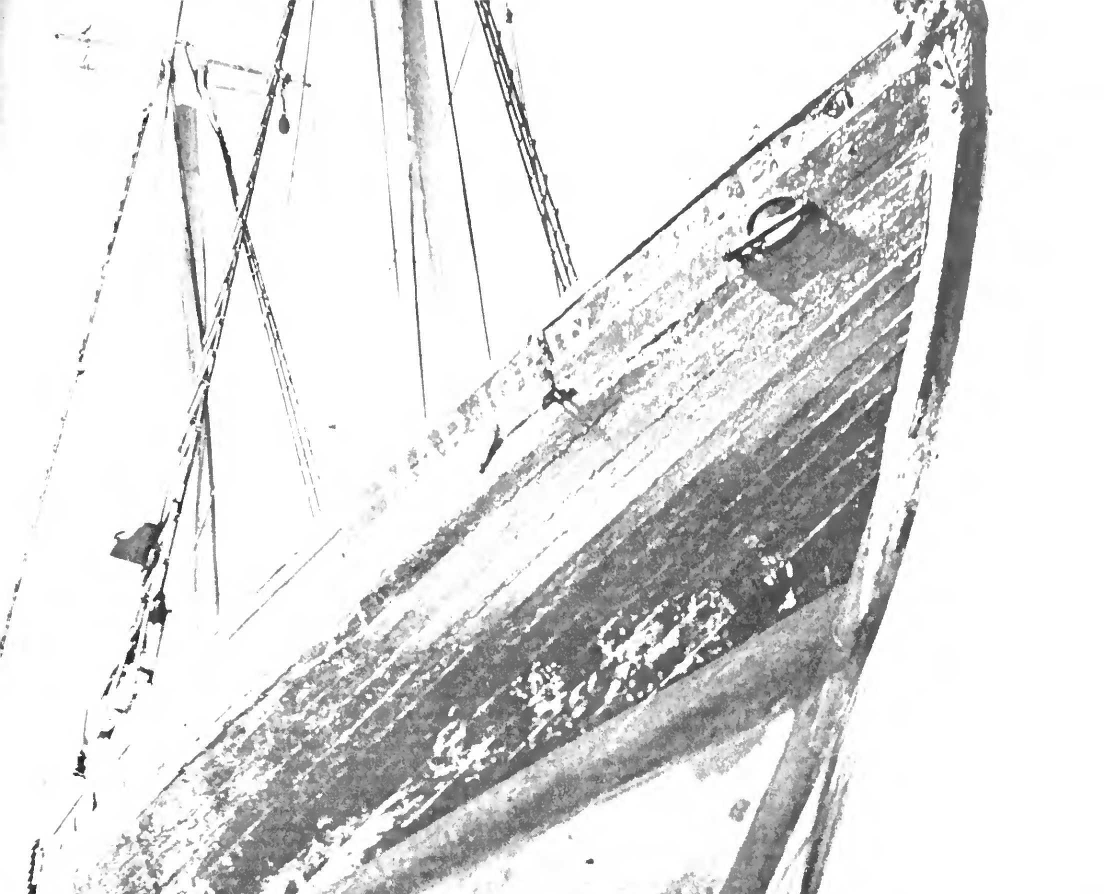

VOL. VI. NO. 4, JUNE 1960

OCEANUS

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EDITOR: JAN HAHN

Published periodically and distributed to the Associates of the Woods Hole Oceanographic Institution and others interested in Oceanography

Hahn

Per angusta ad augusta

THE forces of nature discussed by Dr. Malkus on page 3 are illustrated by our cover. The fishing schooner MARJORIE PARKER did not fare too well during hurricane Carol (1954).

It is to be expected that man will not forever remain the slave of his environment. On a small scale, in some areas, it may be possible already to alter conditions. Yet, we must not forget that manmade changes in nature have backfired and that much more remains to be learned as changing conditions may not always be beneficial.

Earth, "our manned space satellite" must be studied more extensively.

 VOL. VI, NO. 4, JUNE 1960

THE Woods Hole Oceanographic Institution was 30 years old on January 6th, 1960. As far as we know the event passed without attention.

