PROBLEMS IN THE OCEANOGRAPHY OF THE NORTH ATLANTIC

by

C.O'D. ISELIN, Woods Hole Oceanographic Institution, Woods Hole, Mass.

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Progress in our understanding of ocean circulation has generally been even slower than in some of the other branches of oceanography, in spite of the fact that in nearly every marine problem, both biological and physical, the current system plays a basic part.

At first the study of ocean currents was held back by the lack of accurate and convenient instruments. In more recent times, the expense of securing the observations has delayed the accumulation of adequate subsurface data on the distribution of temperature and salinity. If this were known in sufficient detail, it would probably not be a difficult task to settle several of the main problems which now confront physical oceanographers.

In particular, physical oceanographers have been unable to supply the climatologists and fisheries experts with the much-needed data on the variability of oceanic currents. Do ocean currents transport about the same amount of heat year after year, and are they, therefore, unimportant from the point of view of long-range weather forecasting ? It is now known that changes in oceanic circulation have, on occasions, affected the fisheries of Great Britain ; but it is not yet known if fluctuations in the strength of the Gulf Stream off the American coast bear any relation to fluctuations in the circulation of the water masses off the European coast. (1)
Not only are such questions of considerable economic importance in some parts of the world, but also if the answers were known it would be much easier to secure the necessary financial support to develop fully the science of oceanography.

For these reasons it is very encouraging that arrangements have been made during the past year for a co-operative programme of broad scope. The programme is to be undertaken jointly by the Bermuda Oceanographical Committee of the Royal Society and by the Woods Hole Oceanographic Institution. The Royal Society has obtained a generous grant from the British Government for the promotion of the scheme, and the Bermuda Biological Station is being developed as a base for the oceanographic work. The plan, which will shortly be in actual operation, involves the co-operation of the American oceanographers with the now increased staff of the Bermuda Biological Station ; and the British grant, which covers a five-year period, also provides the Station with a much-needed research vessel.

The programme which has been suggested and on which work has already begun (June 1937) is essentially a continuation of modern oceanographic development, but it is hoped it will be possible to stress those aspects of the investigation which now seem most likely to lead to the solution of the practical problems outlined above.

Three somewhat conflicting theories have been put forward to explain the mechanism whereby the changes in strength of the Gulf Stream could influence the fisheries of north-western Europe. The earliest and most popularly accepted belief concerning the influence of the Gulf Stream has the merit of logic and simplicity, but it is by no means certain that it is correct. This theory assumes that the Gulf Stream resembles a river of warm, saline water flowing north-eastward from the Florida Straits towards northern Europe, and that the current is variable. Thus, during years when it is stronger than normal, more warm water reaches the European coast to modify the climate and to alter the survival rate of young fish or to change the feeding grounds of the adults. In the light of recent oceanographic investigations, however, it is now known that the Gulf Stream bears little resemblance to a river of warm water. In fact, even off the American coast, only a very small part of the current is warmer than the surrounding seas, and after the current turns eastward and has passed the Grand Banks, the slight temperature maximum at the surface quickly disappears. For this reason, it now seems likely that only if the current changes vary greatly in strength from year to year (and no sufficiently marked fluctuations have yet been observed) could it so directly cause noticeable variation in the European coastal waters. Nevertheless, as will be explained later, the primary observations of the new project will attempt to follow the changes in strength of the Gulf Stream as it flows between Bermuda and the American coast during the next five years.

A second theory, which minimizes the importance of the Gulf Stream's influence on European waters, has been advanced more recently by Le Danois (2), a French oceanographer. He has pointed out that, on the whole, the North Atlantic Ocean can be subdivided into two great contrasting masses of water and that these do not readily mix. South of a line extending roughly from the Faeroe Islands to the southern tail of the Grand Banks there is found a superficial, wedge-shaped layer of relatively warm and saline water which increases in thickness to 1,000 metres or more in lower latitudes. To the north at all depths, and elsewhere below the warm layer, is found a much greater mass of cold water of low salinity. LE DANOIS believes that the northern boundary at the surface between these two contrasting masses changes its location, depending either on variations in the volume of the warm layer or on a north-south shift of its mean position. An expansion or northward movement of the warm layer is termed a transgression and the opposite movement, a regression. Since the northern boundary of the warm layer is inclined towards the north-east, LE DANOIS believes that the main strength of a transgression is also expended in this direction and, therefore, that periodic variations are produced in the temperature and salinity of European coastal waters. He has collected evidence to support his theory that the transgressions come in cycles of increasing intensity having periods of 1, 4.6, 9.3, 18.6 and 111 years. Thus he has suggested that the periodicity is controlled by astronomical forces.

