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OCEANUS

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MEN, EARTH AND INSTRUMENTS

WE have heard so much Sputnik lately and so much talk about rockets and space flight, as topics in themselves, that it appears as if the object of the IGY: the study of the earth and its atmosphere, seems to have been forgotten.

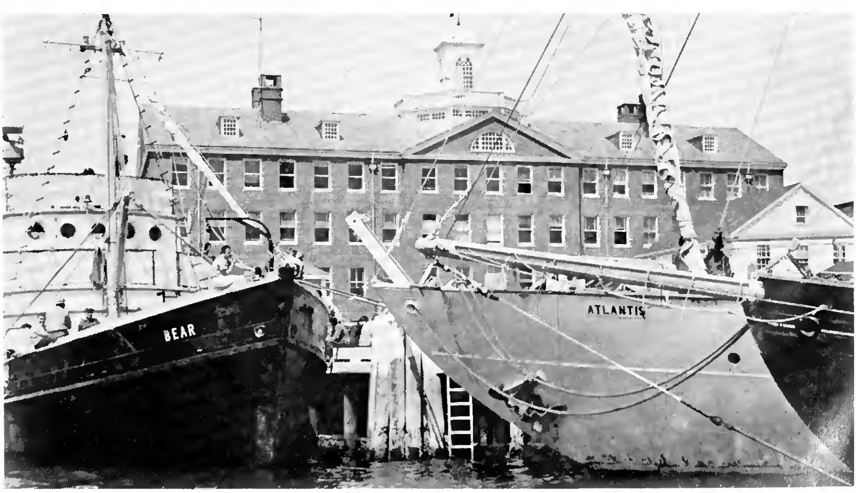
Our cover may help to serve as a reminder that the success of the IGY depends upon men. Men who make the observations, men who sail the ships or fly the planes to transport observers to their chosen positions, men who cook meals often under impossible conditions, men ***and*** women who spend long, often tedious hours, to work up the data and prepare reports for the World Data centers; those who type, draw, reproduce and mail, and finally those very few who will interpret the welter of data and provide new knowledge.

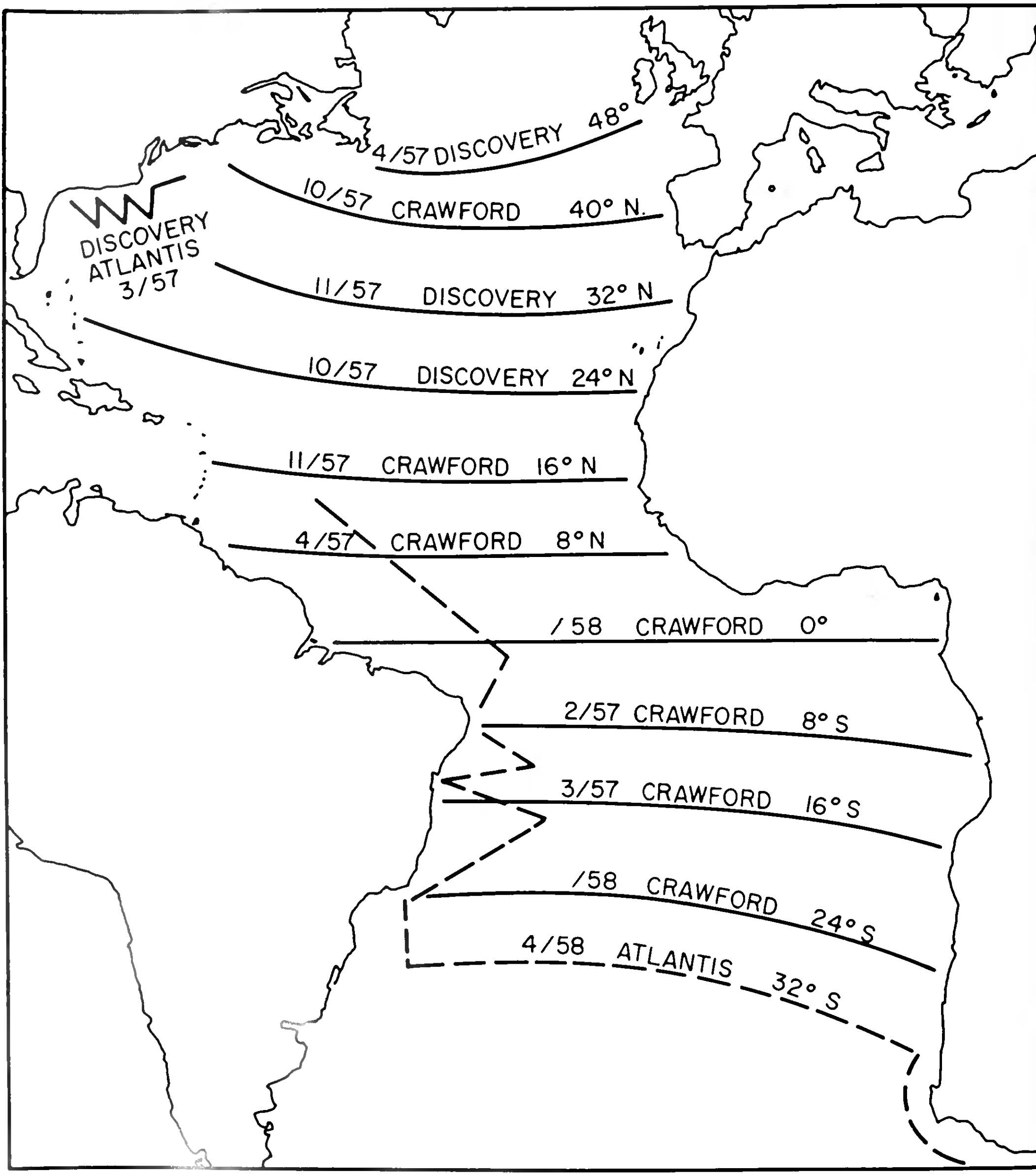
The sea and the continents more often than not will be the only non-cooperative IGY participants in our struggle to understand the earth in order to learn how to become master rather than slave of our environment. The instruments, whether a fancy satellite or the old reliable Nansen bottle, by themselves are valueless. The brains, the work, and the enthusiasm of thousands of men and women all over the world are ***the*** newsworthy items during the IGY.

"GENERAL concepts are difficult to convey, and none is more difficult than that of basic research in science"; so begins a report just issued by the National Science Foundation.

As practically all of the articles in this issue concern basic research, it may be well to quote further from the report: " . . . the emphasis given in the news to the exceptional, unusual, 'newsworthy' aspects of new inventions and developments, often lack reference to the fundamental work without which these could not have been made. The word 'research' in advertising often is used to mean testing, development or invention. Seldom, indeed, is it employed, except by scientists, to mean simply the search for new knowledge and better understanding of the physical world of man, and of man's environment."

The basic research of theoreticists led to the discovery of a countercurrent under the Gulf Stream, as is reported in this issue. This, indeed, is new knowledge. Not often do new findings have immediate practical application. In this case as a result of British-American cooperation, our concepts of oceanic circulation have changed and will result in a much more meaningful interpretation of the oceanographic IGY observations.





Atlantic IGY Program — This chart clearly shows how much of the work has been done already by the small R. V. Crawford. Month and year are indicated to left of ship's name.

C. O'D. Iselin

Synoptic Studies in Oceanography

Our IGY program after a slow start already has accomplished a great deal.

A central and classical problem in physical oceanography is to try to understand the circulation of the oceans as a whole. In order to do this it is first necessary to be able to describe the three-dimensional distribution of the physical and chemical properties of the whole fluid envelope. Until now it has only been practical to secure satisfactory data from rather limited areas. Only a small percent of the observations have been from depths greater than 3,000 meters, although most of the ocean is nearly twice this deep.

Oceanographers have had to be content to study a sort of average ocean constructed from the observations of temperature and salinity and dissolved oxygen obtained by many ships. The distribution of such data is very uneven, both in time and in space. The accuracy of even the best observations has been satisfactory only during the past 30 years or so. Only one ocean, namely the South Atlantic, has ever been surveyed systematically and in a manner that could be regarded as providing a synoptic picture of the deeper water masses. Nevertheless, it has become possible to describe the physical and chemical structure of the oceans in broad outline, and in recent years through multiple-ship operations a beginning has been made in the synoptic oceanography of limited areas.

There is every expectation that through the International Geophysical Year the basic data of physical oceanography will be improved by a whole order of magnitude. If present plans can be carried out this will be especially so for the deeper water masses.

It must be admitted that oceanographers at the working level in this country were at first not too enthusiastic about the prospects of adding significantly to our understanding of oceanic circulation during the International Geophysical Year. It was argued that our ships were already working on a year-round basis and that the existing research programs at our laboratories were the best that could be devised. When the desirability of periodic resurveys of the whole system of currents was pointed out, few oceanographers at the working level had the patience to wait for another 30 years or so before it might be practical to learn about any gradual changes that might be taking place. Some of us also felt that we were being asked to plan a survey of the oceans that our sons would approve and want to repeat and, because of the many changes in our concepts of the basic problems during recent years, there was doubt that any program that could now be organized would in retrospect seem wise.

Stimulation

During the planning period at least three factors have helped to stimulate enthusiasm for the IGY oceanographic program. In the first place, no one foresaw how many research vessels would be able to cooperate. As soon as it became evident that as many as 60 ships might become available many people's attitudes, including my own, changed rather abruptly. For some reason international cooperation in oceanography has been slow to develop, although of course it has been obvious all along that no one nation is likely to bring to bear sufficient resources to do a thorough job of studying more than a limited part of the world's oceans. However, with so many ships available it would indeed be possible to gain a rather complete look at the deeper waters on a somewhat synoptic basis. The fact that all the data would be secured within a two-year period would be quite satisfactory in this case, for the deeper currents are believed to be sufficiently slow so that not much change is likely to occur in the system during that period.

A second encouraging factor stems from the recent observations of Mr. L. V. Worthington of the Woods Hole Oceanographic Institution. He has shown that below a depth of about 2,500 meters in the western half of the North Atlantic the waters today contain about .3 cubic centimeters less dissolved oxygen per liter than was the case 25 or 30 years ago. This is strong evidence that the deeper water has not been renewed during this period. Thus an easily measurable change has taken place in the North Atlantic and it will be interesting to learn whether or not slow trends are also taking place in other areas. In the case of the South Atlantic a particularly complete survey of temperature, salinity, and dissolved oxygen was made by the German ship Meteor during the period 1925-27. Thus, to repeat some of these observations became one of the major objectives of the U. S. oceanographic program for IGY.