The death on May 11th, of John D. Rockefeller, Jr., son of the builder of the Standard Oil Empire, after a lifetime devoted to giving away his wealth, ought to remind us of the Institution's origin. It was due to a grant of approximately three million dollars from the Rockefeller Foundation that we received our start. This grant, together with aid from the Carnegie Foundation, provided for the "old" laboratory, the building of "Atlantis", initial support and the endowment fund.

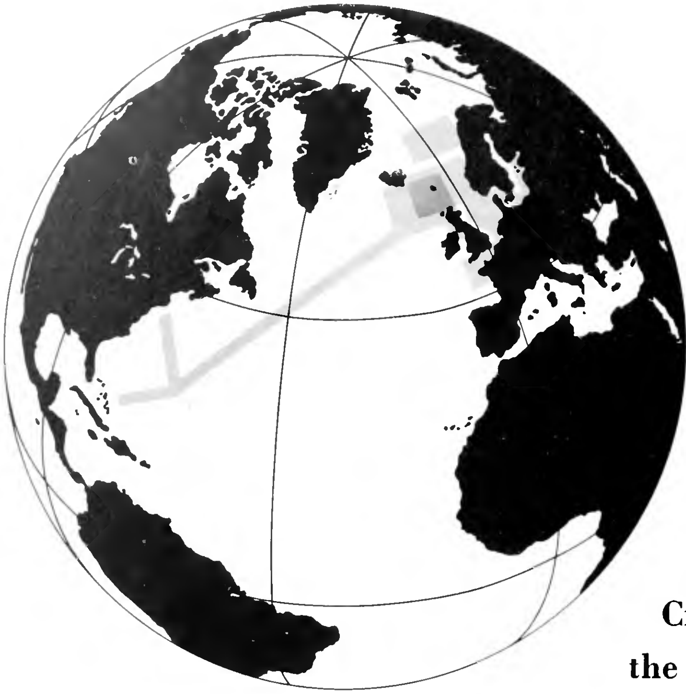
The hopes and expectations of this "pump priming" grant certainly were fulfilled. Today, our annual budget, is equal to the original grant. On the other hand, the endowment fund has increased only through market value and one or two small gifts. Only about 10% of our budget comes from endowment, through the Associate Program and other sources. The rest is obtained from Federal funds. Some important problems that need to be studied and the attracting and supporting of bright, young scientists are difficult to undertake without free funds.

There is much talk about feeding the expanding world population by products from the sea. Dr. Malkus' article in this issue points up another vital field of study. Undoubtedly, the food resources from the sea can be taken more efficiently and in larger qualities, particularly in the southern hemisphere. How much, where and how ought to be subjects of intensive investigations. They are not. The study of the interchange between ocean and atmosphere is pursued by a handful of people with little financial aid.

To quote Mr. Rockefeller: "People give for one of two reasons: either because they believe the cause is a worthy one and will pay dividends in human betterment, or because a sense of duty impels them." In either case you must give them the facts on which to justify a favorable decision.

For six years now "Oceanus" has presented facts; we shall continue to do so to the best of our ability.

Don Fay



Cruise #13 of the R.V. Chain

DEPARTING ON JUNE 30th, the R.V. CHAIN will make a 4½ months cruise for Dr. J. B. Hersey's group in northern European waters. During part of the cruise the ship will work together with the new Norwegian research vessel HELLAND-HANSEN, the British "DISCOVERY II", and the "EXPLORER" of the Aberdeen Marine Laboratory.

The broad program of oceanographic investigations will include the study of bottom sediments, the subbottom and the earth's crustal structure. In addition routine observations will be made by continuous profiles of the ocean bottom, sound velocity measurements, and continuous charting of the upper water temperatures with the thermistor chain towed to a depth of 450 feet.

The heat flow from the earth's interior through the sediment will also be measured, and a sediment core will be taken at the same places. Scattering layers will be investigated by acoustical methods, while the Mid-Atlantic Ridge will receive another intensive probe in our continuing investigation of this enormous submerged mountain range. Bottom photographs and dredge hauls will also be made, as well as seismic reflection studies.

