Seasonal Changes in the Underwaters of Bermuda

By Prof. Walter Garstang

AFTER a visit last year to the Bermuda Biological Station, I directed attention in a semi-popular article to the unique opportunities at this lonely Atlantic island for oceanographic research, and suggested that continuous local investigation of the deep water around the island would be likely to hasten a solution of the "Atlantic Water" problem, which has such important bearings on European fishery and other questions (*Discovery*, December 1935). This opinion has been considerably strengthened by the subsequent study of various hydrographic reports, and especially by a collation of the published data recorded by various research vessels in the immediate neighbourhood of the island.

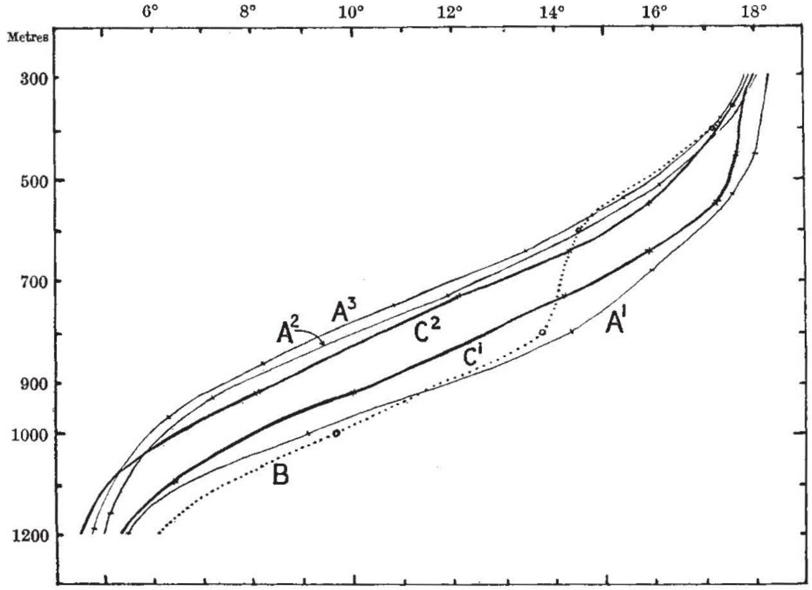

FIG. 1. Temperature curves of selected Bermuda stations (intermediate layer only).
A^1, A^2, A^3: *Atlantis*, February, April and December 1932, respectively.
B: *Bache*, February 1914.
C^1, C^2: *Challenger*, April and May 1873, respectively.

Temperature and salinity determinations at the following stations have been used: H.M.S. *Challenger* (temperatures only), stations 37 (April 24, 1873) and 57 (May 30, 1873); st. 10179 of the U.S. Fish Commission's vessel *Bache* (Feb. 18, 1914); st. 1339 of the Danish *Dana* Expedition (May 10, 1922); and six stations of the Woods Hole Oceanographic Institution's vessel *Atlantis*, namely, 1125 (Dec. 5, 1931), 1145 (Feb. 17, 1932), 1220 (April 17, 1932), 1359 (Aug. 27, 1932), 1431 (Dec. 5, 1932), and 1464 (Feb. 12, 1933). These stations are dotted about the island in various directions, all within a radius of sixty miles, except the first *Atlantis* station (1125), which lay 120 miles to the north-west. The data for this station furnish one of the extremes in the range of variation, but its inclusion seems to be amply warranted by a comparison with other stations at the same period.

The general characteristics of the water-column in the Sargasso Sea are well-known, and many temperature curves from the region have been figured by the *Challenger*, *Dana* and other expeditions. All show beneath the variable surface region two more or less vertical portions, representing relatively uniform layers: (*a*) a sub-surface layer of high salinity (*c*. 36·5 per mille) below the influence of solar radiation (150–400 metres), but preserving the effects of winter convection at a nearly constant temperature of 17°–18° (the average surface minimum), and (*b*) the deep waters (below 1,000 metres) of low salinity (less than 35·0 per mille) and temperature less than 5°. Between these two strata lies an intermediate layer (*c*. 400–1,000 metres) the variations in which are the main subject of this communication. It ranges over a considerable series of closely stratified temperatures and salinities, which confer a characteristic slope upon this portion of the curve. When the curves of the various Bermuda stations are superimposed upon the same large sheet of graph paper, it can be seen that the slope representing the intermediate layer changes its position with the season of the year, running at a higher level and to the left (that is, nearer the surface and through lower temperatures) during the summer and autumn, and lower down to the right (that is, through higher temperatures) during the winter and early spring—the very opposite of seasonal changes at the surface. Temperature and salinity curves follow the same orderly cycle, which, so far as the records go, differs only in amplitude from one year to another

(Fig. 1). The *Bache* curve for February is unique in showing autumn conditions above and winter conditions below. The soundings must have been taken while the winter change was in progress.