A third factor to arouse interest in deep currents has been the recent success of Dr. J. C. Swallow of the National Institute of Oceanography in England in obtaining direct measurements of the flow at considerable depths. In the past the interpretation of deep measurements of temperature and salinity in terms of direction and velocity has been beset by many uncertainties. The question can be stated in deceptively simple terms: How deep are the more powerful, permanent ocean currents? If they are relatively shallow, extending only to 1,500 meters or so, then below them the distribution of density and the available theory demand that deep countercurrents exist. During recent years many different kinds of studies have been made in an effort to resolve this problem but until Dr. Swallow developed neutrally buoyant floats there was little hope of gaining a clear-cut answer.

The influence of these three developments on the U. S. Atlantic IGY oceanographic program has been marked. So enthusiastic have people grown that a good deal of the work has already been completed. Similar efforts in the Pacific lack the stimulus of as complete a set of early measurements for comparison with the deep physical and chemical situations of today, but it seems safe to say that the successes to date in the Atlantic are likely to encourage corresponding efforts in other areas.

Preliminary Results

As mentioned above, the Atlantic oceanographic program has already achieved some preliminary results. In trying to predict what the whole undertaking will amount to, it may be helpful to discuss these first observations.

The program really began in March when the British research vessel Discovery II and the Atlantis met at Bermuda. During the next six weeks their joint operations were so productive that a real milestone in physical oceanography was achieved. The area selected for the work was the outer edge of the Blake Plateau at about the latitude of Charleston. It was known from previous Atlantis temperature and salinity sections that in this area the deep water flow (whatever its direction) was forced well east of the swift and much shallower Florida Current by the Blake Plateau. Thus in this area the ships would not be handicapped by strong surface currents in their efforts to relate deep water movements to deep density structure. (Farther north the deep density gradients are just as pronounced, but they lie more directly under the Gulf Stream.) Because of the availability of Loran navigation in this area, both ships could have excellent navigational control.

While the Atlantis measured the deep temperature and salinity structure often as close as two miles apart, the Discovery tracked neutrally buoyant floats drifting with the water at preselected levels. The floats contained a sound source and the tracking was achieved through two hydrophones suspended from the bow and stern of the Discovery.

With the float at 2,000 meters the net motion at the end of 4 days was so close to the accuracy of navigation that the total drift of only a few miles was not significant. Shallower floats clearly drifted to the northeast, as was expected, and with the expected velocities. But a float set out at 2,800 meters went toward the southwest at about 8 miles per day. Thus, in this part of the North Atlantic, the level of minimum motion is about 2,000 meters and below this the current is moving surprisingly rapidly in the opposite direction.

Many more such observations are needed, of course, before it can be known with certainty how widespread this unexpected phenomenon may be, but at least two things were made very clear by the work accomplished to date: that through international pooling of ships and observers results were achieved that neither group could have accomplished alone; furthermore, that it should be possible through similar opertions in a few other carefully selected areas to interpret with considerable assurance the great mass of deep temperature and salinity observations that will be secured by the other IGY ships. Just a few weeks' work by two ships has made the whole deep-water program much more meaningful. Until this operation, the main hope that scientific sense would be achieved was that somehow the chemical observations made during the IGY could be brought into agreement with the movements of the water deduced from the distribution of density. There is always some uncertainty in this general approach to the deep circulation problem. We do not know quantitatively how much the distribution of the generally observed chemical elements is changed through biological activity.

On her way back to Plymouth from the operations off Charleston, with some help from the people at Woods Hole, the Discovery achieved the most complete North Atlantic profile to date. Temperature, salinity, and oxygen were measured at 40 stations on a line from the Grand Banks of Newfoundland to the approaches to the English Channel. This work sets a very high standard for completeness and accuracy which the other European ships crossing this area during the next 18 months may be hard pressed to match. The accuracy of the salinity determinations was especially high due to the use of a new sea-going conductivity bridge developed recently at Woods Hole.

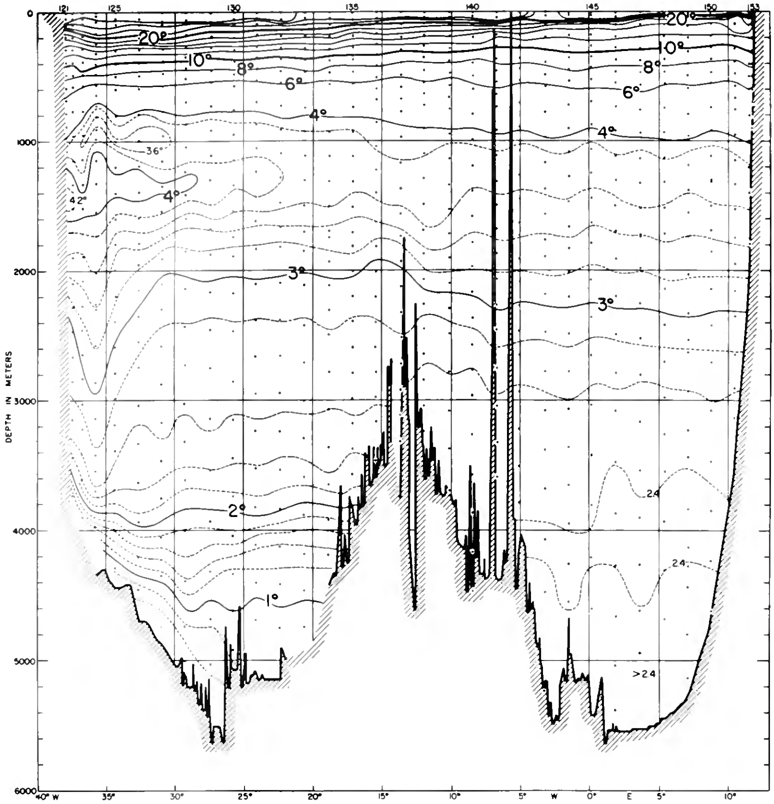
Meanwhile, the research vessel Crawford from Woods Hole, under the skillful leadership of Mr. F. C. Fuglister, had made four complete Atlantic crossings; two in the tropical North Atlantic and two in the tropical South Atlantic. The two latter sections are duplicates of two of the Meteor crossings of 30 years ago. In short, we have already realized five complete Atlantic east-west profiles and three more are scheduled for the same ships before the end of the year.

This paper was presented at the Twelfth Meeting of the U.S. National Committee for the International Geophysical Year, National Academy of Sciences, June 27-29, 1957. The Proceedings of this meeting will be published soon in a single volume.

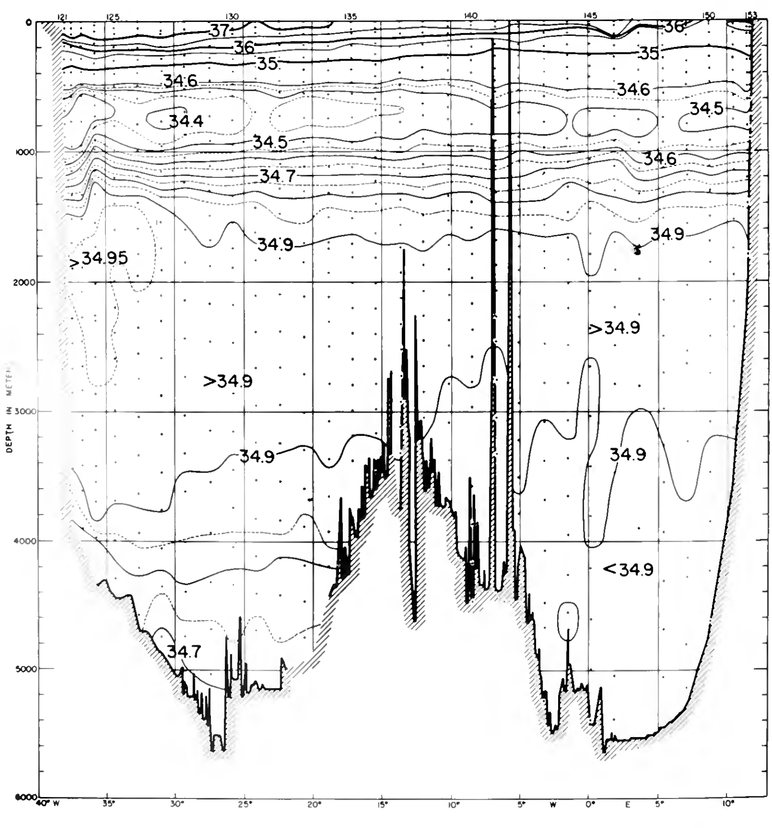
The reasons for "jumping the gun" with the Crawford are the same that prompted Dr. Maurice Ewing of the Lamont Geological Observatory to send the Vema into the South Atlantic last winter. Next winter the Atlantis and the Vema are scheduled to operate together in the South Atlantic during a six-month period. It was felt that we could make much more effective use of this time if we had the benefit of some reconnaissance. Furthermore, the Russian and the Argentine ships that will cruise in the South Atlantic during the next year or more could also benefit. When the work of the Crawford and the Vema has been studied in a preliminary manner, we should all be in a much better position to plan wisely for the main assault.

