Papers in Marine Biology and Oceanography, Suppl. to vol. 3 of Deep-Sea Research, pp. 331-334.

Characteristics of surface water at Weather Ship J *

By R. B. MONTGOMERY
Chesapeake Bay Institute, The Johns Hopkins University, Baltimore, Maryland

Summary—Surface temperature and salinity observed 15 times a month for 3 years at Weather Ship J, west of Ireland, are presented in two-dimensional frequency distribution on a temperature-salinity diagram.

THE TEMPERATURE-SALINITY diagram was introduced by HELLAND-HANSEN (1916). HELLAND-HANSEN and NANSEN (1926) and others have used it as a scatter diagram for representing a large number of discrete, non-uniformly spaced observations. The purpose of the present paper is to demonstrate the suitability of the temperature-salinity diagram for quantitative representation of frequency distribution of water characteristics. A uniform series of data is used to prepare a diagram for a fixed point in the ocean.

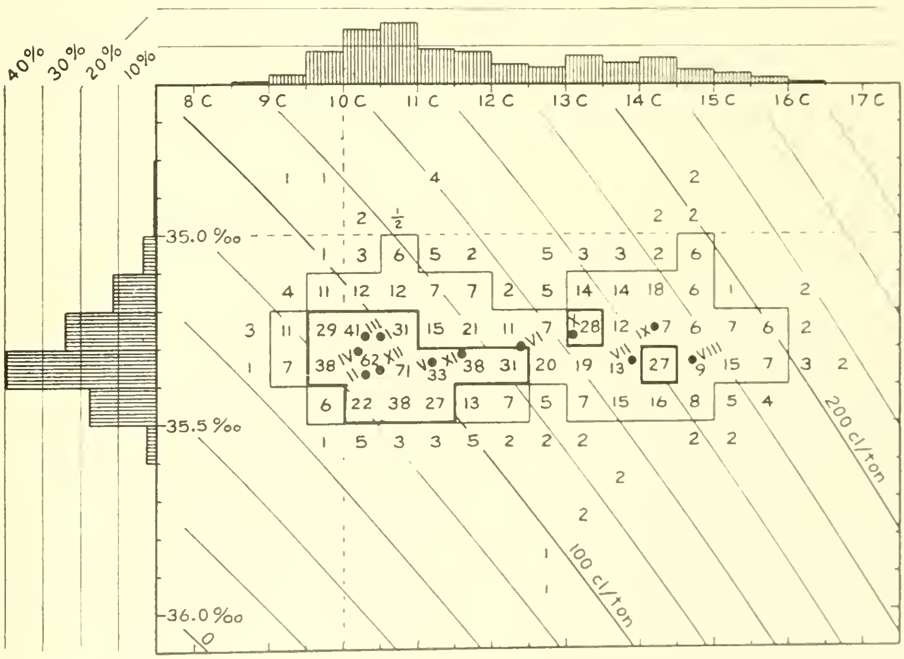

Fig. 1. Annual temperature-salinity diagram for surface water at Weather Ship J, 1948–1950. Number of occurrences per thousand is entered in each square (blank squares have no occurrence). Heavy frequency isopleth ($21\frac{1}{2}$ per mille) surrounds 51 per cent of occurrences, fine frequency isopleth ($5\frac{1}{2}$ per mille) surrounds 89 per cent. Monthly means are plotted as dots, each month identified by a Roman numeral. Anomaly of specific volume is shown by the family of curves.

* Contribution No. 25 from the Chesapeake Bay Institute. This study was supported in part by the Office of Naval Research and by a research grant from the National Science Foundation.

The weather ships, occupying nearly fixed positions, are potential sources of data of great climatological and oceanographic interest. Surface water at Weather Ship J in the North Atlantic Ocean is chosen for the present example, because published observations are available for three years in *Bulletin Hydrographique pour l'année* 1948, 1949, 1950. The data are credited to the Fisheries Laboratory, Lowestoft, Great Britain. Station J lies west of Ireland and south of Iceland. The usual position up to March 1950 was in the 1-degree quadrangle with southeast corner at 53° N 18° W and from April 1950 was in the quadrangle with southeast corner at 52° N 20° W.