In the available space only a few of the curves can be conveniently reproduced, but the regularity of the sequence and the varying amplitude of the annual change come out almost equally well if we take a few representative isotherms and isohalines from the curves, and plot their levels in the water-column at the various times of the year represented. The invaluable *Atlantis* data naturally furnish the basis of such a diagram (Fig. 2). The continuous lines represent the varying depth of the isotherms 17°, 15°, 11·5°, 8° and 6° and between the first four of these the isohalines 36·2, 35·6 and 35·2 per mille run as lines of dots and dashes. The *Challenger* records in 1873 for April (C^1) and May (C^2) have been connected with those of the first *Atlantis* February, the *Dana's* for May 1922 with the *Atlantis* April, and the *Bache's* for February 1914 with the second *Atlantis* December—of course, merely for convenience of reading.

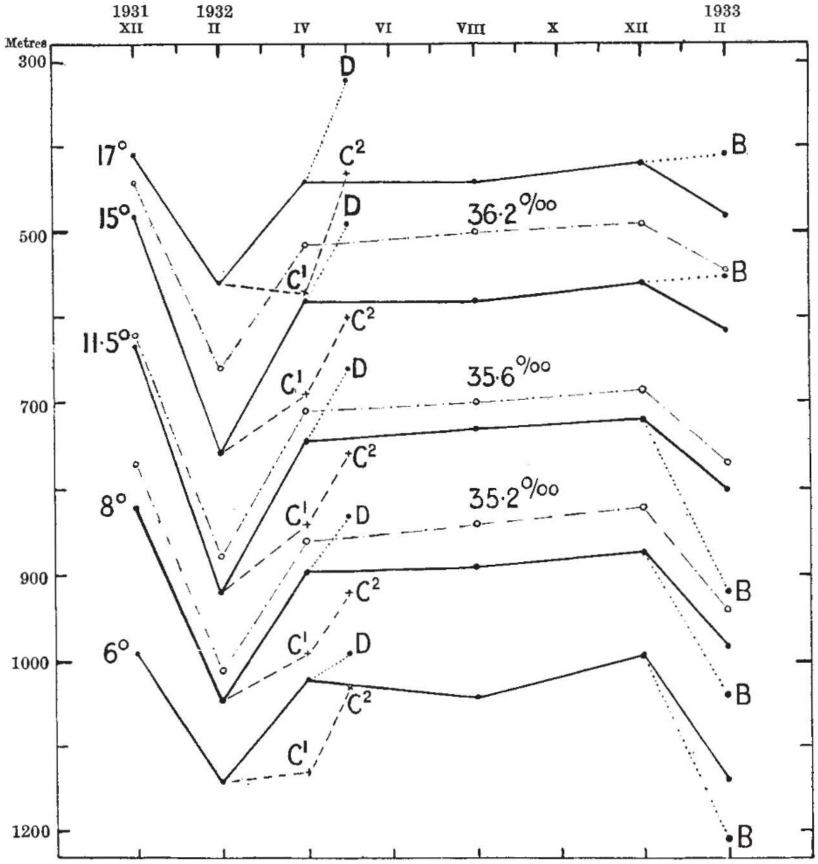

FIG. 2. Depth of selected isotherms and isohalines from the complete curves, showing monthly changes.

●—, *Atlantis* isotherms.
○—.—, *Atlantis* isohalines.
×— —, *Challenger* isotherms (C^1, April; C^2, May 1873).
● . . . , *Dana* (*D*) and *Bache* (*B*) isotherms.

It is plain from the figure that the active parts of the annual cycle are concentrated in the period from December to April or May. In February there is a sharp drop in the level of the isotherms (and isohalines) by some 100–300 metres, and in April (or April and May) a corresponding, but not necessarily an equivalent, rise. It should be borne in mind that, owing to the normal graduation of temperature and salinity from above downwards, the lowering of an isotherm implies a deepening of the mass of warmer water above it, and the lowering of a whole series of isotherms a general increase of temperature throughout the water-column represented. Similarly, a raising of the isotherms implies an upward extension of the colder waters and a corresponding decrease of temperature at the depths under consideration; so also with isohalines and salinity, *mutatis mutandis*. From April to December, the *Atlantis* isotherms and isohalines show little or no changes of level, though there is a slight upward tendency, especially of the isohalines. It may therefore be inferred that the relatively low levels of the *Challenger* isotherms in May 1873 and the high levels of the *Dana* isotherms in May 1922 were probably maintained throughout the summer of their respective years, implying relatively high temperatures throughout the intermediate layer in the summer of 1873, and low temperatures in 1922. The conditions in 1932 were intermediate, but nearer those of 1873 than of 1922, though attained earlier, in April instead of May. Confirmation of the exceptional warmth of the intermediate waters throughout the Sargasso Sea in the summer of 1873 has in fact already been given by Helland Hansen when comparing the *Challenger* station 65 (halfway between Bermuda and the Azores) with corresponding stations of the *Michael Sars* in June 1910 (Murray and Hjort, 1912, Fig. 210).

