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Preliminary look at feasibility of using marine reports of sea surface temperature for documenting climatic change in the Western North Atlantic

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ABSTRACT

The nature and quality of portions of the Marine Deck of sea-surface temperature (SST) records for Marsden Squares 114 and 78 (20°–40°N, 50°–60°W) have been examined to determine their suitability for historical analysis of SST, and for evidence of climatic variation. Apparently the data is numerous enough to demonstrate, using six-year means for individual months, a warming from 1910–1920 to a maximum in 1950–1960, and thereafter a cooling, coherent over both square (both in winter and summer), trends consistent with other sources of data.

We conclude from this very limited preliminary study that the Marine Deck can serve as a suitable data base for a statistical study of climatic variation over much of the Northern hemisphere at least on a decadal, 10° area scale, and on a more highly resolved scale in recent decades.

1. Introduction

Ship reports of surface meteorology and sea conditions have accumulated for over a century and are now filed in archives in computer-accessible form. In the past they have been used in two very different ways:

(i) for producing climatological mean atlases—which involves averaging large amounts of data over many years, and

(ii) for synoptic mapping of limited oceanic regions on a weekly to monthly basis—which involves rather small amounts of data (for example, the Gulf Stream Summary, 1966-to present, issued by the U.S. Naval Oceanographic Office). Because ship reports of sea surface temperature are not very accurate, and the reports themselves include uncorrected errors both in temperature and position, it has seemed likely to us that attempts to delineate synoptic features such as transient Gulf Stream meanders and eddies might not actually be objectively possible, given the data base.

We decided to explore in a limited region a long series of ship reports by computer compilation directly from magnetic tapes of the historical sea-surface temperatures (SST) on file in National Weather Records Center (NWRC), Asheville, N.C. We chose to make our preliminary study along a meridional strip in the north Atlantic

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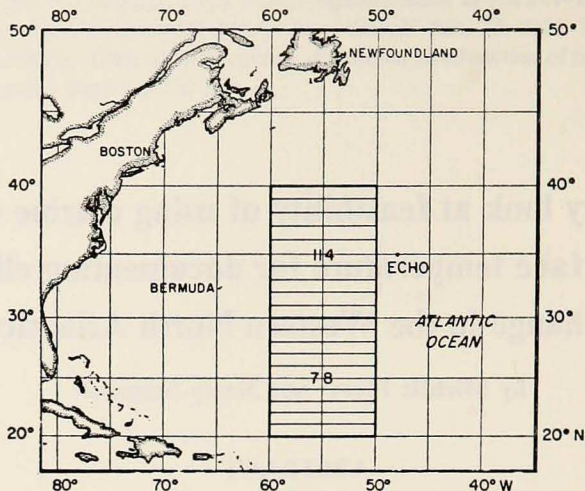


Figure 1. Location of Marsden Squares 114 and 78, Bermuda Islands and Ocean Weather Station ECHO.

Ocean 50° to 60°W and 20° to 40°N (Fig. 1) (Marsden Squares 78 and 114). For comparison we examined independent data from the PANULIRUS stations (Bermuda) and from Ocean Weather Station ECHO (35°N–48°W), data from Woods Hole Oceanographic Institution bathythermograph records and NODC hydrographic stations.

2. General oceanographic setting of the area

The Gulf Stream grazes the northern portion of the area, and the remainder toward the south is part of the main North Atlantic subtropical gyre. Composite bathythermograph sections through this region (Schroeder, 1965) show a seasonal thermocline separated from the main thermocline by a more or less homogeneous mass of 18°C water. In late winter—for example in March—the surface thermocline disappears between 32°N and 38°N, leaving the 18°C water exposed to the surface, at which time it is presumably “formed” (Worthington, 1959; Schroeder, et al. 1959).

One would suppose that during February–March in the region 32°N–38°N that the true horizontal (as well as vertical) variability of SST would be at a minimum, due to the almost 400 m depth of the vertically mixed layer, and that sampling for representativeness would be optimized.

We therefore concentrated our search of the data with a preliminary study of the month of March.

3. Computation of mean SST and statistics for March

As the mean spatial gradients of SST in this area are mostly meridional, each 10° square was divided into strips of 1° latitude and 10° longitude as shown in Figure 1.