Crawford Data

Since the Crawford only returned to Woods Hole on June 1st after a four-month voyage,



TEMPERATURE (°C).
16° SOUTH LATITUDE,
SOUTH AMERICA – AFRICA
CRAWFORD STATIONS 121 – 153,
APR. 1 – 22, 1957

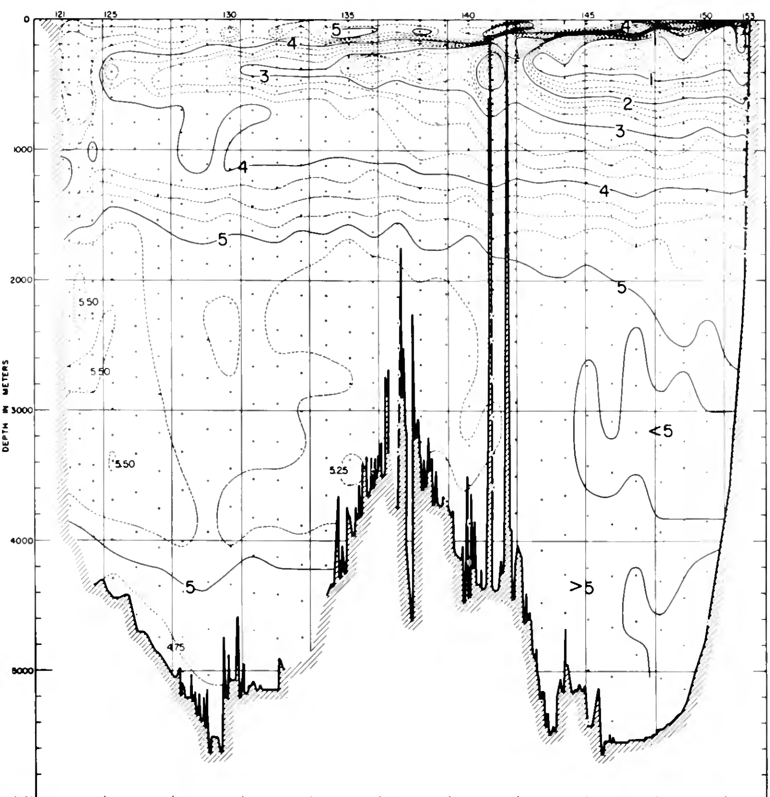


SALINITY (‰).
16° SOUTH LATITUDE,
SOUTH AMERICA – AFRICA
CRAWFORD STATIONS 121 – 153
APR. 1 – 22, 1957

I can give here only one example of her work. This is a profile of temperature, salinity, and oxygen following Latitude 15° 45′S. This is a reoccupation of one of the Meteor sections. The sampling intervals both vertically and horizontally are indicated by dots on the profile. In comparison with the Meteor profile about twice the number of observations were secured.

So far as temperature is concerned there are no striking changes. The deep temperature gradients near the South American continental slope are steeper than in the Meteor profile, but in all probability this is just a consequence of the closer station spacing. The temperature maximum at mid-depths in the west has increased by about .3°C. The salinity profile, too, corresponds very closely to the one secured by the Meteor. There is more detail in the slight salinity fluctuations at mid-depths, due both to the greater accuracy of new observations and to the more closely-spaced points of observations, but at first look there seems to be no large-scale differences.

On the other hand, there have been quite pronounced changes in the dissolved oxygen values during the 30-year interval. This is most easily seen by comparing the individual oxygen-depth curves shown in Figure 4. Especially near the two ends of the profile there is more oxygen today in the oxygen minimum layer and less in the deeper waters. The Antarctic bottom



OXYGEN (ml/l).
16° SOUTH LATITUDE,
SOUTH AMERICA – AFRICA
CRAWFORD STATIONS 121 – 153.
APR. 1 – 22, 1957

water at depths below about 4,000 meters in the western basin has lost as much oxygen as the deep water in the western basin of the North Atlantic. Presumably of recent years the deeper water is not being renewed because sufficiently dense surface water is not formed in winter, either in the far north or the far south. It is interesting to speculate about how long the trend will continue.

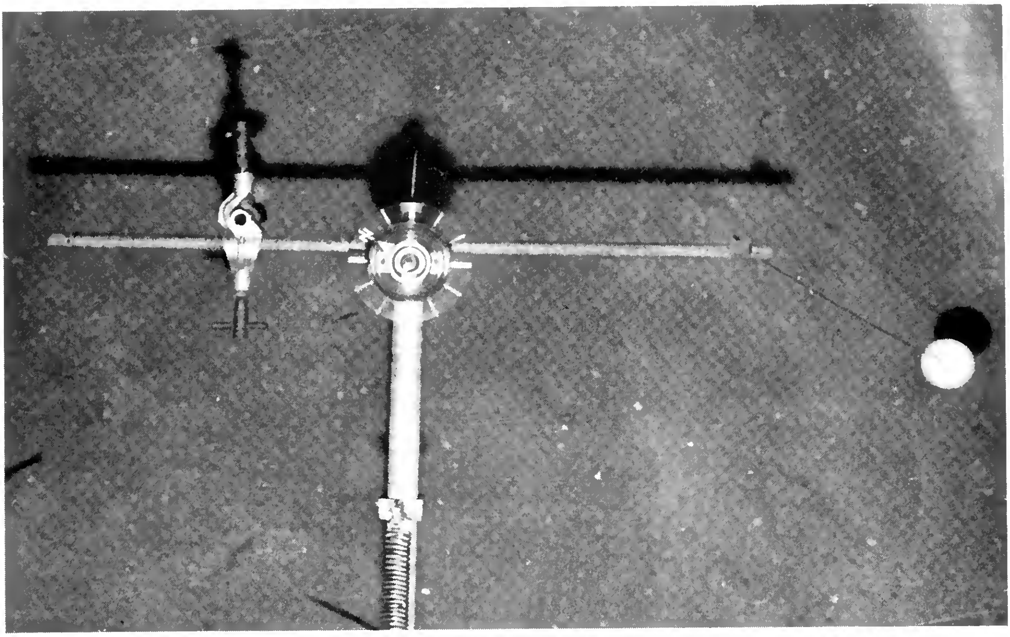
The three other 1957 Crawford profiles are of just as high quality and I think that all oceanographers will agree that this is a remarkable piece of work for so small a vessel; the Crawford when fully loaded displaces barely 300 tons. The data shown here are just one part of a much broader program of observations.

Those who are familiar with the recent papers of Dr. Georg Wüst of Kiel University know the immense amount of work that he has devoted over a long period of years to the interpretation of the Meteor profiles in terms of transport and velocity. He has worked out some fairly convincing arguments that there are three levels of minimum motion in the South Atlantic. The cold and relatively fresh Antarctic bottom water has a northward component, the great mass of water at mid-depths having salinities just above 34.90 ‰ has a southward component. The salinity minimum layer with its axis at about 700 meters is moving north, while nearer the surface there is a southward component. Although most oceanographers will agree that the net components of motion are in these directions at the various levels, the rates of flow computed by Wüst seem to some of us to rest on much shakier ground. Thus, it will be of great interest to set out next winter some of the Swallow-type, neutrally buoyant floats at the critical points in these South Atlantic profiles. Study of the new Crawford profiles will help in the selection of the best depths and locations for gaining this very positive type of observation.

To gain reliable information about the surprisingly swift and narrow deep flow in both the North Atlantic and South Atlantic, the most thoroughly explored and best understood oceans, will not only be of interest in itself, but will also help greatly in the interpretation of the deep observations that will be made by ships operating in the South Pacific and Indian Oceans, which are nearly virgin territory so far as three-dimensional oceanography is concerned

Forward Stride

The rate of overturn of the oceans as a whole is not just an oceanographic problem that is basic to many lines of inquiry



A compass and ping pong ball suspended below an underwater camera indicate a southward drift only 18 inches above the ocean bottom in this photograph taken from the R. R. S. Discovery II.

in biological and geological oceanography, as well as in physical and chemical studies. Since the ocean acts to some degree as the flywheel in the great heat engine in which the motions of both the atmosphere and the hydrosphere combine and interact with each other, such studies are also basic to a better understanding of climatic trends, to the possible use of the deep ocean for the disposal of radioactive waste materials, and to other more or less practical matters. In the past the problem has been attacked by many individual investigators and by a few research vessels working independently. This will be the first time that a large portion of the world's talent and facilities for oceanography will be working within an agreed cooperative program.

If the quality of the data secured during the past winter by the Atlantis, the Crawford, and the Discovery can be matched by most of the other vessels taking part in the International Geophysical Year programs, there is little doubt that a considerable stride forward in our understanding of the oceans will soon be achieved.

Since her commissioning in July 1956, the R. V. Crawford has sailed 39,800 miles during fifteen cruises. Her present cruise will bring the total to 49,810 miles by mid—December 1957.

by G. E. R. Deacon

The Pinger

Recent British-American co-operation in oceanography led to the discovery of a countercurrent under the Gulf Stream.

IT is more than one hundred years since the existence of cold water at the bottom of the tropical oceans showed the deep undercurrents from polar regions, and now deep currents have the same interest for marine scientists as upper-air winds for meteorologists. To measure the deep currents was a difficult problem. Current meters lowered from ships anchored in deep water allowed only slow and uncertain progress. Clearly little advance could be made without some submarine counterpart to the meteorologist's upper-air balloon, some device that could signal its movements by acoustic methods since we cannot look down into the ocean.

The first attempts used an acoustic transmitter sinking very slowly under a string of parachutes. When this proved too difficult, Dr. J. C. Swallow suggested the much more practical idea of a transmitter enclosed in a container so constructed that it sinks to a predetermined depth and there drifts with the water. He used aluminum scaffold tubing closed at the ends to make containers that are less compressible than sea water. Therefore, if loaded heavily enough to sink at the surface, they gain buoyancy as they go down. The depth at which they will float can be arranged within narrow limits The floats drift along with the water, sending out sound pulses which can be picked up by hydrophones in a surface ship up to distances of several miles in fairly bad weather. With the help of navigational aids, echo sounding, anchored marker buoys and radar, the floats can be tracked closely enough to show deep tides and currents. Not an easy routine; deep float tracking demands close attention and cooperation among all engaged in the measuring and in the handling of the ship.

Developed at the (British) National Institute of Oceanography, the technique cannot be used to full advantage until it is more widely adopted and used on the most rewarding problems. Until a few months ago the Discovery II had followed 12 floats for several days at different depths in several parts of the eastern North Atlantic Ocean, as much of the work as possible being done in co-operation with other marine laboratories. The measurements are a considerable addition to our knowledge of the sea and the technique was improved so that it could be used in all but the worst weather.

A Theory

Progress in the theory of oceanic circulation is fastest in the United States. A number of young scientists, stimulated by advances in dynamic meteorology and working close together, are taking realistic account of the drag of the prevailing winds, the effect of the earth's rotation, the density layering of the oceans and the frictional forces which can transfer and dissipate energy. Mr. H. Stommel of the Woods Hole Oceanographic Institution, one of the most active workers, has campaigned for measurements of the water movements at great depths below the Gulf Stream. He maintains that there should be a considerable southward movement, as implied in his two-layer theory of the ocean. It might explain why the Brazil Current in the South Atlantic is so weak compared with the Gulf Stream in the North Atlantic.

