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Meridional Distribution of Temperature-Salinity Characteristics of Pacific Ocean Surface Water

Ronald J. Lynn

Chesapeake Bay Institute
The John Hopkins University
Baltimore, Maryland

ABSTRACT

This paper describes the meridional distribution of the temperature-salinity (t-s) characteristics of Pacific Ocean surface water in a sector between 120°W and 180°, and from the Aleutian Island Arc to the Antarctic ice. The description includes an average t-s curve of the surface water. The average t-s curve is similar to, but more detailed than, the corresponding t-s curve found in Wüst, Brogmus, and Noodt (1954). The curve provides the basis for (1) a comparison between the surface characteristics in the northern and southern hemispheres in the open ocean, and (2) a description of the specific-volume distribution of Pacific Ocean surface water.

Introduction. Iselin (1939) constructed a temperature-salinity (t-s) diagram for meridional bands of the North Atlantic surface water by using maps of average surface properties. Wüst, Brogmus, and Noodt (1954) prepared graphs of average meridional distributions of surface temperature and salinity and used these graphs as the basis for t-s diagrams for the surface water of the Atlantic, Indian, Pacific, and world oceans. The graphs were constructed from surface maps of annual means of temperature and salinity by averaging over the width of the oceans by 5-degree zones.

The present paper uses data from individual meridional tracks to prepare an average meridional t-s distribution of Pacific Ocean surface water within a central sector. The analysis reveals significant detail not evident in the earlier studies. The t-s curve is used in a comparison of surface characteristics between the northern and southern hemispheres in the open ocean, and in an analysis of the specific-volume distribution of Pacific Ocean surface water.

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2 Present address: Bureau of Commercial Fisheries Biological Laboratory, San Diego, California.
The Data and Presentation. The ship tracks used in this paper are listed in Table 1 and are shown in Fig. 1. In order to provide a meridional sequence of data, only the data from those parts of the cruises that had a meridional track are used. Data from no more than four cruises are considered in any particular range of latitude. Where ample data were available, those cruises were chosen that had the longest meridional tracks and whose observations fell within a specified range of longitude. The range of longitude (120° W to 180°) was chosen to include ample data, to avoid shore influences, and to restrict the zonal variation of temperature and salinity.

The uneven distribution of data by season (see ship track dates in Table 1) makes it necessary to establish seasonal restrictions on the resulting t-s curve. The t-s curve is considered to be composed of sections, each corresponding to a major meridional region and to a certain range of months: July through September north of the northern tropic, July through December for the intertropical region, and year-round south of the southern midlatitudes. Remarks on the seasonal restrictions are made on p. 75.

Temperature Variation with Latitude. Plots of surface temperature against latitude are given in Fig. 2. The boundaries of the equatorial currents shown in Figs. 2 and 3 were derived from data of the four equatorial cruises used in this paper. The boundaries were inferred from the changes in slope of the thermocline except in the case of Hugh M. Smith cruise 16 where the boundaries were taken as those of the geostrophic current (Montgomery and Stroup 1962). The current boundaries are essentially the same as those shown by Puls (1895).

The general outline of the curves matches the distributions found on typical surface-temperature charts for the Pacific Ocean (e.g. Hydrographic Office World Atlas of Sea Surface Temperature 1944, or Schott 1935). The characteristic features of the graph are the subtropical maxima and the intervening equatorial minimum. The temperatures of the extrema, averaged from the cruises listed in Table 1 with their typical locations, are as follows:

Temperature maximum 27.7°C at 8°N
Temperature minimum 25.0°C at 0°
Temperature maximum 27.3°C at 11°S

There are no noticeable discrepancies between the above values and the surface temperature distribution charts, of the corresponding months, given by Puls.

Patterson and Smith (1929) have presented a table of seasonal average temperature differences between the equatorial minimum and the maxima along 170°W. Based upon their data, the annual mean temperature difference between the minimum and the northern maximum is 1.0°C (range: 0.6°C to 1.4°C), with the maximum located near 5°N. The annual mean tempera-
turer difference between the minimum and the southern maximum is 2.1°C (range: 0.9°C to 2.6°C), with the maximum located near 9°S.

In the first approximation the curve of temperature against latitude could be considered symmetrical about the equator. A deviation in symmetry is seen in the latitudes of the two major changes in slope of the curve in Fig. 2. For the northern hemisphere this change in slope occurs 15° of latitude farther from the equator than in the southern hemisphere. (The break in continuity of the curves found near 20°N to 22°N is a result of cruises commencing or terminating at the Hawaiian Islands.)

Two features are worth mentioning in detail. There are four plots of temperature against latitude from the Antarctic region; two DISCOVERY II tracks for August and September, and two OB tracks for April. The effect of the five-month time interval between the cruises is a shift of latitude for the isotherms averaging 7° of latitude, with the isotherms of the April OB data being the southernmost. No corresponding shift of isohalines is apparent.