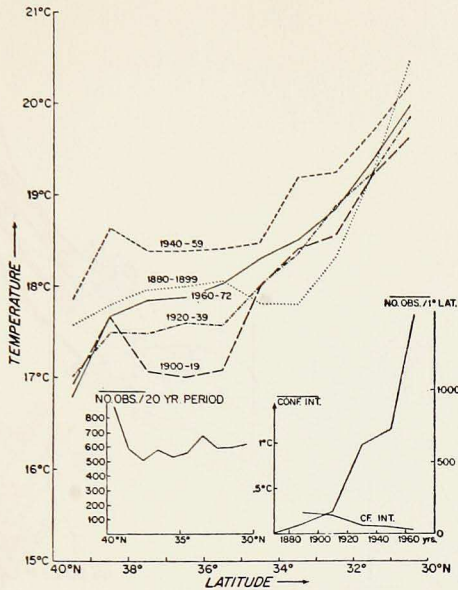


Figure 2. Variations of the sea surface temperature with latitude in Marsden Square 114, for March, over 20-year periods. Large variations occurred from one period to another over the whole square. To the left is the mean number of observations per 20-year periods function of latitude. To the right is the mean number of observations per 1° latitude strip function of the 20-year periods.

The mean SST, the number of observations, the standard deviation and the histograms of SST reports were computed for each strip over different intervals of time. In order to obtain a preliminary view of the data, the distribution with time and latitude and the monthly mean SST were calculated over 20-year periods for the months January through May in Marsden Square 114. These 20-year mean SST's as a function of latitude are shown in Figure 2 for the month of March. After 1920, the number of observations is sufficient to reduce the time span to 6 years (with one year overlaps), in order to get more detail on time variations (Fig. 3). From 1950-1972 the number of observations per year has increased sufficiently to justify computing means for March of each year individually.

Both Figure 2 (for 20-year periods) and Figure 3 (for 6-year periods) illustrate the gradual growth in numbers of observations with recent years, and the uniformity of numbers of observations at different latitudes.

Before discussing the climatic fluctuations revealed in these means we must first establish their statistical significance. This requires a knowledge of the number and standard deviation of individual reports for each calculated mean. This information is contained in tabulations for a particular 6-year March period, and equivalent histograms such as that shown in Figure 4. 95% confidence limits have been computed from such tabulations, for example from Figure 4, the mean temperature for

