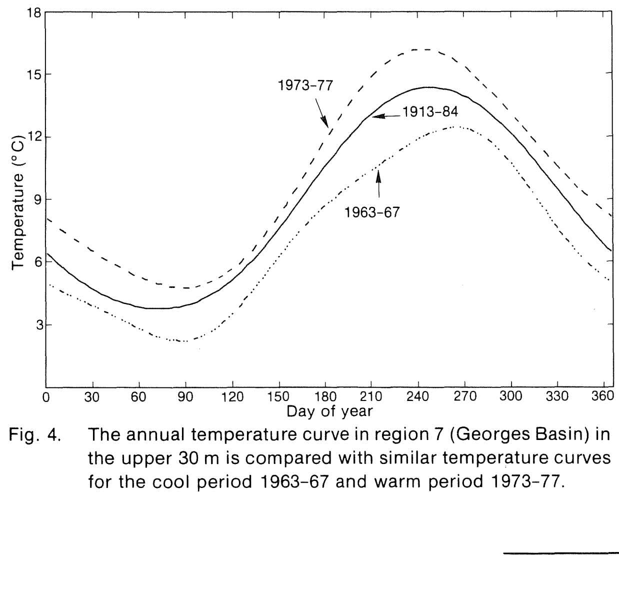

Fig. 4. The annual temperature curve in region 7 (Georges Basin) in the upper 30 m is compared with similar temperature curves for the cool period 1963-67 and warm period 1973-77.

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References

COLTON, J. B., Jr. 1968a. A comparison of current and long term temperatures of continental shelf waters, Nova Scotia to Long Island. *ICNAF Res. Bull.*, **5**: 110-129.

1968b. Recent trends in subsurface temperatures in the Gulf of Maine and contiquous waters. *J. Fish. Res. Board Can.*, **25**(11): 2427-2437.

1969. Temperature conditions in the Gulf of Maine and adjacent waters during 1968. *J. Fish. Res. Board Can.*, **26**(10): 2746-2751.

DOW, R. L. 1977a. Relationship of sea surface temperature to American and European lobster landings. *ICES J. Cons.*, **37**(2): 186-191.

1977b. Effects of climate cycles on the relative abundance and availability of commercial, marine and estuarine species. *ICES J. Cons.*, **37**(3): 274-280.

FLOWERS, J. M., and S. B. SAILA. 1972. An analysis of temperature effects on the inshore lobster fishery. *J. Fish. Res. Board Can.*, **29**(8): 1221-1225.

HOPKINS, T. S., and N. GARFIELD. 1979. Gulf of Maine Intermediate Water. *J. Mar. Res.*, **37**(1): 103-139.

1981. Physical Origins of Georges Bank Water. *J. Mar. Res.*, **39**(3): 467-499.

LAUZIER, L. M. 1965. Long term temperature variations in the Scotian shelf area. *ICNAF Spec. Publ.*, **6**: 807-815.

SCHOPF, T. J. M. 1967. Bottom water temperatures on the continental shelf off New England. U.S. Geol. Surv. Profess. Papers, No. 575D, p. D192-D197.

SUTCLIFFE, W. H., Jr., K. DRINKWATER, and B. S. MUIR. 1977. Correlations of fish catch and environmental factors in the Gulf of Maine. *J. Fish. Res. Board Can.*, **34**: 19-30.

WELCH, W. R. 1967. Trends of mean monthly sea water temperatures, 1950-1966, at Boothbay Harbor, Maine. *ICNAF Redbook*, 1967(IV): 33-36.

1981. Monthly and annual means of sea surface temperature, Boothbay Harbor, Maine. Maine Dept. of Mar. Resou. Res. Ref. Doc. No. 81/8.