Finally, the continuous seismic profiler (an electric spark device developed by the Hersey group to obtain a profile of the subbottom sedimentary layers) will be extensively used. In shallow water rockbed will be reached with this method. Some locations in northern waters were suggested by European scientists to help in their work.

During the first half of the cruise, students will provide needed manpower and receive in return an introduction to these phases of field work. The CHAIN will be present at Helsinki during part of the meetings of the International Union of Geodesy and Geophysics.

Chief scientists during parts of the cruise will be: Dr. J. B. Hersey, Earl E. Hays, and R. H. Backus.

The Ocean

as the

ATMOSPHERE'S FUEL SUPPLY

BY JOANNE S. MALKUS

From cloud drop to hurricane

ONE of the techniques developed by meteorologists today is how to evade or face the question "What can be done about controlling the weather?" The substitute answer that most research meteorologists have learned to recite by heart is the cliché: "First a great deal more fundamental research needs to be done before any such attempts can or should be made". This leaves no one much more enlightened and probably does little to narrow the gulf between the scientific specialist and the person outside the field, whether he be press representative, politician, military man, or interested citizen.

If we explore the heart of this dichotomy further — that is, the apparent discrepancy between the question and the pat answer — by a series of further questions which gradually become more specific, we are led right into the heart of marine meteorology and the subject of the interaction between ocean and atmosphere. In other words, starting from the general question which has been stirred up in many people's minds, we shall find ouselves led to framing the very questions that the workers in marine meteorology, many of them at Woods Hole, have been attempting to formulate and answer long before the subject of weather control reared its head — and thus impelled by a quite different motivation.

What questions ought we to ask if we wish to consider the possibility that man may some day influence, affect, or regulate the behavior of some parts of his atmosphere? Where do we begin? What do we need to know first?

We are often told that the atmosphere is a vast and inefficient heat engine— that the motive power for all its winds, jet streams, and storms ultimately comes from the sun's heat, which is distributed unequally over the globe, with equatorial regions receiving more radiation energy than the poles.