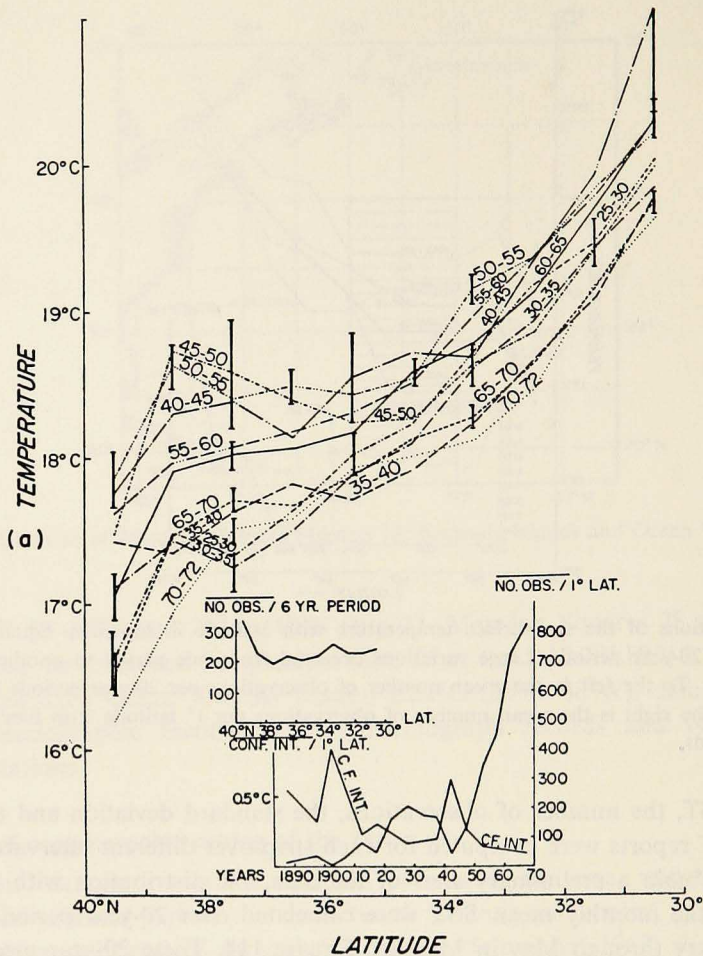


Figure 3. (a) Variations of the sea surface temperature with latitude in Marsden Square 114 for March over 6-year periods, from 1925-1972. The bars are the 95% confidence intervals. To the left is the mean number of observations per 6-year period function of latitude. To the right is the mean number of observations per 1° latitude strip function of the 6-year periods.

(b) From 1885 up to 1925 in Marsden Square 114.

(c) In Marsden Square 78 for 5 of the 6-year periods, the 95% confidence intervals (bars) are much smaller than the sea surface temperature variations from one period to another. To the left, the 95% confidence interval curve shows peaks corresponding to the small numbers of observations (to the right) during the two World War periods.

March 1960-1965 in the latitude band 35°-36°N is 18.16°C and the standard deviation is 1.31°C. The number of observations, 693, is so large that the 95% confidence limit can be computed according to Student's "t" test for a value of $t = 1.96$ corresponding to an essentially infinite population, and hence the 95% confidence limits in this particular core are given by

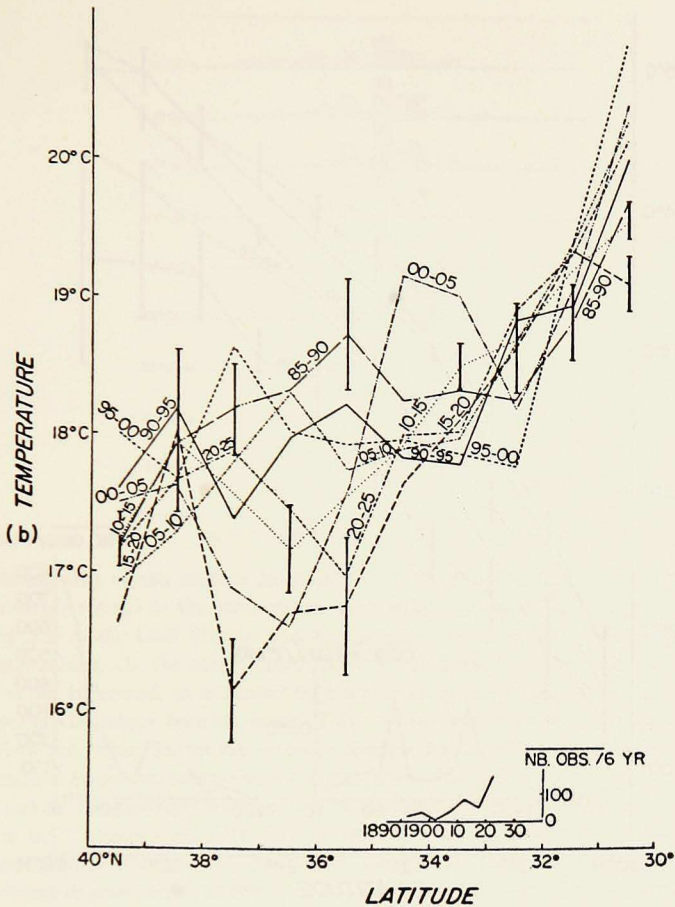


Figure 3 (b).

$$\pm \frac{1.31 \times 1.96}{\sqrt{693}} = \pm 0.097^{\circ}\text{C}.$$

The confidence limits of the various means have all been computed in this fashion, from the statistics of the individual observations.