With some of the details of LE DANOIS' theory many oceanographers cannot agree, and especially they have ample evidence that the continuation of the Gulf Stream, better called the North Atlantic Current, cannot be disregarded. However, the northern branch of this current on the whole marks the northern limit of relatively warm water at the surface, and the main pattern of horizontal circulation in the North Atlantic is undoubtedly a huge clockwise eddy. Therefore, if the warm water at the centre of the eddy should increase in volume, or should its axis shift northward, the effect would be comparable to LE DANOIS' transgression theory. In other words, there is a possibility that changes in the amount or position of the warm-water core around which the North Atlantic eddy revolves and which it can be thought of as confining, may occasionally displace the current system of the northeastern North Atlantic and thus cause marked and widespread variations near the European shore.

On the other hand, there is also the other possibility that the warm surface layer has a relatively constant volume and position, and this leads us through modern oceanographic principles to a newer theory that at the present time seems to have few drawbacks.

If we assume, as most investigators do, that the greater part of the energy which maintains the North Atlantic eddy comes from the trade winds, and if these should vary in strength from year to year, then the Gulf Stream, which is the most spectacular part of the eddy, would also vary in transport. If the current should increase, the BJERKNES (3) principle demands that the thickness of the central mass of warm water (the Sargasso Sea) should also increase. Therefore unless the amount of warm water also increases, the diameter of the eddy must contract. In the same way, if the anti-cyclonic currents weaken, the dynamic height near Bermuda must decrease, which is another way of saying that the warm layer must become thinner. If this occurs, either the eddy must increase in diameter, or warm water must be discharged beyond the outer boundary of the surrounding circulation.

This line of reasoning leads to the idea that during periods of increasing strength of the Gulf Stream, the seas off the coast of Europe will become colder, instead of warmer, and that the reverse will happen during periods of decreasing oceanic circulation. This, of course, is exactly the opposite to the popularly accepted view. Since Bermuda is at approximately the centre of the main eddy of the North Atlantic, the new research vessel will easily be able to follow any changes in the thickness of the warm superficial layer. It can be confidently expected that as soon as this has been done over a period of a few years, it can then be shown which of these possibilities is correct.

Besides these supposed mechanisms involving variations in the intensity of the main horizontal currents, and expansions and contractions of the warm superficial layer of mid-latitudes, another basic theory has often been advanced. In this, the winds across the latitudes between the Grand Banks and northern Europe are considered the primary variable. If the surface water moves in the same direction as the wind, surface temperatures at a given point will rise during periods when southerly winds prevail and will fall with prolonged northerly winds.

Investigators, however, who are convinced by the theoretical studies of EKMAN (4), which demand a net transport of the surface layer in a direction 90° to the right of the wind (for the northern hemisphere), will claim that it is easterly winds which cause increasing surface temperatures off the European coast. However this may be, it is clear that, provided the wind is sufficiently variable from year to year, wind currents in the surface layer can strongly influence surface temperatures. In fact, good arguments can be advanced to show that the variations in the strength and direction of the winds are a much more likely cause of changes in the European coastal waters than possible fluctuations of the oceanic circulation.

For the reasons outlined above, the programme of observations now being carried out in the neighbourhood of Bermuda and in the Gulf Stream involves two main investigations. First, the variability of the Gulf Stream will be examined with as much thoroughness as the available facilities permit, and secondly a detailed study of wind-produced movements in the surface layer will be made. In the Gulf Stream investigation the research vessel *Atlantis* of the Woods Hole Oceanographic Institution will play the leading part, while the smaller ship soon to be sent out to Bermuda, the *Culver*, will be chiefly engaged in examining the frictional effect of the wind on the sea surface. In addition, as already mentioned, she will make periodic observations to follow the changes in the thickness of the warm layer covering the central part of the Sargasso Sea. It is hoped that this dual programme will help to answer the question whether local winds or remote currents or a combination of the two are responsible for the variations in the physical characteristics of European coastal waters.

It may be of interest to discuss here some of the details of this five-year programme of observations. We will consider first the work of the *Atlantis*, begun last June in the Gulf Stream. This current is so powerful and wide that an investigator with a single ship at his disposal is forced to use mainly indirect methods, for the technique of current-meter observations in deep water still remains unsatisfactory and time consuming. However, it cannot be stressed too strongly that the indirect methods should be supplemented as often as is practicable by direct observations of the strength of the current. The most reliable indirect method of measuring the volume of such a current as the Gulf Stream is to observe the vertical distribution of temperature and salinity at a number of stations spaced about twenty miles apart on a line crossing the current at right angles. From these observations the distribution of density can be calculated, and by applying the formula of BJERKNES the velocity and volume can be computed. While this method involves certain assumptions, on the soundness of which not all oceanographers are agreed, there is little doubt that should the current in this way be found to vary in strength over long periods by 20 per cent or more, the observations would impress even the most sceptical.

At the outset, therefore, the *Atlantis* has undertaken to occupy a section extending from Montauk Point on Long Island towards Bermuda at approximately monthly intervals. If this were to be continued for five years, practically the entire time of the vessel would be consumed and the mathematical computations would also be most laborious. However, in theory it is only necessary to observe the density of the water at two points on each side of the current, and this greatly simplifies the calculation of the volume of flow. As soon as the validity of this new shorter method can be established, the *Atlantis* routine observational programme will be greatly shortened.