For most days there is one observation of temperature and salinity, but for some days there is none. In order to obtain a homogeneous series from the somewhat irregular original series, 15 observations have been chosen for each of the 36 months. If available, the odd days 1, 3, . . . 29 have been used. Missing odd days have been replaced with other days or with observations from nearby positions. January 1948 has the fewest observations, only 10, and has been completed by including 4 from late December 1947 (*Bulletin Hydrographique pour l'année* 1947) and 1 from early February 1948.

The homogeneous series of 540 observations serves as the basis for the statistics presented on the temperature-salinity diagram in Fig. 1. The frequency for each two-dimensional class with temperature interval 0·5 C and salinity interval 0·1 per mille is tabulated in per mille.

By arranging the frequencies in order of decreasing magnitude and summing cumulatively, the result is found that about half (51 per cent) of the observations fall in classes with frequency 22 per mille and greater; these classes are enclosed by a heavy line. About nine tenths (89 per cent) fall in classes with frequency 6 per mille and greater; these are enclosed by a fine line.*

Summing the two-dimensional distribution horizontally and vertically respectively gives the one-dimensional frequency distributions of salinity and temperature, shown by the histograms at the left and top of Fig. 1.

Three-year monthly means for Weather Ship J are shown as points in Fig. 1. This method of showing monthly means was used by NEUMANN (1940, Abb. 25). His *Feld* 1 (Abb. 25, Nr. 6), the 5-degree quadrangle with northeast corner at 50° N 20° W, is represented by a circuit of similar shape (nearly isohaline), but with temperature range 1·5 C greater, mean temperature 2 C higher, and mean salinity 0·4 per mille higher.

Specific volume of surface water at Weather Ship J is shown by including isopleths of specific-volume anomaly. This quantity (which for surface water equals thermosteric anomaly) is chosen in preference to density or sigma-*t* for the reasons presented by MONTGOMERY and WOOSTER (1954). Any other temperature-salinity

* Two items of terminology are needed for two-dimensional frequency distributions. First, for a frequency isopleth of stated frequency a handier term than Bilham's " constant-frequency graph " (BROOKS and CARRUTHERS, 1953) is desirable. Secondly, an even more useful term would represent a frequency isopleth that encloses a stated proportion of the occurrences. If the first isopleth were called alpha and the second beta, the 0·0055-alpha would separate 5-per-mille classes from 6-per-mille classes, while the 0·9-beta would enclose nine-tenths of the occurrences; in Fig. 1, these two isopleths coincide. The betas have the advantage of being approximately independent of class intervals, for the alphas expand as the class intervals increase. It may be noted that beta is not similar to the term quantile (BROOKS and CARRUTHERS, 1953) used with regard to one-dimensional frequency distributions, because the maximum frequency coincides with 0-beta but with an intermediate quantile.

function, such as sound speed or surface concentration of dissolved oxygen, could be shown in the same manner by including the appropriate family of isopleths.

For lack of information, the accuracy of the observations is not discussed here.

The frequency distribution in Fig. 1 is self-evident, but some aspects are noteworthy. There is no apparent correlation between temperature and salinity at Weather Ship J. The frequency distribution of salinity is symmetric, but those of temperature and specific-volume anomaly are very asymmetric.

The peak frequency of temperature occurs near the minimum temperature. This pattern reflects the annual variation, which has a blunt minimum and a sharp maximum. Presumably the explanation is to be found, at least in part, in the deep, persistent winter mixed layer of large heat capacity in contrast with the shallow, changeable summer mixed layer.

The two-dimensional frequency distribution contains a suggestion of a waist at middle temperatures and of a secondary peak at higher temperatures. Whether these features will remain if the series is extended over more years is uncertain.