4. The climatic fluctuations in reported March SST and comparison with February and August

Let us begin our examination of SST in Marsden Square 114 by considering the 20-year mean March SST as a function of latitude as depicted in Figure 2. Except for the first period, 1880-1899, in which the confidence limits are rather large, there is a similar shape to the curves: general increase of temperature with decrease in latitude, a fairly flat place between 35°-38°N where the 18° or perhaps better called

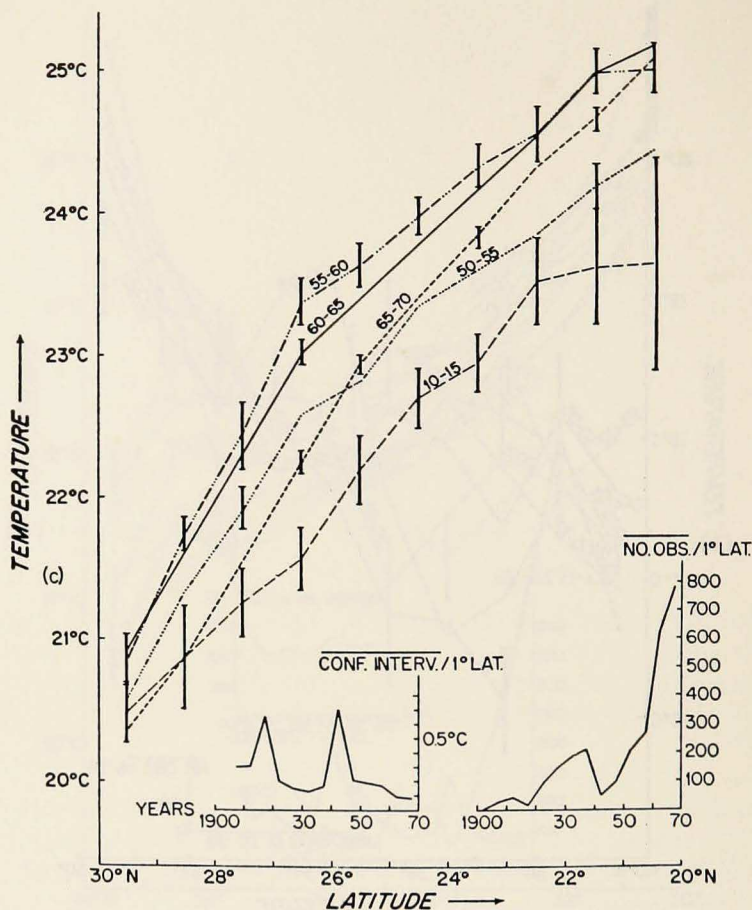


Figure 3 (c).

“subtropical mode water” (SMW) is exposed to the surface, and generally a small maximum between 38°–39°N which corresponds to the “warm-core” of the Gulf Stream. The striking feature of this figure is the large differences from period to period. These differences appear to occur simultaneously at all latitudes 30°N–40°N, and to be statistically significant.

Although the oldest (1880–1899) and most recent (1960–1972) means indicate SMW of nearly 18°C, the period 1940–1959 appears to be substantially higher, 18.3°C and the period 1900–1919 much colder, 17.0°C. These variations—particularly the coldest period—pose problems for the concept advanced by Worthington (1959) and Schroeder et al. (1959) of a subtropical mode water (SMW) of nearly constant 18°C.

In order to resolve these fluctuations in more detail, six-year overlapping means for March were computed for each degree of latitude. The period to period variability

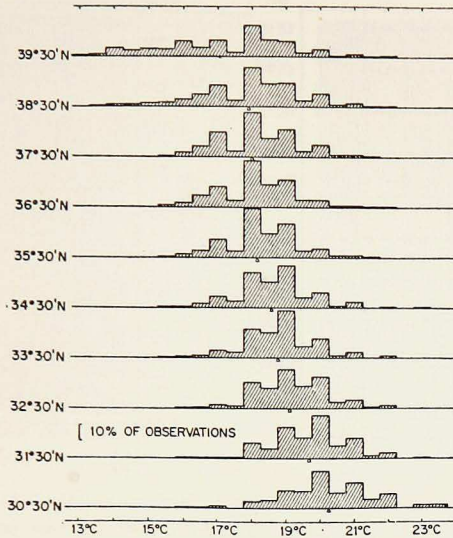


Figure 4. Histograms of sea surface temperature in Marsden Square 114 for March 1960-1965. There is a larger spread in the temperature distribution north of 38°N than to the south which is probably due to the Gulf Stream and its meanders which lead to larger variations in the sea surface temperature. On the other hand, there is a minimum spread over the isothermal region where 18° water is formed, as indicated by a minimum standard deviation. The maxima at whole degrees centigrade occurs because most of the temperature reports are rounded to the nearest degree. When the temperatures are given in degrees Fahrenheit, also rounded, the frequency in the intermediate boxes increases. On some histograms (i.e., 1955-1960) there is a gap in the data at 17.5°C due to the transformation of whole degrees Fahrenheit to degrees Centigrade and the grouping in 0.5°C boxes (i.e., 63°F falls in the 17°C box and 64°F in the 18° box). Since one degree Fahrenheit is smaller than one degree Centigrade, and as there is a strong tendency to report in round degrees, there seems to be a loss in accuracy with the Centigrade reporting.