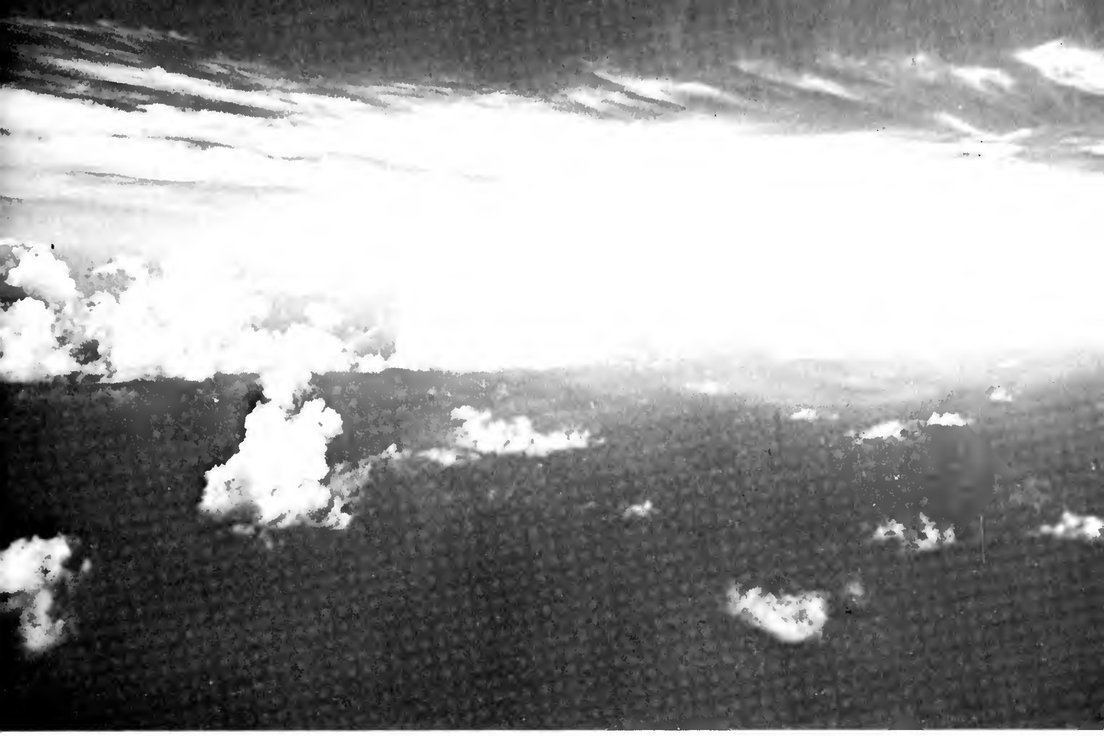
In itself this 'heat engine' statement doesn't get us very far, although it can serve the important purpose of leading us to the next link in a chain of increasingly informative questions. We say that the motions of the atmosphere are ultimately driven by heat. The most basic question to ask is, therefore, how is heating converted into motion in a fluid? This question is so basic, in fact, that it underlies not just meteorology, but much of oceanography, astrophysics, geophysics, and engineering. The conversion of heat energy into fluid motion is even at its simplest, a difficult process to understand. In the complicated, rotating turbulent atmosphere with many sizes of motions, and complicated boundaries, a direct attack is prohibitive. We must first seek the simplest examples of heat driven fluid motions that we can find, where the essentials can be isolated. In these prototype systems, quantitative relations between heat transfer and motions can be established by mathematical deduction from physical laws and the resulting predictions can be tested by controlled laboratory measurements. Quite a few such examples are being conceived and studied by the theoretical group at Woods Hole. Strangely enough, one of the classical examples of such a hydrodynamic heat engine is very closely illustrated by the motions going on in a coffee cup. The patterns of light and dark lines which one often sees if one pours in the cream without stirring, outline organized regions of ascent and descent — there are "cells" in the shapes of squares, hexagons, sometimes other polygons or regular many-sided figures. This pattern of motions is maintained because of the cooling of the coffee from above — the fluid has found the most effective way of moving to transport its heat upward from the bottom. Theoretical studies enable us to predict or forecast what size and shape these many-sided cells will take, and the size and location of the up and down motions, when we are told initially what kind of fluid we have, how deep it is, and how its boundaries are confined.

DR. MALKUS, well known meteorologist on our staff, has flown many miles in our aircraft and on Navy planes to study the weather as it happens. A profile on Dr. Malkus was published in the April 20th edition of "Science World".

Rotating coffee

Our theoretical group has brought this example a great step nearer to real geophysical phenomena by studying the modifications introduced when the coffee cup is on a rotating platform, as the real ocean and atmosphere are on the rotating earth. The resemblance which then arises between the model and some real atmospheric and oceanic circulations becomes exciting and suggestive. More important than resemblance, however, is that this type of study provides a language, a way of asking questions, and suggests those questions which are fruitful to ask, and guides as to the relationships and variables which are worth measuring. The fantastic labor and expense involved in making and evaluating oceanographic and meteorological measurements makes it imperative that we select the critical things to measure, and avoid collection of reams of irrelevant data.

But it is important to point out that even the simplest fluid heat engines are *not* simple. We have been able



C. Ronne

Endless miles of tropical ocean normally are covered with puny cloudlets. Most clouds remain small and stunted with their tops at about 5,000 feet and rarely exceeding 8,000 feet.

to obtain these coffee cup circulations with the aid of complete mathematical solution and prediction. If I attempted to explain the difficulties we had to overcome and the exciting results, this article would not get to the real atmosphere. So, let us proceed by a crude analogy to the method of progressing by successive questions from the known to the unknown and start from a heat engine we all know, namely the automobile. Suppose we are Martians freshly deposited on earth and confronted with a motorcar. If our nature resembles human nature, we are challenged both to understand and to control its operation. The first question we would probably ask is "What makes it go — what is its fuel supply and where do we get it? How is this odd fluid called gasoline utilized to drive the motion of the wheels?" Applying this to the atmosphere, it is safe to say that the gasoline, the gas stations, and the fueling process are now fairly well described. Crudely stated, the fuel is sea water and the gas station the tropical oceans.