The circulation theorem of BJERKNES is based on the principle that when a current in the northern hemisphere increases in strength, the sea surface must fall on its left hand side and rise on the right hand side. The relative changes in height of the sea surface on the two sides of the current can either be calculated from the subsurface distribution of temperature and salinity or can probably be observed by means of tide gauges. This method has not yet been given a thorough trial, but a comparison of the tidal records from Bermuda and from the American coast has been made, and for years when subsurface oceanographic observations are available good agreement has been found. Thus it may well be that before long the *Atlantis* routine observations on the Montauk Point-Bermuda section can be very much curtailed or even entirely abandoned and the fluctuations in the strength of the current followed entirely through the tide-gauge records. The theory tells us that the surface of the Sargasso Sea is about 100 cm. higher than that of the waters north-west of the current. This difference in level will vary directly with the strength of the current. Thus an increase of 20 per cent should cause a rise of about 10 cm. at Bermuda and a corresponding fall on the opposite side, a change readily observed from the records of a properly located recording tide gauge.

This method should prove especially useful in the Straits of Florida, through which about a third of the ultimate volume of the Gulf Stream passes. Consequently the *Atlantis* has recently set out to install a tide gauge in the Bahamas, just across from Miami where the U.S. Coast and Geodetic Survey maintains a similar instrument. It is hoped that when these records are compared with the results obtained farther north, it will be possible to say whether or not the Gulf Stream as a whole increases and decreases in strength from year to year.

In the case of wind currents and the calculation of the exact coefficient of friction between the atmosphere and the sea surface, the observational difficulties are considerably greater. Several methods are in theory available. For example, the stress exerted on the water by the wind can be observed through the disturbance produced in the turbulent layer of either the sea or the atmosphere. It is a problem in which both meteorologists and oceanographers are equally concerned and to which the methods of both sciences can be applied. Unfortunately, in the past it has been found to be extremely difficult to secure sufficiently precise observations. The difficulty is partly instrumental, but it also results from the disturbance produced both in the water and in the air by a large research ship. In addition, wind currents can of course best be observed in regions where there are no permanent deep currents. It is hoped that the small vessel which is being sent out to Bermuda by the Royal Society, will prove handier for this work than other ships that have already been tried out. Likewise, it is hoped that a region can be found not too far from Bermuda where the permanent currents are negligible.

It was first assumed that the stress exerted by the wind on the surface of the sea was probably proportional to the strength of the wind. But recently ROSSBY has presented evidence which indicates that there is a critical wind velocity below which the wind can get little grip on the water. He believes that this critical velocity is probably reached when the wind has a strength of about 15 miles per hour. If this can be demonstrated by satisfactory observations, then the surface movements produced by the winds can be calculated from the ordinary daily ocean weather maps and all winds less than the critical velocity can be neglected.

Moreover, there has recently been collected an increasing amount of evidence that the strength of the wind currents depends also on the stability of the surface layer. When the stability is great, apparently only a shallow layer is affected by the wind and the principle of EKMAN's spiral perhaps breaks down. Thus if these matters can be more fully investigated, the wind currents for the practical purposes of this new programme can perhaps be neglected during seasons when stability of the surface layer in mid-latitudes is very great due to the absorption of solar energy. Although the full magnitude of the problem can now be but dimly seen from the available observations, it is hoped that the calculation of surface movements from weather charts may not be insurmountable.

The possibility that there exists a critical velocity below which the coefficient of friction is extremely small leads us back to the variations in the strength of the Gulf Stream. As already mentioned, in all probability it is the energy absorbed from the winds across the latitudes of the trades which supplies the initial driving force for the current. If the trade winds vary slightly in strength over long periods and if the critical velocity falls within this range, then it is evident how the ocean can absorb much greater amounts of energy in certain years than in others. On the other hand, if the coefficient of friction is proportional to the wind velocity throughout the range met with in the trades, it seems unlikely that they can be the cause of important variations in the currents farther north.

In conclusion, we must frankly admit that the general outline of the Bermuda project given here will probably seem over-ambitious. However, if we had been able to go into more detail, it could have been shown that many of the special phases of the main problem are much less complicated and that the five years work that is planned will by no means fail if the main objectives prove to be hopelessly complex. When the twenty-odd investigations already started or planned are examined, it is evident that the chief strength of the whole programme lies in its attempt to encourage promising lines of investigation in physical oceanography. If several of these succeed, the entire effort will be justified. However, until physical oceanographers are able to show whether or not the surface layer of the ocean varies in temperature from year to year by a significant amount, they will get no peace from those who consider that science should have a practical objective. For this reason we hope we are justified in having attempted to explain how the work of the six or more co-operating investigators may eventually be fitted together. Let us hope that by such simple methods as observing the strength of the Gulf Stream in summer or by calculating the shift of the surface layer resulting from a prolonged spell of strong winds over the critical area west of Ireland, physical oceanographers will eventually be able to predict a mild winter or a good fishing season for northern Europe.

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