is acceptably above the 95% confidence limits between 1925-1972, as shown in Figure 3a but in earlier periods before 1925 (Fig. 3b), the means appear to wander about mostly as a result of the random errors. Because the variability seems to be space and time coherent over all latitudes in Marsden Square 114, it seemed to be of interest to produce a similar graph for the square adjoining to the South (Marsden Square 78), (Fig. 3c). Finally, in order to view the time fluctuations more clearly, graphs of the SST mean anomalies were prepared (Fig. 5), contoured in 0.5°C intervals. Figure 5a and 5b correspond to the curves shown in Figure 3a and 3c—they show that the 6-year mean March SST anomalies tend to occur nearly simultaneously over both Marsden Squares, that is the full range of latitude 20°N-40°N, although the times of actual maximum SST at low latitudes appear to lag those to the north somewhat. There is indication however of a marked cooling of SST since 1955-1960 at all latitudes in both squares. In order to demonstrate that these climatic changes (of order $\pm 0.7^\circ\text{C}$) thus reported occur at other times of the year, the anomalies

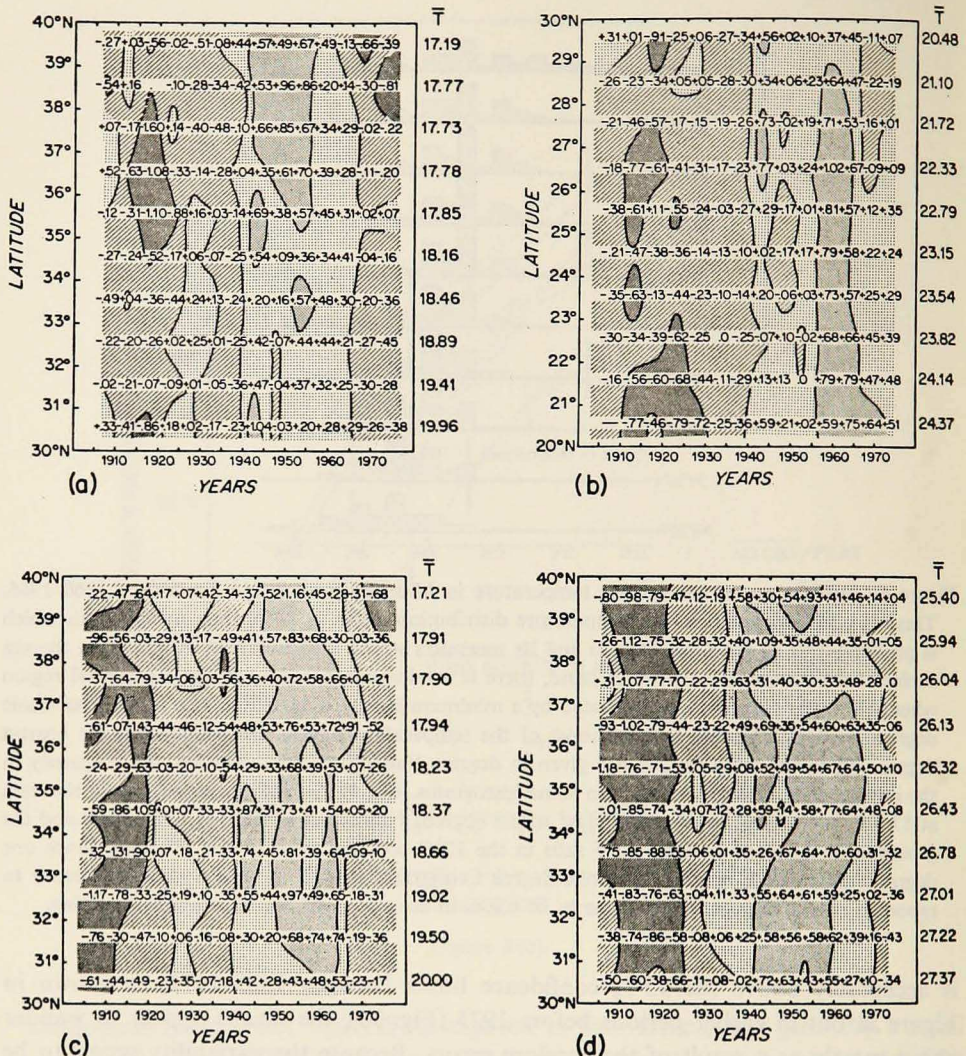


Figure 5. Sea surface temperature anomaly function of latitude and time over 6-year periods.

- (a) in MS 114 for March,
 (b) in MS 78 for March,