Dr. Deacon is director of the National Institute of Oceanography in Great Britain. His first experience was gained thirty years ago in the Antarctic Ocean. His chief aim is to encourage theoretical and experimental studies of the water movements and the interchange of energy with the atmosphere.

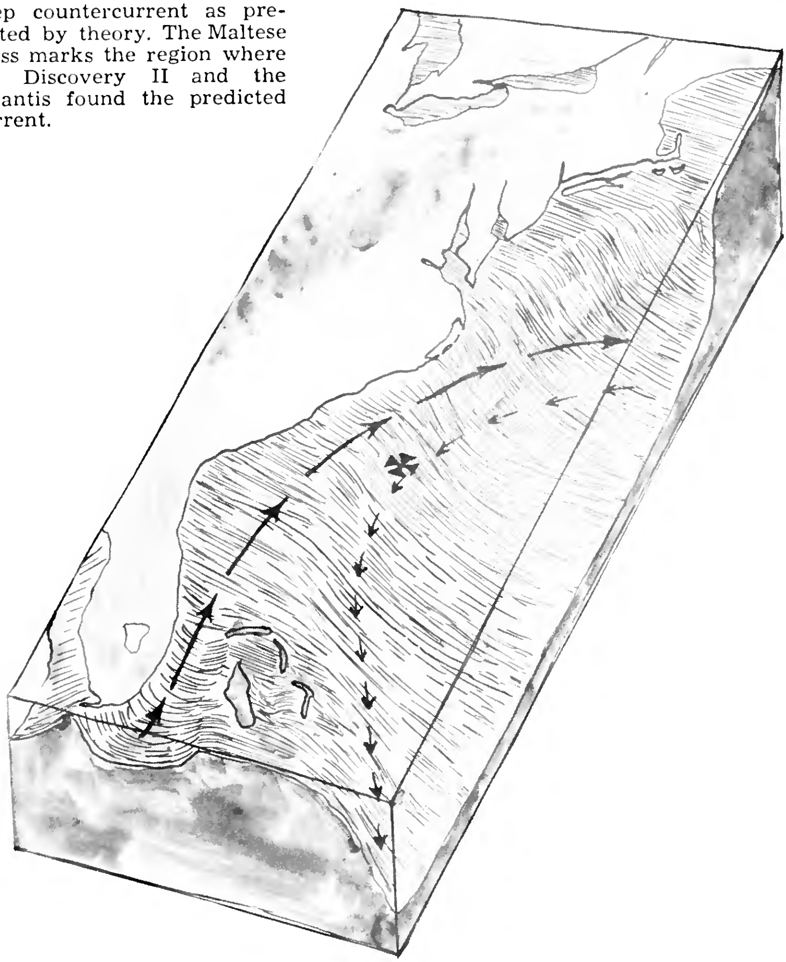
A Plan

The National Institute of Oceanography could not have sent the R. R. S. Discovery II across the Atlantic Ocean without generous help from the Woods Hole laboratory. The work would not have been effective had the R. V. Atlantis not been there to carry out close temperature and salinity measurements from surface to bottom in the investigated area. These observations allow the construction of isobaric charts for the sea, like those in weather reports, and such charts can be used to calculate the water movements if some initial assumptions can be checked by direct measurements.

A Result

Work on these lines by Defant and Wüst pointed to the existence of an area of little or no horizontal movement at a depth of 5000 to 6000 feet below the Gulf Stream with northward movements above and southward movements below, but

Block diagram of eastern coast of United States. Heavy arrows show the path and direction of the Gulf Stream's surface water issuing from the Florida Straits and flowing over the relatively shallow Blake Plateau. At Cape Hatteras the stream breaks away from the coast to flow eastward into deep water. The smaller arrows show the deep countercurrent as predicted by theory. The Maltese cross marks the region where the Discovery II and the Atlantis found the predicted current.



before this joint operation no one had measured the southward current and we could only guess its speed if it really was there. The northward flowing Gulf Stream was strong near the surface. There was little or no movement between 4500 and 6000 feet and three floats at 8200 feet and four at 9200 feet went south. One of the deepest did ⅓ knot steadily, travelling 23 miles in 66 hours. Photographs of the deflection of a ball suspended by string from a compass only 18 inches above the bottom still showed an appreciable southward movement. Without full account of such massive movements at great depth it is clear that no attempt to understand the surface currents and their variations could be complete. It will be some time before the observed currents, density, and pressure distributions can be fully considered, but there is no doubt that this collaboration between the British and U. S. laboratories is a landmark in Marine Science. The comparison of direct measurements with the conclusions based on density distributions will add greatly to the value of much work of this nature which is to be done in the International Geophysical Year.

Gifts and Grants

Two grants were received from the National Science Foundation. $36,700 for support of research entitled "Chemical Composition of Phytoplankton as Related to Environmental Changes" under direction of Dr. Bostwick H. Ketchum.

$56,700 for support of research entitled "Measurement of Light in the Sea" under direction of Dr. George L. Clarke.

Currents and Tides

Dr. G. Wüst has asked us to correct two statements made on pp. 33-34 of the last issue. Dr. Wüst was the chief of the physical oceanographic work of the Meteor expedition and scientific advisor to the general leader: Captain F. Spiess, German Navy.

The story of the scientist and the sea serpent turned out to be an old one and did not involve Dr. Bruun. We deeply regret the printed inaccuracies.

Dr. Joanne S. Malkus and Claude Ronne invaded a foreign domain and flew thousands of miles across the Pacific Ocean to study cloud formations. An official protest from Scripps may be expected at any moment.

Any back issues available?

As there is a constant demand for back issues the Editor will be most appreciative if unwanted copies of Oceanus can be returned to him. Postage will be refunded.

Particularly needed are the first issues of Volumes I and II and Volume III, number 3.

A Breaching Humpback

Humpback whales are very frolicsome and are often seen thrashing about at tne surface, waving their tails and flippers in the air and smacking the water with them. By far their most spectacular stunt is leaping partly or entirely out of the water — "breaching", the whalers called it.

Good photographs of these acrobatics are rare; usually the camera catches only the ensuing splash. This picture is one of a small number of successes and was taken by William M. Dunkle, Jr., from Atlantis on 22 July 1957 off the northeast end of Georges Bank. It is considerably enlarged; in the original the whale covered only 1.8 mm., about one fourteenth of an inch.

These acrobatics have been variously and often extravagantly explained; they are the observational basis for the accounts of battles between thrashers, sharks, or swordfish (which the reporters do not ordinarily see) and the whales. Another favorite explanation is that the whales are trying to rid themselves of parasites. However, it seems simpler for the present to suppose that these antics are mere playfulness. It may be worth noting that in all the breachings I have seen the whale has hit the water on its back, as this one did; in some published photographs the whale is on its side, evidently on its way over.

W.E.S.

Associates' News

Welcome Gifts

Associate Samuel A. Peck recently donated the 32-foot day cruiser "Gay Song" to the Institution, to be used or disposed of in any way the Institution desires.

This is the second time Mr. Peck has helped our program in this way. In 1952 he donated the 45-foot sportfishing boat "Allure".

A gift of $500. was received from Life Member Mr. Donald B. Straus.

New Industrial Associates

The Carter Oil Company	Tulsa, Oklahoma
Chance Vought Aircraft Incorporated	Dallas, Texas
Coastal Oil Company	Newark, New Jersey
United Fruit Company	Boston, Massachusetts

New Life Members

Mr. and Mrs. D. H. Braman, Victoria, Texas
Mr. and Mrs. Laurance S. Rockefeller, New York, N. Y.

Gifts and Grants

The Esso Education Foundation renewed a $3,500. grant to the Institution with the statement: "The Foundation feels that the program toward which this contribution is made is a worthy one and hopes that its grant will be helpful in achieving its objectives."

The Gulf Research and Development Company made a generous gift of equipment and supplies, including six Nansen bottles and a large orange-peel dredge.

Basic Research Report

The National Science Foundation report mentioned in our editorial presents a strong case for the increased support for basic research from private as well as public sources. The report suggests re-definition of tax exemption privileges for non-profit research institutions and changes in the Federal income tax laws to stimulate private philanthropic giving for basic research.

Copies of **Basic Research — A National Resource,** 1957, may be purchased for 45 cents from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. The Institution has a number of copies available for interested Associates.

Thermal

Circulation

by George Veronis

Radical new thoughts on the movement of the ocean's water masses are being tested during the I. G. Y.

IN 1955, Henry Stommel of this Institution theorized the existence of a deep countercurrent under the Gulf Stream. In March of this year the Discovery II — Atlantis expedition found that this current indeed existed — an observation which calls for a major revision in the fundamental concepts of dynamic oceanography.

The deep countercurrent, according to Stommel's thermohaline theory, is a result of changes in temperature and salinity which produce density differences which in turn produce the circulation. In almost all previous theories of the general circulation the ocean currents are considered to be driven by the major wind systems which could be modified by density differences, but in which salinity and temperature changes did not set up sizable currents. It now seems clear that thermodynamic forces must be as important as the wind in setting up the large-scale current systems in the ocean.

The Discovery II — Atlantis cruise brought to a close a cooperative effort which is perhaps unparalleled in the history of oceanography. In the twenty-

PREDICTION FOR DEEP CURRENT

This chart shows a theoretical prediction of the pattern of flow in deep water (the average transport beneath 2000 meters). From temperature-salinity distribution it seems evident that the deep water all over the world is supplied at two source regions indicated by the heavy black circular areas off Greenland and the Weddell Sea. This water is then distributed all over the world where it gradually rises at the rate of a few centimeters a day up through the main thermocline. The chart shows the actual distribution of these deep currents as predicted by the simple theory. There are a number of rather startling predictions:

The white areas indicate dep

TS

In central oceanic areas the cold deep water flows away from the Equator, not away from the poles!
There is a countercurrent under the Gulf Stream and the Agulhas Current.
The current under the Brazil Current and Korushio is not a countercurrent.
There is a marked deep current toward the north off New Zealand flowing along the western wall of the Tonga-Kermadec trench. One should find high velocities and a very narrow current.

epths over 4000 meters.

month period between Stommel's proposal and the actual observation, Dr. John B. Swallow of the (British) National Institute of Oceanography developed the neutrally buoyant float; the joint cruise was arranged in order to test both Stommel's theory and Swallow's instrument; and a careful program was planned whereby the Atlantis under the leadership of L. V. Worthington was to make standard oceanographic stations (i.e., gather data on salinity and temperature against depth) with which to guide the Discovery II in its choice of points at which the buoys were to be released.