So far, I have described this sequence in terms of obvious changes in the level of isotherms and isohalines, which, as oceanographers know, are liable to disturbance from a variety of causes. Although some of these factors could at once be eliminated from the present case, it is sufficient here to note that the Bermuda cycle is not conditioned simply by a periodic undulation of the isotherms, but by measurable changes in the temperature-salinity ratio. Fig. 3 shows the salient differences in the salinity associated with various degrees of temperature at the Bermuda stations regardless of depth. The ratio of salinity to temperature attained a maximum height in December 1931, and was followed in February by a smart fall, which continued to April. The *Dana's* records for May 1922 show the minimum for the whole series, thus pointing to the probability that a fall in the salinity ratio is a regular phenomenon from February until April or May. After April 1932, the ratio rose slightly through the summer and autumn to December, when it was succeeded by a marked rise in the following February, greater for the lower degrees of temperature than the higher.

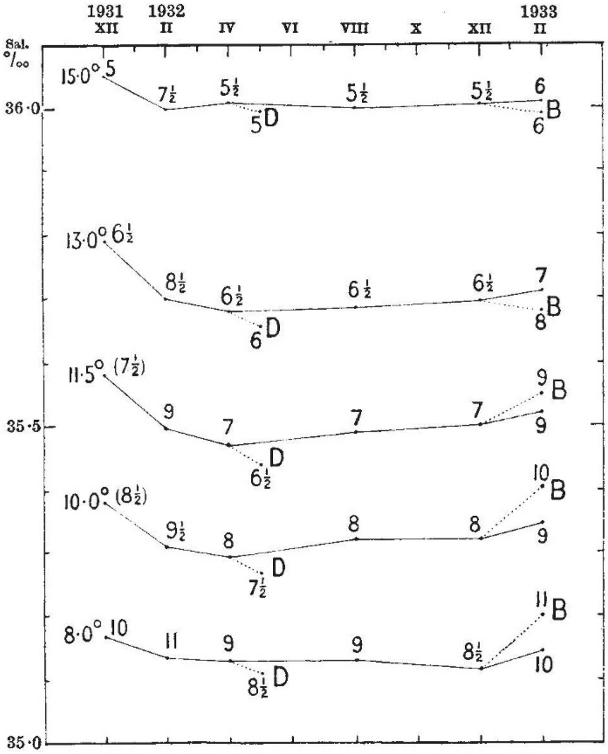

FIG. 3. Salinity ratios for selected degrees of temperature (from T/S curves). The numerals represent approximate depths in hektometres. *Atlantis* data with addition of *Dana* (May) and *Bache* (February).

The apparent inference to be drawn from these changes is that occasionally in February (1932), and regularly in April or May, there takes place a general infiltration of alien water of less than normal salinity, the influx of which declines during the summer and autumn and is usually cut off more or less completely in February (1914, 1933). This cycle is, of course, precisely that of ice-bound coastal waters, locked up by frost in winter, and released in full flood in spring. The only possible source of such water in the present case is the coastal tract of mixed waters on the north side of the Gulf Stream, mainly derived, according to Bigelow, from the Gulf of St. Lawrence by the Cabot Strait, but mixed undoubtedly with Gulf Stream overflows and the coastal waters of the Gulf of Maine, probably also in severely 'Arctic' years like 1929 with contributions from the Labrador Current itself.

This conclusion may seem to conflict with some recent opinions as to the nature and relations of the Gulf Stream, but, so far as I can see, it is not opposed by any established facts. If we turn to Jacobsen's hydrodynamic current-charts (1929, figs. 53–56) we find the hub of the Atlantic circulation placed off Cape Hatteras in lat. 36° N., long. 74° W., where Gulf Stream and Antillean Current turn markedly east and give rise to great eddies on the right, some of which are completed as inner, middle and outer anticyclonic circuits, the middle one bathing Bermuda on its way to the Windward Isles to a depth of some 500 metres. As the depth of reference is only 1,000 metres and the deep waters, admittedly recruited from the "cold wall", are certainly moving in spring, these charts cannot be regarded as defining the bottom limit of the currents indicated. The *Challenger*, in fact, at st. 37 in April found a south-east undercurrent at Bermuda from 200 fathoms down to 400 fathoms (350–750 metres) moving at a rate of about $\frac{1}{4}$ mile per hour above and 1/10 mile below. Such a current would require at least two months to bring water to Bermuda from the water-parting off Cape Hatteras, but it may well have been twice or three times as strong during the climax of the May flood.