- (c) in MS 114 for February,
 (d) in MS 114 for August.

The coldest period occurs around 1910–1920 and the warmest during 1950–1955 in MS 114 and 1955–1960 in MS 78; a general cooling has been in progress ever since up to the present.

are also computed in Square 114 for February (5c) and August (5d). It is thus not just a wintertime phenomenon but is apparent throughout the year.

For the last 22 years, during which the number of observations is maximal, the averaging time span has been reduced to a single year, for the month of March in MS 114 (Fig. 6a). The 95% level confidence intervals corresponding vary between

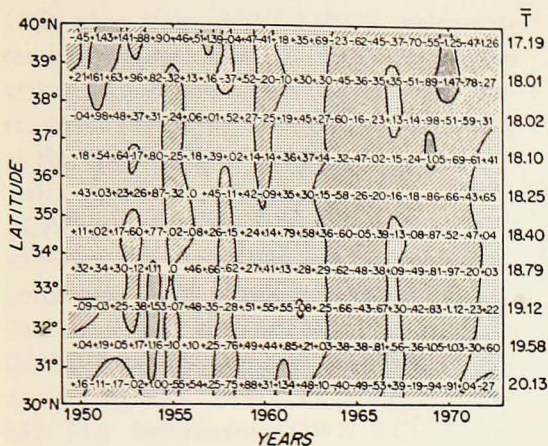


Figure 6 (a).

Figure 6 (a). Sea surface temperature anomaly function of latitude and time over one-year periods in MS 114, for March, from 1950 up to 1972. Despite the large confidence intervals, the contours show rather good consistency with latitude and time. The warmest year seems to be 1954 and the coldest 1970.

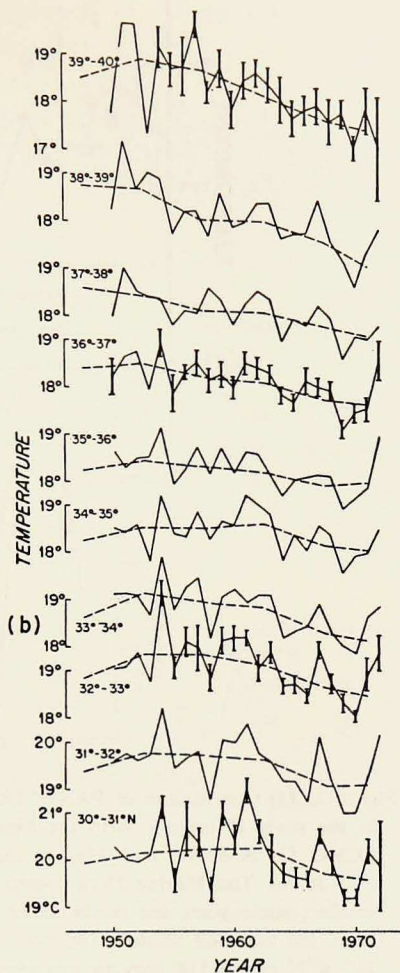


Figure 6 (b).

.15°C and .50°C which may be as large as the year to year variations (Fig. 6a, 6b). Hence they are not as significant as those for 6-year periods.

Between 34° and 38°N, in the roughly isothermal area, the SST fluctuations may reach 1.5°C, i.e., a variation of the '18° water' from 16.5°C to 18.5°C.