The heat energy supplied by the sun is not taken in directly by the air itself, but passes straight through it to be absorbed by the earth's surface. The tropical regions, which are largely ocean, receive the lion's share of the heat energy. Sea water, in evaporating, takes up heat from the sun-warmed ocean and puts it into the air — but in hidden or latent form, which only turns into actual heat when the water vapor is condensed and returned into liquid water — it may be carried about in latent form by the winds for a long time before this actually happens. Thus the atmosphere is fueled from below, and the fuel gets into the overlying air largely in the form of evaporated sea water. The ability to carry around stored fuel is quite a neat complexity that the simple coffee cup heat engines do not have, and which introduces untold difficulties in the face of a quantitative mathematical description.

Qualitatively, however, we are now making progress. Having asked and answered a specific question based on our experience with the automobile, namely, what is the fuel for the atmospheric heat engine, we have now paved the way for the next specific question, namely how and where is the fuel combusted? In the automobile, the fuel is carried from the gas tank to the cylinders, where it is burned or exploded. The combustion creates a pressure, which eventually drives the crankshaft and wheels. In an automobile, the cylinders are all the same size, fixed in number, and regular, we hope, in their operation. What about the cylinders in the atmosphere?

Heat release

Actually our question and answer about the fuel pointed the way to the next question and answer. The latent heat in water vapor is released when the water vapor condenses into actual drops of liquid. We know how the atmosphere does this — it makes clouds, and when the clouds make rain, the water is returned to the sea and the released heat is left in the air. Thus the rainmaking process is of much more than agricultural importance to man. It doesn't just water his crops, but also releases the heat that drives the wind and governs the climate and weather. However, this proceeds in a roundabout manner. Most of the water vapor collected over the tropical oceans is first carried into equatorial regions by the tradewinds. There it is condensed by huge towering clouds, called cumulonimbus, which look like our enormous thunderheads that sometimes build on summer afternoons. The equatorial zone is, in a real sense, the firebox of the engine and the huge clouds are cylinders, in that they convert stored fuel into heat and the heat into pressure head. The steps from the release of this energy by rain clouds over the tropical oceans to winds and storms over the middle latitudes are long and complicated; the energy must undergo many transformations and transportations before it builds the fluid pressures that drive distant winds, more chains of gears and linkages are involved even than those between the cylinders and wheels of a motorcar — but we have now focussed attention on an essential link in this process.

We have been looking at a basic energy release of the atmospheric heat engine, namely tropical rain, and upon the heart of marine meteorology, namely the ocean's role as the atmosphere's gas station. If we ponder here we shall soon come up with an interesting paradox, which probably some of you see already, if you ponder, as many summer vacationers have been unhappily forced to do, upon the topic of rain. This paradox is closely related to the subject of regulation or control which we raise initially. On even a cursory comparison between ocean and atmosphere, it strikes us forcefully that the ocean is much more constant in its structure and behavior than is the atmosphere. In the variable and notoriously fickle atmosphere the most variable and notoriously fickle feature is undoubtedly rainfall. Despite old wives' tales to the contrary, rainfall is particularly unreliable in the tropics. In beautiful Hawaii, immersed in the steady trade winds, a monthly or even annual average rainfall statistic means nothing — nearly all the rain in a given month falls typically on two or three rainy days, while the yearly average is built of four or five drought years plus one that is flooded. And therein lies the paradox.

The tropical oceans are particularly constant and uniform; evaporation of sea water into the air goes on regularly, monotonously and with little fluctuation in time or space. The ocean is a vast reservoir of heat and water, like a regulating flywheel with high inertia. Yet tropical rain is a sporadic, spasmodic see-saw between feast and famine, but with rare feasts and more or less continuous famine. What does this paradox tell us and what is the clue to unravelling it? Here is an engine, with a constant fuel supply and a vast reservoir of gasoline which is slowly and uniformly trickling in — and yet the combustion goes on in fits and starts and the wheels turn in an extremely jerky manner — why?