The most significant aspect of the joint venture is the marked interdependence of the three phases of it. Stommel's analysis is based on *assumed* rising and sinking of large water masses in the sub-polar regions, an assumption which cannot easily be checked. The only alternative for determining the validity of the theory was to test the results by observation. Since the deep countercurrent under the Gulf Stream is the most pronounced feature of the model, the determination of its existence served as the crucial test of the validity of the theory. For this it was, of course, necessary to have an instrument for measuring deep currents.

It was fortuitous that Swallow had been designing just such an instrument.* When he had developed the float to the point where it was ready for a field test, the two institutions arranged the joint cruise. The Blake Plateau was specifically chosen as the testing ground. There, because of the gradual slope of the continental shelf, the surface portion of the Gulf Stream is farther inshore than the deeper portion. Thus the Discovery would not have to work against the surface Gulf Stream during the tracking of the float. The Atlantis preceded the Discovery II to the site and made hydrographic stations at several locations in order to determine the most appropriate points for releasing the buoys.

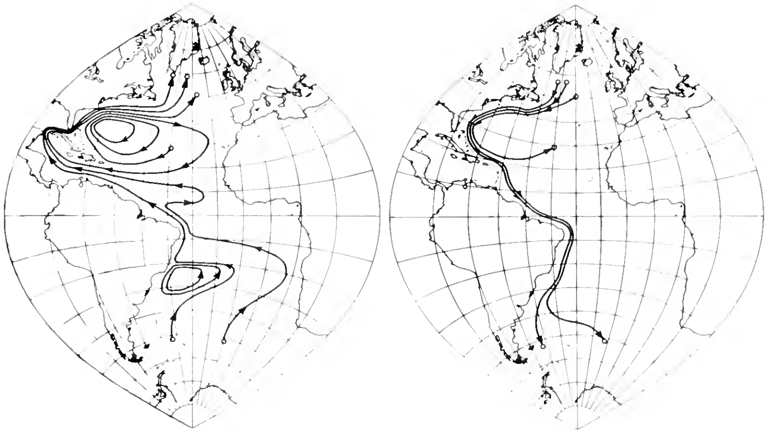
Seven buoys were released (at different times) at various depths between 2000 m and 2800 m. The buoys all moved essentially to the south with speeds ranging from 2.8 centimeters per second to 17 centimeters per second. The existence of the countercurrent was established beyond a doubt.

Dr. Veronis, Research Associate in Mathematics, is interested in transient and thermal circulation. He was formerly at the Institute for Advanced Study at Princeton.

Theories

Until the end of World War II no dynamical theory of the

* See page 13 in this issue.



Interpretation of the total water transport in the surface layer (left) and bottom layer (right) of the Atlantic Ocean. The small circles indicate where water sinks or rises across the level surface.

general circulation of the oceans existed. Suggestions had been made of the probable factors determining the general circulation but no model had been worked out. In a remarkable paper, published in 1933, Goldsbrough had been able to reproduce theoretically a circulation resembling that of the Atlantic Ocean. There were, however, severe restrictions in his theory which at the time seemed insurmountable. Over a long period of time new concepts have evolved and were formally realized by Stommel in 1956.

The first important step toward an understanding of the general circulation was made by Stommel in 1947. He showed that the rotation and curvature of the earth are the essential factors producing the observed intensification of currents on the western sides of the oceans. This westward shift is independent of the form of the boundaries or of the frictional forces which are assumed to keep the flow in a steady state. Stommel considered an ocean with rectangular boundaries and bottom friction, both of which are clearly unrealistic but neither of which is essential to his argument.

In 1950 Munk attempted to refine Stommel's model by eliminating bottom friction. He showed that it is possible to attain a steady state with the assumption that the retarding force be concentrated at the lateral boundaries. Later in 1950 Munk and Carrier applied boundary layer methods to a triangular ocean (roughly the shape of the Pacific) and derived results similar to the previous rectangular ocean model.

It now appears that the actual dissipative mechanism in the oceans is more complicated than

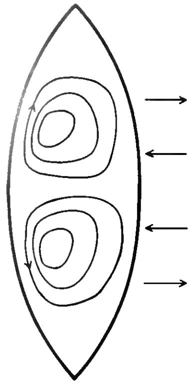


FIG. 1

that envisaged by Munk. His essential contribution was the careful determination of the total stress applied to the North Atlantic by the prevailing wind system. Since the ocean can be considered frictionless except for the boundary regions, the stress over the interior portion of the ocean determines the net amount of water transported by the circulation. Thus the precision of Munk's result could be checked observationally by a measurement of the transport through the Gulf Stream.

A Discrepancy

At this point in the analysis a puzzling discrepancy appeared. Munk's computation indicated that the Gulf Stream transported 35 million cubic meters of water per second. Observations indicated a value of 70 million. There appeared to be no way to resolve the discrepancy.

There were other dilemmas also. The wind system in the South Atlantic is equivalent in magnitude to that over the North Atlantic, so that theoretically the wind should produce a southward flowing Brazil Current comparable in intensity to the Gulf Stream (fig. 1). In reality as indicated by the dynamic topography there is practically no Brazil Current.

Two Layer Ocean

In 1955 Stommel found a way of incorporating the thermohaline* component of the circulation into a dynamical model. This circulation would be the result of large-scale rising or

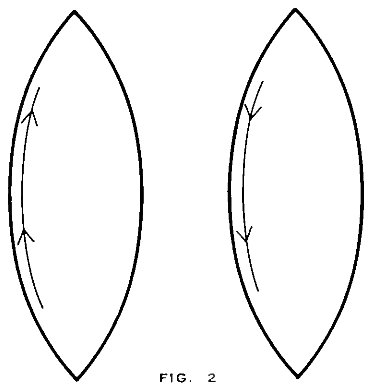


FIG. 2

sinking of water masses in the sub-polar regions. Stommel assumed that the ocean is divided into two layers and that water from the upper layer sinks to the lower layer in the sub-arctic region. In the sub-antarctic, lower layer water rises to the upper layer. Although the mechanism for such a water mass exchange

* The name "thermohaline", meaning literally "temperature-salinity" is derived from the fact that changes in temperature and salinity produce density differences which in turn produce the circulation.

is not investigated, this suggestion is in accord with an observational study of the southern ocean by G. E. R. Deacon as a result of the series of oceanographic cruises made by the Discovery II in the years 1929-39.

The result of the proposed exchange of water masses in the Atlantic would be a strong narrow current, northward at the surface and southward in the lower layer, along the entire western edge of the Atlantic (fig. 2). If this current is simply added to the wind-driven current, the net result on a chart of the Atlantic Ocean is as shown in fig. 3. From figs. 1 and 2, it can be seen that at the surface a superposition of the two currents intensifies the Gulf Stream and weakens the Brazil Current. In the lower layer the reverse is true, i.e., the Gulf Stream is weakened and the Brazil Current strengthened. Since the wind-driven currents decrease sharply with depth, the thermohaline bottom current is the dominant one and the flow under the Gulf Stream is actually to the south.

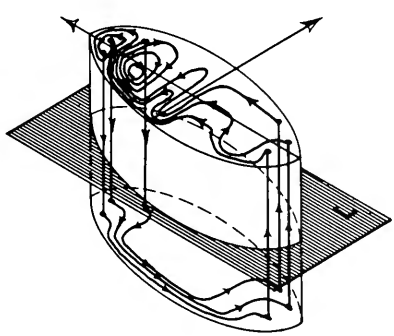
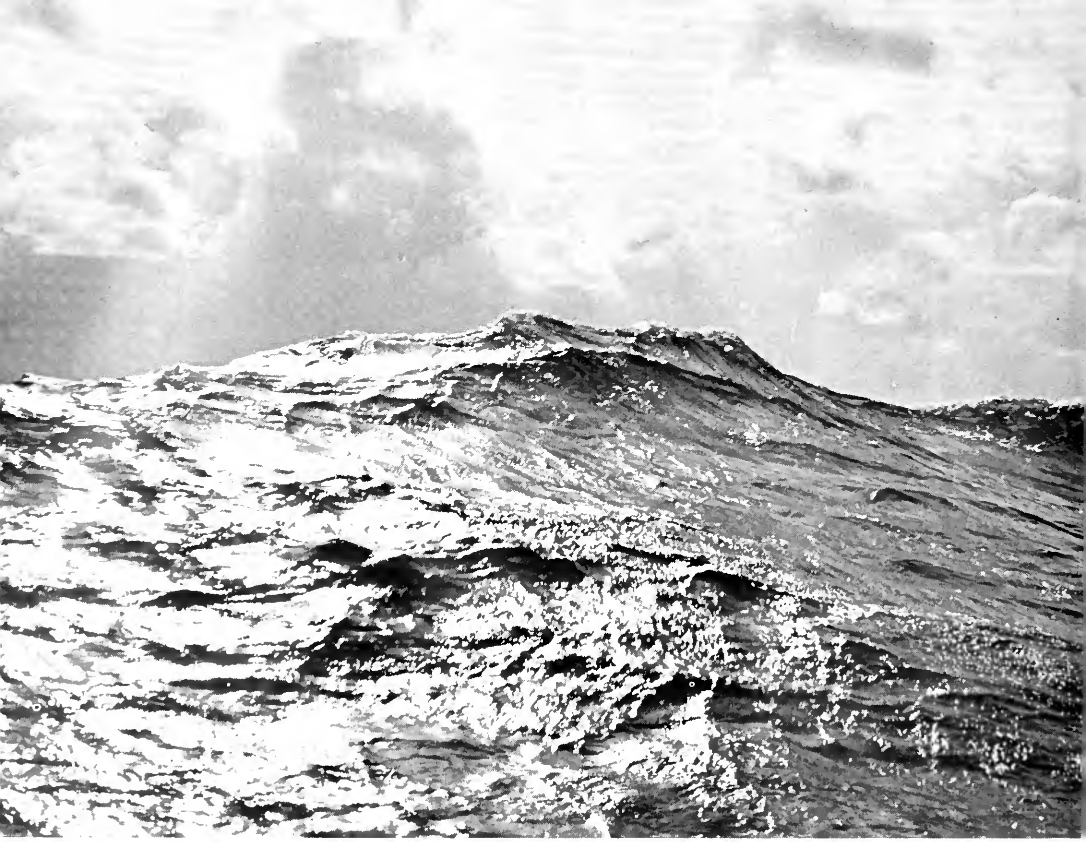


FIG. 3

The consequences of Stommel's model have been confirmed in one part of the ocean by the Discovery II — Atlantis expedition. See p. 15. Moreover, from 1933 Meteor expedition data, Georg Wüst has computed strong southward deep currents off the coast of Brazil. The model also explains the very weak dynamic topography of the Brazil Current. A final indication of the validity of the theory is that the net northward transport in the Gulf Stream is reduced by about a factor of two thus bringing it into agreement with Munk's computed transport.