5. Comparison with other data sources

The reported temperatures in the Marine Deck may be biased in different ways, and it is a matter of concern to decide whether these climatic fluctuations revealed by the statistical analysis are actually real and representative of the ocean, or whether some systematic error—such as might be introduced in engine room design or

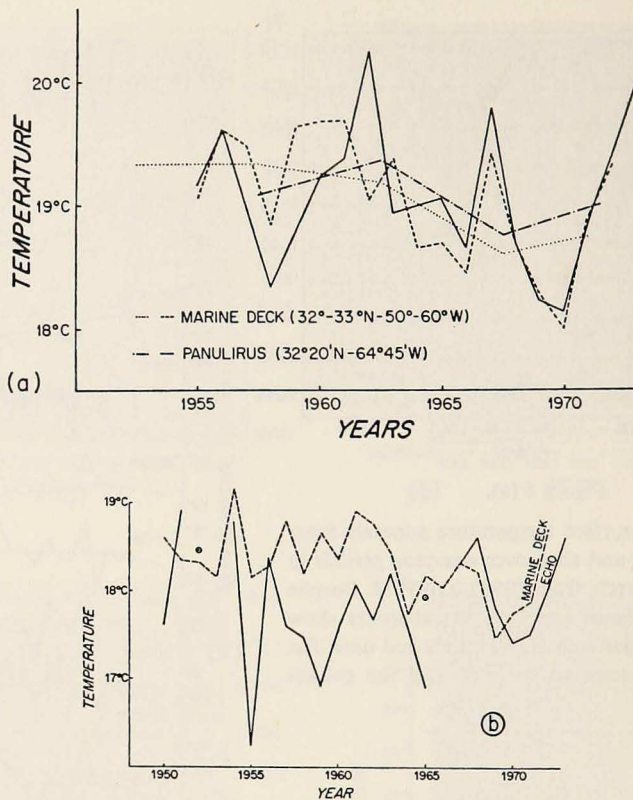


Figure 7. (a) Comparison of PANULIRUS and Marine Deck (NWRC) sea surface temperature in the same 1° latitude strip for March-yearly and 6-year means. (b) Comparison of OWS ECHO (35°N-48°W) and Marine Deck sea surface temperatures over the 2° latitude strip (34°-36°N). The Marine Deck means are smoothed over a larger area and the variations are smaller; some years are much colder at OWS ECHO (1955, 1959, and 1965) and the fluctuations are not well related. The two points correspond to BT mean temperature for the area 34°-36°N in MS 114; they are more similar to the Marine Deck temperatures than to the ECHO ones.

historical changes in means of propulsion, for example, might cause errors which vary systematically with time.

In order to investigate these possible types of error of interpretation, we offer the following—admittedly incomplete and not totally satisfactory—comparison with other data.

(i) The PANULIRUS (Bermuda Biological Station's Vessel) observations, located near the Bermuda Islands (32°20'N-64°45'W), consist of one or two hydrographic stations a month taken with care from 1954 up to 1973 (Woods Hole Oceanographic Institution files). Although there are many more SST observations from the Marine Deck, they have been compared with the mean SST in the strip 32°-33°N. Nevertheless the variations of the SST are similar (Fig. 7a) even year by year except for

1962, when then, PANULIRUS temperatures were warmer. This similarity despite the very small number of PANULIRUS measurements is a reassuring check on the consistency of the Marine Deck data set.

(ii) The Ocean Weather Station (OWS) ECHO (35°N–48°W) observations, from 1952 to present (Mariners Weather Log), are compared with those of the strip 34°–36°N (Fig. 7b) on a year to year basis, because the ECHO data are not continuous in time. According to Riehl's data set (1887–1936) the MS 113, surrounding OWS ECHO, had colder sea-surface temperatures than the MS 114; indeed, during the period 1950–1972, most of the ECHO mean temperatures were colder than the Marine Deck ones in MS 114. The comparison with ECHO data is not as good as with the PANULIRUS ones; a discrepancy which we cannot resolve in the absence of examination of the ECHO data for possible systematic errors.

(iii) Bathythermograph data (which include special SST measurements) from 1945 to 1970 (on file at Woods Hole Oceanographic Institution) for the strips 34°–35°N, 35°–36°N, and 36°–37°N are compared with the Marine Deck data of the same strips (Fig. 8). Because of the paucity of the BT observations, the comparison is also made on a yearly basis. The individual BT sea-surface temperatures show a large spreading even during one month of March (more than 1°C), but the values are most of the time spread around the mean Marine Deck sea-surface temperature, and the downward trend stands out. Use of bathythermograph data is fraught with danger because they often represent data taken with an experimental bias (e.g., study of cold eddies) and may not be truly representative of a time and area.