The second feature is that the range in temperature found in the equatorial region is, at least in part, caused by the zonal temperature variation. There is a 2°C difference between the S351 and S352 curves whose data were taken within 40 days at a longitude interval of 25°. This zonal temperature variation is similar to that shown on Schott's charts of surface temperature for August. Outside the tropics the isotherms are essentially oriented in an east-west direction.

Salinity Variation with Latitude. Plots of surface salinity against latitude are given in Fig. 3. The general outline of the curves matches the surface-salinity distribution given by Schott.

The major features of the salinity distribution with latitude are two major maxima with the intervening minimum. The salinity of the extrema, averaged from the cruises listed in Table 1 with their typical locations, are as follows:

- Salinity maximum 35.5‰ at 29°N
- Salinity minimum 34.0‰ at 10°N
- Salinity maximum 36.4‰ at 16°S

The minimum at 10°N appears to fall on the boundary of the Equatorial Countercurrent and the North Equatorial Current. In his analysis of Hugh M. Smith cruise 5, Cromwell (1954) found that the salinity minimum falls in the Equatorial Countercurrent. However, Austin (1954a), in his analysis of Hugh M. Smith cruise 11, found that the salinity minimum occurs in the North Equatorial Current, as did Montgomery and Stroup (1962: 25) in their analysis of Hugh M. Smith cruise 16.

In addition to the major extrema, a small reversal in the general trend appears between 2°S and 10°S. A slight maximum in salinity occurs between 2°S and 7°S, and a slight minimum between 5°S and 10°S, according to three
of the four equatorial cruises. The one exception is the Horizon Downwind Expedition, which had widely spaced stations (at 2°S, 6°S, and 10°S) and could have missed such a phenomenon. The salinity section for Hugh M. Smith cruise 16, as given by Montgomery and Stroup, shows that the small maximum in the surface salinity is associated with the subsurface high-salinity tongue extending from southern latitudes (near 100 m). Unpublished sections for Hugh M. Smith cruise 35 reveal a similar salinity distribution. Sections along 140°W (May-June 1952) given by Austin (1954b) show the same feature. The phenomenon appears as a hook in the average t-s curve.

The low salinity found by the Horizon at 25°S is suspect. It is nearly 1% lower than values measured at stations of similar latitude. Its anomaly is more evident on the t-s diagram in Fig. 7. This t-s point was ignored in forming the average t-s curve and its envelope.

**Construction of the t-s Curve.** Similar t-s characteristic values are found at largely different latitudes. In order to distinguish the meridional sequence of these similar values on t-s diagrams, it is necessary to provide diagrams for different zones. Four zones were created by employing the latitudes of the major salinity extrema as division points. All the t-s data from the cruises listed in Table 1 were plotted on one of the four t-s diagrams (Figs. 4, 5, 6, and 7).

No statistical method of averaging could reasonably be applied to the scatter diagrams of t-s data to form an average distribution curve. The average t-s curve (Fig. 8) was constructed by estimation. The envelope of the curve was drawn to include all data points.

**Discussion of t-s Characteristics.** The average t-s curve (Fig. 8) offers a useful view in the description of the surface waters of the North Pacific and South Pacific oceans. The most striking feature of the t-s curve is the consistent difference between the hemispheres. The surface specific volume is everywhere greater in the northern hemisphere than at corresponding latitudes in the southern hemisphere. Because the temperature variation with latitude is almost symmetric about the equator, this feature of a consistent difference in specific volume appears as a result of the salinity variation.

In the following discussion of the average t-s curve, the extrema of specific-volume anomaly are analyzed. The coordinates of every value of specific-volume anomaly are given in parentheses in the following manner: temperature, salinity, approximate latitude. The units of specific-volume anomaly are centiliters per metric ton (cl/ton).

The maximum value of specific-volume anomaly for the t-s curve, 600 cl/ton (27.5°C, 34.0°/oo, 9°N), is found immediately south of the northern salinity minimum. From the typical location of the boundaries of the equa-
torial currents, the maximum of specific-volume anomaly appears to occur within the Equatorial Countercurrent and near its northern boundary. Support for this conclusion is given by Montgomery and Stroup (1962: 25).

North of the maximum, the decrease in specific-volume anomaly is due to the salinity increase and the temperature decrease. Just north of the northern salinity maximum, a minimum in specific-volume anomaly is reached, 400 cl/ton (24.5°C, 35.5°/oo, 29°N). The subsequent decrease in salinity allows an increase in specific-volume anomaly to a second, but weak, maximum, 440 cl/ton (23.0°C, 34.4°/oo, 36°N). This weak maximum is consistent in data from all four cruises used in the average (Fig. 4). Confirmation of the last two extrema can be found in the Morskoi Atlas (1950). The chart of surface density for August shows a maximum near 28°N and a minimum near 35°N. The NORPAC Committee Atlas (1960) shows this inversion in trend of specific-volume distribution in detail for summer 1955. The latitude of the weak maximum, 36°N, is also the latitude of a substantial change in slope of the curves of temperature versus latitude (Fig. 2). North of 36°N, the sharp decrease in temperature counteracts the decrease in salinity to produce a continuous decrease in specific volume up to the northern extent of the curve (Aleutian Island Arc).