We have now come close to the frontier in marine meteorology and to studies in progress. Largely as the result of theoretical inquiries we are beginning to see some light. The jerky fits and starts in which the fuel combustion occurs, and the time scale of these variations suggests that the combustion elements are limited and variable in number, evanescent or short-lived, and are somehow organized into systems or galaxies which have a space scale of a few hundred miles and a life time of days. One of the exciting recent developments in marine meteorology has been the identification of the combustion elements as the towering tropical clouds.

"The lonely impulse of delight drove to this tumult in the clouds." (W. B. Yates). The photographer was moved to this quote while watching the growth of Typhoon 'Agnes'.

C. Ronne

Our theoretical work predicted that only 1500 to 5000 of these huge cumulonimbus clouds around the equatorial belt of the globe at a time would be enough to combust all the water vapor fuel imported by the trade winds. The updrafts in these giant chimneys, some ten miles high, would raise the combusted fuel to great heights, thereby balancing the local heat budget and supplying the leftover excess energy for export away from the equatorial zone, to drive winds and balance the heat budget in higher latitudes. This number of elements was quite a startling prediction, and, if true, fraught with implications. In such a limited population of cylinders, fluctuations of a few hundred members could give rise to noticeable jerks in the operation of the engine.

We needed to test the prediction, to count and map the large clouds in the equatorial regions. We also needed to know something about fluctuations, which meant repeated counts. Furthermore, we needed to know how these huge clouds were organized into groups, since the variability of tropical rain suggest that the individual cylinders are bunched into discrete systems or galaxies. What are these systems, and how many large clouds are contained in each? Since such a relatively few elements do the combustion in this equatorial firebox region, might this be a link in the energy supply chain where human intervention could be contemplated? We have made a film of the tropical Pacific for a cloud mapping study. These movies were taken by C. Ronne and myself from a military cargo plane crossing the Marshall's area in the Pacific Ocean. The plane flew at 8000 ft. and our time-lapse camera, aimed due north at right angles to the fuselage, took one frame per second so that when projected at the normal 16 frames per second, we shall appear to be flying at 3000 miles per hour. The cloud maps we constructed from these films showed that all giant clouds and significant rain were concentrated in restricted regions — namely tropical storms, with wind circulations resembling waves or vortices — about one in a hundred of these blows up in runaway growth into a hurricane. The results of this and others of our tropical cloud studies led to some exciting work on hurricanes, which we shall describe in a future issue of *Oceanus*. The section of film shows the breeding ground active in the pre-hurricane stage. At other times this breeding ground is totally inactive and only stunted clouds and clear skies are found. Giant clouds grow only in the storm areas, which contain 200 — 300 active towers at once, and the intermittency of these storms is thus responsible for the jerkiness of the combustion. The relationship between tropical clouds and these vortical storms is the next unknown frontier to be pursued.

Martian flies

In conclusion, let us return to our automobile analogy, and re-assess, now that we know a little about the fuel and its combustion, our Martian's chances of being able to operate the car. One very important factor has been left out of the analogy until now, namely the amounts of energy involved. A single one of the giant clouds you see on the photo, releases in its few hours of life as much energy as several atomic bombs, and a single tropical storm burns up 50,000 — 100,000. It might not be totally facetious to conclude our analogy by reducing our Martian friend to the size of a fly and then re-examine his chances of learning to drive.

Game Fish Studies

TWO bluefin tuna tagged and released in 1954 off No Mans Land, Mass. were recaptured in August 1959 by French fishermen in the Bay of Biscay. One tuna grew from an estimated 18 pounds to about 150 pounds in its five years of freedom. This exciting news was of great interest as most biologists hold to a theory that the eastern and western Atlantic bluefin populations are distinct races. Apparently, they do intermingle.

After years of tenacious work and patient waiting the efforts of hundreds of co-operating sports fishermen have started to bring results. Since 1954, when Frank J. Mather III of our staff started the game fish tagging program, some 766 tuna, 1000 white marlin, 475 Atlantic sailfish and 230 Pacific sailfish have been tagged, as well as smaller numbers of other gamefish. Obviously, biologists have neither time, nor the money to do much tagging, nor are many excellent anglers, as Mr. Mather is. We are most grateful that hundreds of sportsmen have become interested in the program and have released so many fish. In some tournaments the organizers now award points and prizes for tagged and released fish.