The conclusion which one must draw, therefore, is that the ocean has a strong thermal circulation. Many questions are raised by the existence of such a flow.What complex non-linear interaction exists between the thermohaline and wind-driven boundary currents? Is the Antarctic Circumpolar Current an integral part of the Atlantic circulation through the water mass exchange? Is it meaningful to talk any longer about a one-ocean circulation or does the general circulation encompass the flow of all the world's oceans? These and many other questions arise. It seems to be a good way to start off IGY.



The heat and water budget of the earth will be studied intensely during the IGY.

THE great saga of the Norse kings, the "Heimskringle", begins with the words "Earth's round face, whereon mankind dwells". The Vikings, like other primitive peoples, thought of Earth as their home and of themselves as its creatures. Today we know that Earth is the only planet of our solar system on which human life could have developed, for no other satellite of our sun has land masses surrounded by an ocean of liquid water or an atmosphere containing abundant free oxygen.

Our bodies are made up almost entirely of four elements drawn from sea water and air, hydrogen, carbon, oxygen and nitrogen. The narrow temperature range in which we can survive is maintained by the great heat capacity of the sea and the atmosphere. The waste products that otherwise would suffocate us are continuously dispersed by the easy motions of the atmosphere. We can exist as land animals only because the sun's deadly ultraviolet and X-rays are fended off by the protective shield of the air, and because the great natural engine of the sea and the atmosphere pumps water continuously from the sea surface and pours it gently down upon the land.

Yet from our point of view, the earth is a careless mother.

Sun, Sea *and* Air

by Roger Revelle

Large areas of her surface are too hot or too cold, too dry or too wet to support any large number of human beings. Moreover, she is unreliable. Areas where there was once sufficient water for men to build civilizations are now so dry that only a few desperate nomads can live in them. Elsewhere, a mile-thick blanket of ice has crept down and obliterated once green farms and forests. Millions of our species suffer when a slight change in the running of the sea-atmosphere engine causes drought or flood. Sometimes the engine runs with unpleasant violence. Then thunderstorms and hurricanes, tornadoes and typhoons bring destruction and death to many of us.

Because of our dependence on events taking place in the air, almost everyone is an amateur meteorologist. Wherever two or more people are gathered together the first topic of conversation is the weather, and this was probably just as true in the time of Hammurabi or Amenhotep as it is today. Professional weathermen are a new development, however, and it has only been within the last few decades that we have begun to gain an understanding of the great interrelated mechanisms of the air and the oceans.

The Sun

We know that the sun pours a flood of particles and visible and invisible light into the top of our atmosphere. The amount of visible light appears to be nearly constant, but the intensity of ultraviolet and X-rays and the number of particles varies by at least a hundredfold. The particles are chiefly electrons and protons. The average number of hydrogen nuclei entering our atmosphere is surprisingly large, perhaps a billion per square centimeter per second. During the geological lifetime of the earth, if all this hydrogen were combined with oxygen as water, it would correspond to a layer over the ocean about twenty meters thick. The energy carried to the earth by these particles from the sun during periods of sunspot activity may be as much as one tenth of the total energy of sunlight.

In addition to particles of ordinary hydrogen, there is new evidence that most of the tritium or radioactive hydrogen on earth also comes from the sun. It was formerly thought that all the tritium was produced by cosmic rays bombarding nitrogen and oxygen molecules in the upper air, but recent calculations indicate that the amount present is nearly ten times too large to be produced in this way.

The marked variations in ultraviolet radiation and in the number of particles coming from the sun cause large variations in the temperature and in the electrical and magnetic behavior of the upper atmosphere, because there is such a small amount of air at these high levels. Neither the majority of particles nor the ultraviolet rays penetrate very deeply, however, and it is not clear whether the variations in the amounts coming from the sun have appreciable effects near the earth's surface. Visible light is the dominant form of solar energy entering the lower atmosphere. Part of this light is reflected back to space, chiefly from the surface of clouds, snow and ice. Most of it is absorbed in the atmosphere and the sea, from which it is ultimately re-radiated as infrared radiation.

In this respect, the atmosphere behaves much like the glass in a greenhouse. It easily transmits visible light but is rather opaque to the infrared or heat radiation coming from the ground and the sea surface. Just as in a greenhouse, the air temperature must be considerably warmer than it would be in the absence of materials that absorb infrared, in order to allow a balance between incoming and outgoing radiation. In the greenhouse the absorbing material is the glass roof. The corresponding materials in the atmosphere are three substances present in quite minor amounts: water vapor, carbon dioxide and ozone.

The temperatures in the upper air do not vary markedly with latitude and consequently the amount of back radiation is roughly the same all over the globe. But the amount of incoming sunlight is greater in the tropics than in high latitudes. As a consequence, air and water warmed in the tropics must move toward the poles. Part of the energy received from the sun is thus used to carry the excess heat absorbed in low latitudes to high latitudes where it can be re-radiated. The amount of heat transported across the parallels of 30° is 10 to 20% of the total incoming radiation, but the mechanical work involved is less than 1%.

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Heat Engines

The situation can be thought of as if the sea and the atmosphere were interlinked heat engines of very low efficiency. These engines do mechanical work against friction by carrying the working fluids, sea water and air, from the "firebox" of the tropics to the radiation-cooled "condenser" of the polar regions. The circulation of the working fluids is manifest in the winds of the air and the currents of the sea. In the atmosphere, it takes place through the coupling of rotary current patterns of all possible shapes and sizes. These include the trade-wind cells of ocean-wide dimensions, the large-scale high- and low-pressure areas of mid-latitudes, the wavelike jet stream, hurricanes, tornadoes, tiny whirls and vortices. In the sea, major units of the circulation include the Gulf Stream and the Kuroshio, the fast moving equatorial currents and the sluggish currents of the abyssal depths. These circulation patterns are partly unstable, and this shows itself to those of us who live in mid-latitudes as the radical changes in weather with which we are all familiar. In low latitudes over the ocean the instability produces the terrifying hurricanes of the western Pacific and of our own east coast.

The behavior of the interlinked heat engines of the sea and the atmosphere is profoundly influenced by four facts: First is their peculiar shape; they are essentially two thin sheets wrapped around a sphere; second, the sphere is rotating; the lower layers of air are dragged along by the rotation, and the movements of both the sea and the air are largely determined by the forces generated by the rotation (at a height above our heads of several hundred miles there is a transition to a zone where the sparse atoms of gas no longer move around the earth's axis); third, the ocean is not a continuous sheet like the atmosphere, but is broken up by the relatively dry areas we call continents; fourth, like an invisible pousse café, the atmosphere is stratified in thin layers that do not mix readily with each other and each of these layers has to a considerable extent a separate behavior of its own. The same is true of the ocean but with the marked difference that while the temperatures of the different layers of the atmosphere are alternatively lower and higher as we go upward, the temperature of the ocean decreases continuously nearly to the freezing point at great depths. It increases slightly near the bottom because of the heat coming from the interior of the earth.

The energy needed to drive the sea-air circulation is only a small portion of the incoming solar radiation, but it is still enormous on a human scale. The winds of the earth have a total kinetic energy estimated to equal seven million atomic bombs, or more electric power than all the power plants in the United States could produce in a hundred years. This energy must be replenished every nine to twelve days because of the loss by friction between the winds and the earth's surface.

Although there is a general agreement about the foregoing generalizations, our mental model of the sea-atmosphere system is so inadequate in many essentials that meteorologists are unable to predict anything very useful for more than a few days in advance about the circulation of the atmosphere.

Climatic changes

Even more fundamentally, we do not know the factors that determine the average conditions. Consequently, we are quite unable to forecast changes in climate. Yet we know that such changes have occurred in the relatively recent past. Only about ten thousand years ago the earth emerged from a dark age of snow and ice; less than five thousand years ago, Greenland offered a fair and pleasant habitation for human beings. Within the last fifty years, the climate over eastern North America and northern Europe has again become slightly warmer and the Arctic wastes are perhaps again becoming accessible to human beings, while elsewhere prolonged droughts are destroying the work and hopes of decades. For the farmer, the strategist and the statesman, an accurate forecast of climatic change over the next fifty years would be of immeasurable value. But such a forecast is completely beyond our present ability. Ability to forecast depends on understanding, and this comes in two interrelated ways: by constructing small models in our heads of the two great earth fluids, and by testing and refining these models through observations. This second method is one of the major objectives of the International Geophysical Year. In particular, we are concerned with measurements in areas that have never been adequately explored and of phenomena that have never been adequately studied.

To increase our understanding of climatic change we can ask first, what changes have occurred in the past and how did they happen? Second, because a change in climate is essentially a change of average air temperature, we need to examine the ways in which the heat content of the air can vary. The heat content must be that required to give a balance between incoming and outgoing radiation, hence it can vary if there is a change in the amount of incoming radiation from the sun, in the proportion of sunlight reflected versus that absorbed, or in the amount of the infrared back radiation absorbed by carbon dioxide, water vapor and ozone. A 1% change in the intensity of the incoming sunlight or in the amount of sunlight reflected back to space would give about a 1° centigrade change in the average air temperature.

The total solar radiation seems to be remarkably constant. The most recent continuous observations are those made at the Lowell Observatory since 1953. During this period of sunspot minimum no solar variations in the blue region of the spectrum greater than 0.3% have occurred. Ionospheric observations show, however, that ultraviolet components of the solar radiation are larger during periods of sunspot maxima, and the visual spectrum observations must therefore be continued throughout at least one sunspot cycle before we can say definitely that solar radiation is virtually constant over decades.