Tracing the t-s curve southward from the maximum value of specific-volume anomaly, a similar pattern is found. The hook discussed previously is ignored here. The southward decrease in specific-volume anomaly is principally due to the increase in salinity to its maximum for the t-s curve. From the salinity maximum, 36.4°/oo at 16°S, the southward decrease in temperature continues the decreasing trend in specific-volume anomaly to its lowest value, 82 cl/ton (−1.9°C, 33.8°/oo, 70°S). The almost imperceptible maximum immediately south of the southern salinity maximum cannot be clearly demonstrated from the data used. A check of the ships’ tracks (Fig. 1) shows that there is only one continuous cruise through this region: the Horizon Downwind Expedition. The widely spaced stations of this cruise do not allow a very detailed analysis.

The t-s curve is only roughly comparable to the curve obtained by Wüst et al. Their averaging of surface distributions by zones for the entire oceans has the result that the equatorial temperature minimum and the secondary specific-volume maximum are eliminated and that the salinity maxima are reduced. In their curve the southern salinity maximum is lower by 0.7°/oo, and the northern salinity maximum is lower by 0.4°/oo.

The form of the t-s curve shows some resemblance to Cochrane’s (1956) frequency distribution of surface t-s characteristics. His paper presents the frequency of occurrence of surface t-s characteristics with an interval of 2°C and 0.4°/oo for the entire Pacific Ocean. His work is based on contoured maps of the surface distributions. The frequencies of t-s characteristics are shown
on t-s diagrams both by numbers and by isopleths. The present average t-s curve, when drawn over corresponding t-s diagrams from Cochrane's paper, approximately coincides with the ridge of high frequency. The best correspondence occurs with his August diagram for the North Pacific and with his yearly-average diagram for the South Pacific.

No comprehensive estimate of the importance of the seasonal restrictions will be made here; however, a few brief qualitative remarks are in order. If winter data were included in the averaging process, the part of the t-s curve for the Pacific north of the northern tropic would move to lower temperatures. Furthermore, the Morskoi Atlas density charts indicate that the secondary weak specific-volume maximum would diminish or disappear. However, McGary and Stroup (1956) have shown that the feature persisted to mid-winter 1954 between 141°W and 151°W. The data of their report cover an area between longitudes 141°W and 165°W.

The tropics have a more complex pattern of surface temperature and salinity than elsewhere. The seasonal changes of the t-s characteristics for the tropics will depend, in part, on the seasonal development of the equatorial current system. As a result, the average t-s curve is least predictable for the tropical zone. No estimation of the different forms that this part of the curve could assume is made here.

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Figure 1. Ship’s tracks of those parts of the cruises listed and identified with symbols in Table 1.
Figure 2. Top: Surface temperature plotted against latitude for all cruises listed (and identified) in Table 1. Curves have been faired through the plotted values, which are represented with dots. All stations used in this paper lie between 179°E and 110°W. The approximate location of the Equatorial Current system is indicated by the letters: SEC, South Equatorial Current; EC, Equatorial Countercurrent; NEC, North Equatorial Current.

Figure 3. Bottom: Surface salinity plotted against latitude for all cruises listed (and identified) in Table 1. Curves have been faired through the plotted values, which are represented by dots.
Figure 4. Top: Surface salinity plotted against surface temperature for CHARLES H. GILBERT Cruise 17 (G17), HUGH M. SMITH Norpac (SN), and SPENCER F. BAIRD, Chinook Expedition (BC1 and BC2). In Figs. 4 through 7 only data from stations in a meridional sequence have been plotted. In Fig. 4 only points north of the northern-hemisphere salinity maximum are shown. Family of curves is specific-volume anomaly in units of centiliters per ton. Dashed line represents freezing.

Figure 5. Bottom left: Surface salinity plotted against surface temperature for those parts of cruises that fall between the northern-hemisphere salinity maximum and salinity minimum. In addition to those cruises identified in Fig. 4 are Horizon Downwind Expedition (HD), HUGH M. SMITH Cruise 16 (S16), and HUGH M. SMITH Cruise 35 (S351 and S352).

Figure 6. Bottom right: The continuation of curves of Fig. 5 for those points that fall between the northern-hemisphere salinity minimum and southern-hemisphere salinity maximum. The additional cruise is LOTUS (L1).
Figure 7. Top: Surface salinity plotted against surface temperature for DANA World Cruise (D), DISCOVERY II (Dy1 and Dy2), Horizon Downwind Expedition (HD), LOTUS (L2), and OB Cruise 3 (OJ1 and OJ3). Only those points south of the southern-hemisphere salinity maximum are shown in this figure.

Figure 8. Bottom: Meridional distribution of temperature-salinity characteristics of Pacific Ocean surface water as averaged from the t-s data points of Figs. 4-7 (heavy solid line). Dashed part of heavy line indicates a lack of data to form an average. Light dashed line gives the envelope of all t-s data. The latitude values give the approximate location of important features of the t-s curve.