The returns have shown that some original fears — that released fish might not survive after the struggle of capture and wounding by the tag — were groundless. All three types of tags in use have been among the recoveries.

Species of fish	*Tagging date and locality*	*Recapture date and locality*
White marlin	July 11, 1955 Ocean City, Md.	July 18, 1959 Ocean City, Md.
Sailfish	Nov. 1954 — Jan. 1955 Stuart, Fla.	Jan. 12, 1956 Islamorada, Fla.
Bluefin tuna	Aug. 11, 1957 Chatham, Mass.	Aug. 30, 1959 Gloucester, Mass.
Bluefin tuna	July 27, 1954 No Mans Land, Mass.	Aug. 16, 1959 Bay of Biscay Off Bilbao, Spain
Bluefin tuna	July 25, 1954 No Mans Land, Mass.	Summer of 1959 Bay of Biscay
Bluefin tuna	May 24, 1959 325 miles east of Ocean City, Md.	Aug. 20, 1959 Provincetown, Mass.
Sailfish	Jan. 28, 1958 Palm Beach, Fla.	Jan. 14, 1959 Stuart, Fla.
Sailfish	Feb. 5, 1958 Palm Beach, Fla.	April 19, 1959 Hillsboro Inlet, Fla.
Sailfish	Feb. 12, 1960 Palm Beach, Fla.	May 22, 1960 St. Petersburg, Fla.

Associate Fellowships

The Woods Hole Oceanographic Institution Associates' Fellowships for the academic year 1960-1961 have been awarded as follows:

Mr. David A. McGill, 252 Terrace Park, Rochester, New York; in the Department of Zoology, Yale University. This is a renewal of last year's fellowship.

Mr. Bruce A. Warren, 71 Chester Street, Arlington 74, Massachusetts; in the Department of Geology and Geophysics, Massachusetts Institute of Technology.

Mr. Norman S. Neidell, 78 Forest Street, Providence, Rhode Island; in the Departments of Physics and Geology, Brown University.

These fellowships, supported by funds contributed by the individual and corporate Associates of the Institution, are awarded annually to full-time graduate students at any suitable institution. The awards, judged by the Fellowship Committee of the Institution, are based on academic excellence and on promise of outstanding contribution to any aspect of marine science. This year, for the three awards, twenty-eight applications were received from this country and abroad. Since most of these were of very high quality, the choice was difficult, and the group above is one of which the Institution is especially proud.

Institution Fellowships

SINCE 1930, the Institution has awarded a number of Fellowships each summer to attract promising students to Woods Hole during the summer months. For many years the funds for this program came from our endowment income. Although we shall continue to do so, a recent grant from the Ford Foundation has made it possible to enlarge this invaluable program. Oceanography cannot expand through financial support alone, we must be able to attract bright and brilliant students to continue our advances.

Recipients:

Robert A. Berner, Harvard University, Graduate.
Robert R. Blandford, California Institute of Technology, Graduate.
William Blumen, Massachusetts Institute of Technology, Graduate.
Richard A. Cone, University of Chicago, Graduate.
Ronald L. Duty, Brown University, Graduate.
Walter Eckhart, Yale University, Senior.
Robert Ellis, Miami University, Senior.
Michael E. Emptage, Middlebury College, Senior.
Augustine S. Furumoto, St. Louis University, Graduate.
Kenneth I. Gross, Brandeis University, Senior.
William R. Holland, University of California, Graduate.
David T. Mason, University of California, Graduate
John P. Kerr, University of Michigan, Graduate.
Dennis W. Moore, Harvard University, Junior.
Gilbert S. Omenn, Princeton University, Junior.
Bernard L. Oostdam, McGill University, Senior.
Joseph Pedlosky, Massachusetts Institute of Technology, Graduate.
Judith Sandberg, Hahneman Medical College, Graduate.
Bruce A. Taft, Johns Hopkins University, Graduate.
David G. Towell, Massachusetts Institute of Technology, Graduate.
Bruce A. Warren, Massachusetts Institute of Technology, Graduate.