In contrast to the apparent constancy of the incoming radiation, the reflectivity of the earth would appear to be easily changeable. Clouds, snow and ice reflect most of the sunlight that falls on them, whereas the ocean surface, vegetation and bare ground are highly absorbing for visible light. At present about 50% of the earth's surface is normally covered with clouds, while large areas are capped with snow and ice, particularly during winter. An average of 35% of the incoming sunlight is reflected back to space without being absorbed. The average air temperature would decrease by 1° centigrade if the reflection increased to 36% through increased cloudiness or a spreading of the snow and ice-covered areas.

Dust in the upper air also scatters and reflects sunlight before it can reach the ground and ocean surfaces. After the explosion of the volcano Krakatoa in 1883, the incoming radiation from the sun and sky decreased by 5 to 10% for three years. Changes in the water vapor, ozone or carbon dioxide content of the air change the amount and character of the infrared absorption. Calculations indicate that a 25% change in the carbon dioxide content of the air would change the average air temperature by 1° centigrade.

The factors affecting the average air temperature are interrelated; there are in fact what electronic engineers call "feedback" relationships between them. These feedback linkages are both positive and negative. For example, an increase of air temperature from whatever cause would result in a melting of part of the snow and ice cover of the earth and a corresponding reduction in the reflection. Consequently, the amount of absorbed radiation would increase and the temperature would rise still further. This is a positive feedback. Similarly, an increase of average air temperature would increase the evaporation from the oceans, hence the water vapor content of the air and absorption of infrared radiation. The temperature would not increase without limit, however, because an increase in evaporation must eventually result in an increase of cloudiness as the water vapor condenses, hence an increase in the proportion of reflected sunlight. This is a negative feedback. Such complex feedback linkages tend to hunt or oscillate, with time constants determined by the speed of the different processes involved.

Thus far we have been discussing comparatively small changes in average air temperature over the earth. Such changes may be of great significance — it is generally estimated by meteorologists that a 4° drop in average air temperature would be sufficient to bring on a new ice age. But with present meteorological observing facilities they would be almost impossible to measure. What is observed are local changes of much greater magnitude. These must be brought about chiefly by variations in atmospheric and perhaps oceanic circulation, specifically in the locations of north-south transport of heat and matter.

For example, the January mean temperature at Spitsbergen increased by 24° from 1913 to 1937, whereas during almost the same period there was a 3 to 5° drop in January mean temperature in the Great Basin of the western United States.

Because of the complex relationship between the amounts of insolation and infrared absorption on the one hand and the circulation patterns of north-south transport on the other, it is by no means certain whether an increase of insolation or absorption would bring on a colder or a warmer climate.

Past Changes

The circulation patterns are profoundly affected by the distribution of continents and oceans, and therefore it is of great importance to make comparative studies of past climatic changes in the northern and southern hemispheres, because of their markedly different patterns of sea and land. Since changes in the intensity of the north-south circulation should have different effects in high and low latitudes, it is also necessary to attempt to determine the nature of simultaneous climatic changes in different latitude zones.

The great ice caps of Antarctica and Greenland and the mountain glaciers throughout the world are remarkable indicators of climatic change. During periods of warming or reduced precipitation the glaciers retreat; when the atmosphere is cooled or snowfall increases they thicken and rapidly advance. Moreover, the layers of ice laid down in successive years constitute an unrivalled record of events on earth during past millenia.

Many aspects of glaciers will be studied during the IGY. Among the most significant from the standpoint of the heat and water budget of the earth will be the thickness of the ice. This will be measured by the seismic techniques used in prospecting for oil. Bore holes and cores will also be taken to study the frozen record of the past.

Ice caps now cover about 3% of the earth's surface. A melting of two feet per year over these surfaces seems quite possible from present data. This would result in a rise of sea level of about an inch per year or roughly ten feet in one hundred years. Even such a rise as this would bring serious consequences to many thickly populated coastal areas.

The sediments of the deep sea floor, like the ice caps, contain a detailed climatic record extending back over many thousands of years. For example, variations in the numbers of limy shells of the tiny animals called foraminifera reflect variations in the oceanic circulation near the surface. The ratios of oxygen isotopes in these shells tell us something about past ocean temperatures. At least part of the present temperature differences we can measure between different layers in deep sea sediments may be the result not of heat flow from the earth's interior but of warmer temperature of the deep ocean waters a few hundreds or thousands of years ago. Studies of these sediments and their significance for climatic change will be an important part of the series of oceanographic expeditions to be conducted during the International Geophysical Year.

The meteorologist and the oceanographer can seldom use that peerless tool of the laboratory scientist—controlled experiment. As substitutes for experiment they must attempt to make comparative investigations of the behavior of the earth fluids under different conditions. For this reason a major part of the IGY meterological program will be focussed on comparisons between the southern and the northern hemispheres.

Because the earth is closer to the sun in January than in July, the southern hemisphere receives about 6% more radiation in summer than does the northern. The geometry of the two hemispheres is also quite different. In the north, the Polar Sea with its thin, cracked skin of ice is surrounded by continents; in the south a continent nearly twice the size of the United States, having an ice covered surface two miles above sea level, lies at the pole and is surrounded by the great southern ocean. This high central plateau, sheathed in darkness for six months each year, is a focal point for inward-circling storms and outward surges of cold air. The weather conditions in the Antarctic are nearly incredible; for example, wind velocities at Adelie Land have averaged 110 miles per hour for a day, more than sixty miles per hour for a month and about forty miles per hour for an entire year. The American IGY party now maintaining a vigil at the South Pole have already recorded temperatures below−100° F. with 15 to 20 knot winds.

As is well known, the testing of large atomic weapons produces considerable amounts of radioactive substances, some of which decay rather slowly. A large part of the radioactive material produced by atomic weapons tests is injected into upper strata of the air and can be used by meteorologists as a tracer of atmospheric movements, for example to determine the rate at which the air at different levels is carried from the northern to the southern hemisphere and vice versa, and the rate of mixing between the upper and the lower atmosphere. An important IGY objective will be world-wide measurements of these artificially radioactive substances.

Gains and Losses

A slight excess or deficit in the input of solar energy over the output of infrared radiation from the earth may cause large changes in weather and, if long continued, in climate. At present we are unable to determine whether such differences between income and outgo exist.

Here the earth satellite program shows great promise; one of the first satellites will carry relatively simple equipment for measuring the difference between the amounts of incoming and outgoing radiation at all points over its path. Later satellite experiments will include actual mapping of the earth's cloud and snow cover, allowing accurate and continuous measurements of the amount of sunlight reflected from the earth, a quantity that can at present only be rather crudely estimated.

A change in average air temperature represents, of course, a gain or loss of heat from the air, but it need not represent a gain or loss from the ocean-atmosphere-glacier system of the earth. On the other hand, an excess of heat could be stored for long periods on the earth without much change in the temperature of the lower air. There are two great mechanisms for this: one is the melting of ice caps, the other is the heating of the deep waters of the ocean. The latter has by far the larger capacity. The energy required to melt all the ice in Antarctica is equivalent to about two and a half years' supply from the sun at the present rate of 175,000 calories per square centimeter each year. This same amount of energy would raise the average temperature of the ocean by only a little more than 1° C. (On the other hand, the melting of ice caps would be somewhat more obvious to everyone, since it would result in a rise of sea level by at least 200 feet, and the consquent destruction of most of the world's largest cities!)

Because of the great heat capacity of the ocean, many meteorologists and oceanographers now believe that climatic changes lasting over decades or centuries may be intimately related to changes in the circulation of the deep sea. Effective techniques for studying this circulation have become available only in the last few years, and it is little understood. We know that cold water sinks to great depths from the surface in high latitudes, moves slowly toward the equator and perhaps across it, and returns by an unknown path to the starting point. The time required for the round trip is not known; it may be measured in decades or millenia. Nor do we know whether the circulation is steady or intermittent like the flushing of water in a bowl.

One of the major enterprises of the International Geophysical Year will be a series of great oceanographic expeditions, conducted by seventy ships belonging to many countries. Their principal objective will be to obtain a comprehensive picture of the temperature and other properties of the deep sea waters, and to make direct and indirect measurements of their motions.

The Earth and Man

President Eisenhower has said that water is rapidly becoming our most critical natural resource. During the last few years, serious attempts have been made to develop inexpensive machines for converting sea water into fresh water. The fact is, of course, that nature herself operates a most effective distillation system. Nearly one-third of all the energy of sunlight falling on the sea surface is utilized in converting sea water to fresh water by evaporation. The immense quantity of solar power used in this way is several thousand times all the power produced by our industrial society from hydroelectric power and the burning of coal, oil, and natural gas.

The total quantity of water evaporated, if all of it fell on the surface of the land and was uniformly distributed, would result in an average rainfall of over one hundred inches a year. Evidently the trouble with the natural distillation process is not the quantity of fresh water produced, but rather that nature's pipe lines are badly placed. Too much water moves to some areas and not enough to others; moreover, the valve system seems to be capriciously managed. Sometimes the discharge is too great, bringing floods, while at other lines there is only a trickle and droughts occur.

Can anything be done about this faulty distribution system? The quantity of solar energy used in driving the engine of the sea and the atmosphere is so great compared to any of the energy sources under man's control that it would seem impossible for us to affect weather or climate materially by any human action. Yet, a close look shows there may be some things we could do. Many of the processes in the atmosphere are metastable: a slight action may initiate a very large-scale process. We might learn how to regulate climate if we could find the right lever to pull.

One may predict that with the coming of greater understanding, promising methods for control of weather and climate will be found. The average reflectivity of the ground surface over the large areas might be reduced, for example, by rapid melting of the snow cover, thus increasing the percentage of sunlight absorbed. On the other hand, it might be possible to shut off some of the sun's radiation before it reaches the earth's surface, for example, by injecting a small amount of absorbing or reflecting substances into the upper atmosphere.