It seems likely that the pattern of annual frequency distribution of water temperature at Weather Ship J is characteristic of a large region in middle latitudes, but some very different patterns can be expected for other regions. As found by HESSELBERG (1943, p. 14), SIPLE (1949-1952), and FEUSSNER (1952, Abb. 4), the annual frequency distributions of air temperature at some land stations in middle latitudes show a rather symmetric bimodal pattern.

The annual frequency distribution of temperature is an economical expression of the temperature climate and might well be used more widely. The three references above are the only ones the author has found that employ this method.

The extreme range of temperature in the present series is 7·9 C,* while the difference in mean temperature between the warmest and coldest month is only 4·5 C. The frequency of temperatures below 10 C and above 15 C, hence outside the range of 0·5-C classes containing monthly means, is 17 per cent. It is clear that monthly mean temperatures, which are often the only statistics presented in climatological summaries, give but a faint picture of temperature conditions.

A welcome departure from the usual adherence to monthly means is offered by several series of oceanic Monthly Meteorological Charts published by the Meteorological Office, London. These charts include upper and lower 5-percentile isotherms of both air and water temperature, based on 2-degree quadrangles. The preparation of these charts must have entailed compiling further statistics that would be of interest if published.

The temperature-salinity diagram is but one of the oceanographic and meteorological class that has been called characteristic diagrams (MONTGOMERY, 1950), all of which would be suitable for the representation of frequency distributions.

Acknowledgements—The author wishes to record his benefit and pleasure from discussing this subject with Mr. JOHN D. COCHRANE, Mr. ARNOLD COURT, and Dr. JOHN B. LEIGHLY.

* With access to all data, FRANKCOM (1954) reports the extremes at Station J as maximum 17·8 C and minimum 7·8 C.

REFERENCES

BROOKS, C. E. P. and CARRUTHERS, N. (1953), Handbook of statistical methods in meteorology. London, Her Majesty's Stationery Office, M.O. 538, 412 pp.

Feussner, K. (1952), Über Wert und Verwendbarkeit von Temperatur-Häufigkeitsverteilungen für die Urteilsbildung. *Ber. Deutsch. Wetterdienstes, U.S. Zone*, **7**, (42), 440–446.

Frankcom, C. E. N. (1954), " Half-century " of voyages by each of the British ocean weather ships. *Meteor. Mag., London*, **83**, 282–283.

Helland-Hansen, Bjørn (1916), Nogen hydrografiske metoder. *Forh. Skand. Naturf. Møte*, 357–359.

Helland-Hansen, Bjørn, and Nansen, Fridtjof (1926), The eastern North Atlantic. *Geofys. Publ.*, **4**, (2), 76 pp., 71 pls.

Hesselberg, Theodor (1943), Die Verwendung des Maxwellschen Verteilungsgesetzes auf meteorologische Häufigkeitskurven. *Geofys. Publ.*, **13**, (9), 19 pp.

Montgomery, R. B. (1950), The Taylor diagram (temperature against vapor pressure) for air mixtures. *Arch. Meteorol., Geophys., u. Bioklim.*, (A), **2**, 163–183.

Montgomery, R. B. and Wooster, W. S. (1954), Thermosteric anomaly and the analysis of serial oceanographic data. *Deep-Sea Res.*, **2**, 63–70.

Neumann, Gerhard (1940), Die ozeanographischen Verhältnisse an der Meeresoberfläche im Golfstromsektor nördlich und nordwestlich der Azoren (Aus den wissenschaftlichen Ergebnissen der internationalen Golfstrom-Unternehmung 1938, 1. Lief.). *Ann. Hydrogr. Mar. Meteorol.*, **68**, (Beiheft zum Juniheft), 87 pp.

Siple, P. A. (1949), American climates. *Bull. Amer. Inst. Archit.*, Sept., 16–36. (Also subsequent numbers.)