These different mean SST sources do not always compare well, because one corresponds to only a single position (PANULIRUS, ECHO), the other to very few observations (BT). Errors of a mean temperature may arise from the temporal

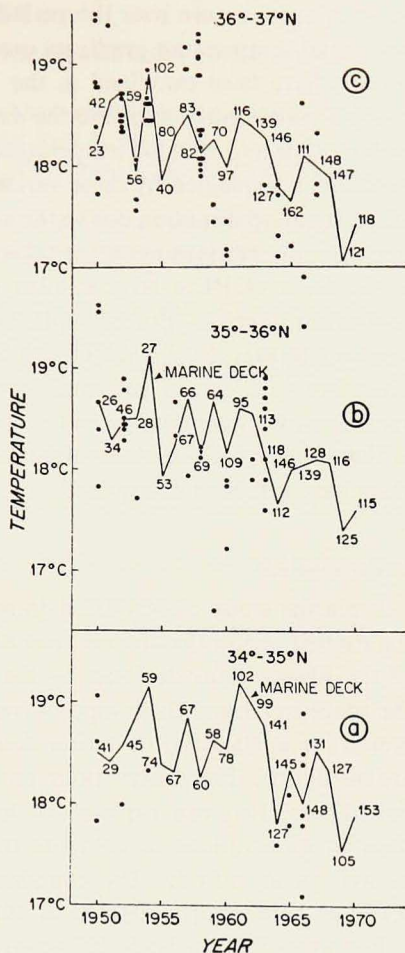


Figure 8. Comparison of Marine Deck and BT sea-surface temperatures for March in 3 strips: (a) 34°–35°N, (b) 35°–36°N, and (c) 36°–37°N. The curve is the mean Marine Deck SST, the points are the individual BT SST.

trend of temperature over the period involved, the space trend depending upon the horizontal temperature gradients over the strip where the mean is calculated. These sources have been examined in the 1° latitude strip (36° – 37° N) as an example. In fitting a multiregression line to the data including variation with days, with longitude, with latitude and with air temperature, one finds that only 20 to 30% of the standard deviation is explained by these variations. This means that $.8^\circ\text{C}$ or $.9^\circ\text{C}$ is the value of the standard deviation due to the accuracy of the observation; that is not surprising since the observations are often taken in rounded degrees. With a standard deviation of the order of 1°C a large number of observations is needed in order to get small confidence intervals. For example, with a standard deviation equal to 1°C the confidence interval (95%) is $.28^\circ\text{C}$ with 50 observations and $.19^\circ\text{C}$ with 100 observations. Therefore in order to get small confidence intervals compared to the mean SST variations, we were constrained to average over several years. Long term variations in the accuracy of the observations and systematic errors associated with individual ships have not been determined.

6. Conclusion

From the study of NWRC data set in MS 114 and 78, it has been found that in the studied region the observations are uniformly distributed in space. The spreading of the observations depicted by the standard deviation is only partly explained by the space trend and the temporal trend over the period involved (i.e., March 6-year period). The standard deviation due to error or inaccuracy in the measurement is around 0.8°C . The observations are usually taken in round degrees Fahrenheit or centigrade; that can explain the high standard deviation. When there are more than 50 observations to compute the mean SST, the results are coherent in time as well as in latitude. The confidence intervals for 6-year periods decrease from 0.7°C in 1915–1920 to 0.09°C in 1965–1970.

Reported SST in both 10° squares exhibits a cold period during 1910–1920, a warming during 1925–1930, then a slight minimum between 1935–1940; then during the fifties there is a warm period, and finally a decrease up to 1972. Variations from one year to another can be at least as large as the variations during the whole period. Agreement is found with data from BT observations and PANULIRUS but not from ECHO. The SST trends observed seemed to be similar to those observed (1907–1966) along the New England coast (Chase, 1967), in studies (1950–1968) of ice drift at Iceland (Sigtryggson, 1969), and on the total northern hemisphere atmosphere (1958–1963) (Starr and Oort, 1973).

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