Great Experiment

During our lifetime we may be witnessing an example of one way in which human actions can affect weather and climate. Since the beginning of the industrial revolution, an amount of carbon dioxide equal to about 12% of the total already present in the atmosphere has been produced by the burning of coal, oil, and natural gas. The ability of the ocean to absorb carbon dioxide is very great and probably most of the amount added to the atmosphere during the last century has gone into the sea. During the next hundred years, however, the increasing use of fossil fuels in our world-wide industrial civilization should result in the production of about 1700 billion tons of carbon dioxide — 70% of the amount now in the atmosphere. Because of the rapid increase in the production rate, the fraction of the added carbon dioxide absorbed by the ocean will be lessened and an increase of perhaps 20% in atmospheric carbon dioxide can be expected. The effect of such an increase is not easy to predict, but there is some theoretical reason to believe that it could result in a warming of the lower atmosphere by several degrees. Thus, by consuming within a few generations the fossil fuels laid down in sedimentary rocks over many hundreds of millions of years, we are conducting, more or less in spite of ourselves, a great geophysical experiment. It is of vital importance to keep accurate records of this experiment in order to increase our understanding of the mechanisms controlling climate. With this in mind, careful measurements will be made during the IGY of the carbon dioxide content of the atmosphere, and studies will be initiated to refine our estimates of the absorption of carbon dioxide in the sea.

In Memoriam

WITHIN a single week during August oceanography suddenly lost its two greatest leaders. Carl-Gustav Rossby died on August 19 in Stockholm and Harold Ulrich Sverdrup passed away equally unexpected in Oslo on August 21. Professor Rossby had been associated with the Institution from its beginning. He worked here on many occasions during the summer and for longer periods. Most physical oceanographers in this country were at one time among his students. Professor Sverdrup was the director of our sister laboratory, the Scripps Institution of Oceanography, during the period 1936-46. He has visited Woods Hole on many occasions and while fewer of us have actually studied under his direction, we all are entirely familiar with his classical text book, "The Oceans." Both men were actively engaged in research and teaching at the time of their death.

C. O'D. I.

Currents and Tides

Among distinguished visitors in recent months were: U.S.S.R., Professor L. Zenkevitch; Great Britain, Dr. K. F. Bowden, Dr. G. E. R. Deacon, Dr. Ronald Fraser, Professor A. C. Hardy, Dr. M. N. Hill, Dr. N. B. Marshall, Dr. John B. Tait; West Germany, Dr. G. Böhnecke, Dr. Gunther Dietrich, Dr. Hans Walden; Denmark, Dr. Anton Bruun, Professor E. Steemann Nielsen; Japan, Mr. Bunkichi Imayoshi, Dr. Y. Miyake, Mr. Haruyuki Koyama, Mr. Ichiji Yoshitani; Norway, Professor H. Mosby; Argentina, Cdr. L. R. A. Capurro; United States, Dr. Roger Revelle, Dr. Norris W. Rakestraw, Dr. John E. Tyler; British Columbia, Dr. John D. Strickland; Netherlands, Mr. P. Santema, Dr. J. Th. Thijsse; India, Dr. B. D. Laroia; New Zealand, Dr. R. Culver, Dr. F. H. Sagar; Australia, Professor W. Stephenson; Bermuda, Dr. W. H. Sutcliffe, Jr.; Greece, Mr. Athanasios Hatzikakidis.

The WOODS HOLE OCEANOGRAPHIC INSTITUTION in the INTERNATIONAL GEOPHYSICAL YEAR

The International Geophysical Year (IGY) is a cooperative program of research in the earth sciences, an outgrowth of previous international Polar Year Surveys. The U. S. program is coordinated on the international level by the National Academy of Sciences-National Research Council, while working groups direct the research in each particular field. Mr. Iselin, our director, is the current chairman of the international work group in oceanography.

Within this country, the National Academy of Sciences has set up a National Committee for the IGY to distribute funds provided by direct congressional appropriation to support the programs of the U. S. participants.

Approximately one-sixth of the national budget of $1,870,000 in oceanography has been granted to this Institution for the support of programs being carried out in cooperation with the Lamont Geological Observatory, Texas Agricultural and Mechanical College, the Scripps Institution of Oceanography, the University of Washington, and several Government facilities.

Deep Currents

One of the major U.S. programs is the study of those deep currents which move the water masses below 6,000 feet. As the chart on page 2 of this issue shows, a considerable amount of the work in the Atlantic Ocean already has been accomplished and it is a source of satisfaction that the R.V. Crawford (Captain David F. Casiles) has been able to do so much work in such a short time. This is, of course, due to the hard work and cooperation among the scientific parties, the ships' officers and crews, and our shore facilities.

By the end of this year we shall have finished profiles of salinity, temperature, and oxygen along parallels eight degrees apart over most of the Atlantic Ocean with only a few left to be done next year. Three of the eleven profiles have been made by our friends on the R.R.S. Discovery II (Captain S.S.F. Dalgleish). Altogether, this program represents an enormous amount of work. Observations from the sea surface to the ocean bottom have been obtained 80 miles apart in deep water and at closer intervals near the coasts. One of the more interesting items has been the fact that the Crawford returned with worked up data which, in the past, was mostly left to be done after the return of a cruise. This has become possible not only by dint of hard work but also due to the development of Karl E. Schleicher's shipboard salinometer. Formerly, thousands of water samples were brought back to be titrated in the laboratory at Woods Hole.

In the South Atlantic the work is duplicating that done by the German Meteor Expedition, 1925-27, to detect any long-term changes which may have taken place in thirty years. Mr. F. C. Fuglister was in charge of the work in the South Atlantic. Mr. W. G. Metcalf is chief scientist during the present work along the 40th and 16th parallels while Messrs. L. V. Worthington; F. C. Fuglister and H. Stommel have taken part in the Discovery II cruises.

In addition to the hydrographic observations, large water samples have been and are being collected for analysis of geochemical properties. This work is being supervised by Drs. V. T. Bowen and B. H. Ketchum. For the study of radioactive elements in sea water it was necessary to obtain much larger water samples than those taken by Nansen bottles. A 55-gallon collapsible rubber sampler was developed by Dr. Bowen and already has seen much service.

The study and analyses of these samples will provide information on the naturally occurring radioactive elements and the distribution and mixing of fallout material from weapons tests. The former is especially important to establish a baseline to which future measurements may be related. The radioactive isotopes to be studied are: carbon, hydrogen, antimony, cerium, cesium, promethium, and strontium, while analysis will also be made for oxygen, nitrates, ammonia, phosphate, total nitrogen, phosphorus, and chlorine. It is hoped that unique data on the distribution of certain radioactive fission products in the Atlantic may be obtained.

CO^2

A continuously recording carbon dioxide gas analyzer has been purchased. The instrument has been adapted for use on board ship and in our new DC-3 aircraft (Captain Norman Gingrass) by Drs. Bowen and Leahy. As Dr. Revelle has pointed out in this issue, it is vitally necessary to obtain information on the level and distribution of carbon dioxide in the ocean and in the atmosphere. Previous measurements have been spotty. The continuously recording apparatus will make it possible to study problems of a detailed and restricted nature, for instance, the rate of exchange of CO^2 between the ocean and the atmosphere. In conjunction with some of the radioactive studies we may also obtain important information on convection and vertical mixing in the upper layers of the ocean.

Indian Ocean

In 1958 the Atlantis (Captain W. Scott Bray) will sail to the South Atlantic to make a north-south section along the South American coast and some short sections at 12° South and 20° South to fill in gaps in important areas not covered by the Crawford. She will then make the final southernmost profile at 32° South before sailing for the Indian Ocean to work with the Vema of the Lamont Geological Observatory for joint geophysical and oceanographic observations. (Another joint cruise with the R.R.S Discovery II is reported on page 13 of this issue.)

Arctic Observations

Another extensive area of operations during the IGY will be the Arctic Ocean, where observers camp on the ice island "T-3" and a large floe of ice north of Point Barrow. Maintained by the U. S. Air Force for the IGY program the two camps are occupied by about twenty scientists and military personnel. The Institution's scientists sent to this area working under the leadership of Mr. W. G. Metcalf make deep hydrographic observations from the ice. By occupying both available stations and taking advantage of the drift of the ice, a series of short hydrographic sections probably can be completed. Such observations will contribute significantly to the present rudimentary oceanographic data from that area.

As a part of a general acoustical study of the ocean, frequency calibrated measurements of sea sounds in the arctic basin will be made under the direction of Dr. J. B. Hersey. The two major contributors to the noise level in arctic waters are marine animals and the sounds of moving sea ice. Working under Dr. F. Birch of the Dunbar Geophysical Laboratory of Harvard University, another group will measure the heat flow from the earth in this area. Such measurements have been made previously at sea by dropping a long temperature sensitive probe into the bottom sediments and measuring the difference in temperature between successive thermal elements in the probe. The knowledge gained by such measurements is of major importance to our understanding of the earth as a whole. Prior attempts from shipboard have been hampered by the difficulty of hovering in position over the probe long enough to allow the thermal elements to come into equilibrium with the bottom sediments. By making the measurements from relatively stationary ice in the Arctic it will be possible to wait long enough for the equilibrium to develop. Besides furnishing data from a new area, the observations may also provide a check for shipboard measurements which had relied on a theoretical temperature equilibrium curve.

The major significance of the IGY for the Institution is probably not the increase in available funds for oceanographic research, but in the concept of the program itself. It is now possible to visualize an extension of cooperative research beyond the period of the IGY, conceivably with continuing financial support resulting from the activities of this special period. The Special Committee on Oceanographic Research (SCOR) of the International Council of Scientific Unions has been formed as an organizational nucleus for such continuing research effort. Long-range, large-scale plans were made during the August SCOR meetings at Woods Hole, heralding a new phase of international cooperation in oceanographic research.

The PBY amphibian plane is no longer with us. Too old for service she has been replaced by an R4D, U. S. Navy plane given to the Institution on loan. An R4D is the Navy designation for a DC-3.

With typical abandon the Institution's scientists have drilled holes in the sides and bottom of the plane for instruments, cameras, etc. Captain Norman Gingrass is her commander.

Yes, we know the instrument on the front cover is not a Nansen bottle. It is an Ekman bottle used by the Bermuda Biological Station on board the Caryn. The gentleman standing on the cruel sea is its director, Dr. Wm. H. Sutcliffe, Jr.

The R.R.S. Discovery II visited Woods Hole from November 8 to 16 while making the sections along the 24th and 32nd parallel.

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