It is also noteworthy that exactly abreast of Jacobsen's water-parting (vortex ?), but on the landward side of the Gulf Stream, lay the *Bache* station 158 and the *Dana* station 1349 (the former in lat. 36° 12′, long. 74° 25′, the latter in lat. 36° 16′, long. 74° 33′), which presumably reveal the relations of the coastal waters to the Gulf Stream in February and May respectively. In February, Bigelow found an isolated 'tongue' of water of temperature 11°–12° and salinity less than 35·2 per mille dipping down from the surface like a 'waterfall' over the edge of the continental shelf to a depth of some 300 metres, and separated from the Gulf Stream by a nearly vertical wall of water 500 metres deep, of 35·5–36·0 per mille salinity. In May the *Dana* found this wall, from

200 metres downwards, bent outwards as an inclined plane, beneath which the mass of coastal water, *colder and less saline throughout than in February* 1914, was completely continuous (except the most superficial stratum less than 35·0 per mille) with the intermediate layers of the Gulf Stream column. At 300 metres the temperature and salinity at the *Bache* station were 11·4° and 35·19 per mille; at the *Dana* station in May they were down to 8·17° and 35·08 per mille. At the *Dana* station 1351, in the Gulf Stream itself, water with approximately this temperature and salinity lay 600 metres deep. At Bermuda at the same time it lay at 900 metres.

There can indeed be little doubt, after comparing these facts and the illuminating sections* provided in their respective reports by Bigelow (1915, figs. 11, 12, and 49), Nielsen (1925, Section 4), and Jacobsen (1929, fig. 11), that during the flood period in spring the pent-up coastal waters are incessantly mixing with the left side of the Gulf Stream, to pass through it in part, and for the rest to be swirled eastwards into the general circulation of the Sargasso Sea (cf. Jacobsen, p. 19). Iselin also, in a preliminary forecast of *Atlantis* results, has remarked of the Gulf Stream: "Very little of the Gulf water remains when Cape Hatteras is reached. The current is of course continuous, but gradually the Gulf of Mexico water becomes replaced at all depths by Sargasso Sea water *or a mixture of this and Slope Water*" (1933, p. 231).

Altogether, in spite of the fragmentary data on which it necessarily rests at present, the case for a seasonal cycle in the Sargasso Sea and its dependence on the periodic release of ice-bound coastal water seems unmistakable. The interest of the relation is practical as well as theoretical, for it opens up at once the prospect of our ability to attack the 'Atlantic Water' problem from a new and much more promising angle. The periodic incorporation into the intermediate layer of the Sargasso Sea of millions of tons of alien water must result in a periodic eastward spreading of the whole water mass. Annual variations in the amplitude of the extension may well be concerned in determining the irregularities of Atlantic incursions upon the coasts of Europe. If this argument is sound, the first step should obviously be to confirm the periodicity at Bermuda by regular observations at much more frequent intervals, especially from December to May, so as to date the changes with greater precision, and over a period of years sufficient to include the greater annual fluctuations. Only at Bermuda is such a continuous record practicable. Unfortunately, we have missed the opportunity of record-the effects on the Sargasso Sea of the great frost and floods of the last American winter.

In conclusion, my thanks are gratefully tendered to Dr. E. J. Allen, of Plymouth, Mr. Donald Matthews, of the Admiralty, Dr. J. N. Carruthers, of Lowestoft, and Mr. A. J. Clowes, of the *Discovery* Expedition, for help in getting access to relevant literature.

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* A temperature section from *Atlantis* data given by Iselin (1933, fig. 2) for the same region in February cannot readily be compared owing to lack of isohalines. It is noteworthy, however, that the isotherms are shown appreciably lower than in the *Dana's* sections for May, though with less difference than at Bermuda.

The 'Specific Action' of Ultra-short Wireless Waves

By Prof. W. E. Curtis, F.R.S., Dr. F. Dickens, and S. F. Evans

DURING the last ten years or so many investigations have been made concerning the biological and medical effects of short wave radiation. The absorption of such radiation by tissues necessarily results in the liberation of heat, and many of the effects observed are admittedly due to this cause. They could alternatively be produced by other methods of heating, although the radiation method frequently offers special advantages and potentialities. It is being pursued energetically in various laboratories and clinics, and appears to rest on a sound theoretical and experimental basis[1].

The literature of the subject, however, contains frequent references to other effects, usually termed 'specific', in the sense that they can only be produced by the short-wave method, that is to say, that they are not primarily thermal in origin. In some cases also it is claimed that the effects are restricted to certain wave-lengths, or that an optimum wave-length exists. So far as is known at present, from physical and chemical evidence,