Recent Books

"The Earth Beneath the Sea,"
by Francis P. Shepard.
The Johns Hopkins Press,
Baltimore 18, Maryland. $5.00

FRANCIS SHEPARD has phrased into very non-technical terms a summary of Marine Geology. He writes with familiarity of his subject based on a lifetime devoted to study of the sea.

The book is particularly good for laymen. It provides a good coverage of marine geology and is interestingly written. Students who read this book should keep in mind that it is not meant to be an exhaustive treatment of the subject, consequently no effort is made to review all ideas about a particular subject. The book is not without its provocative side, particularly when discussing turbidity currents where the point of view is taken that some of the classic examples of turbidity current effects can be explained in other ways.

The book is worth having for its point of view and is particularly valuable when someone asks, "What can I read to give me a general idea about the earth beneath the sea?"

Dr. Shepard is Professor of submarine geology at Scripps Institution of Oceanography. For 35 years he has been active in field investigations on ships and on beaches.

J. Z.

"Marine Boring and Fouling Organisms." A Symposium, edited by Dixie Lee Ray, University of Washington Press. $8.50

We have not seen this book, but from the publisher's description it appears to be a useful addition to the field of marine fouling. The outcome of a Friday Harbour Symposium it is, of course, a technical publication. Now that millions of Americans have taken to the water, it may be expected that the annual economic damage to boats, pilings, etc. will increase enormously. A chapter on economic implications and evaluations is included.

J. H.

"Oceans,"
by Ernst Behrendt.
Nelson Doubleday, Inc., New York.

This small, richly illustrated paperback is an excellent introduction for the young reader. Prepared in cooperation with Science Service, "Oceans" is one of a series of science booklets. One might wish that the text were not so abbreviated. On the other hand, the publication provides an excellent answer to the perennial request: "Please send me some pictures to illustrate a term paper."

J. H.

New Corporate Associates

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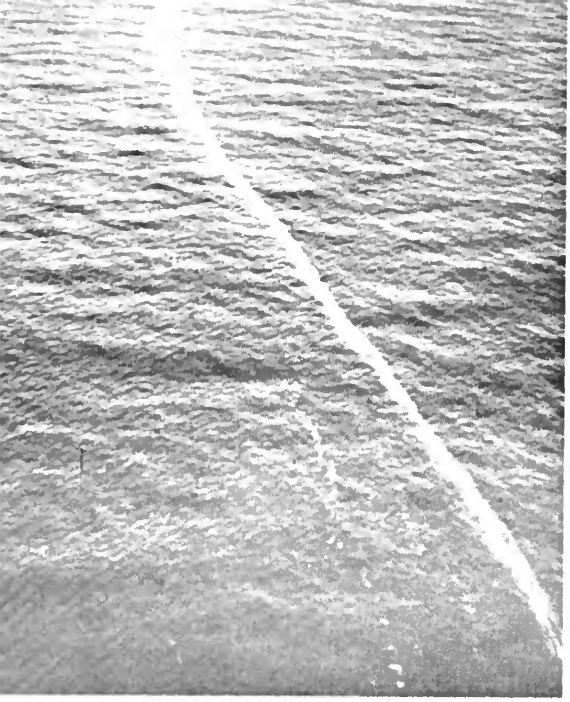


Appearance of the Gulf Stream's Edge on a Calm Day off New England

The U. S. Navy Air Development Unit based at South Weymouth, Mass. has been kind enough to fly our oceanographers over the Gulf Stream south of Cape Cod and eastward to 55° West longitude. On clear days with light wind the edge of the Gulf Stream is clearly demarked as shown by the different in tone or by a long streak of foam as shown in the above photographs. Sometimes with wind of 10 to 15 knots there is a different sea state on the two sides. We are also flying an airborne radiation thermometer which enables us to obtain an indication of the temperature of the water on both sides of the visual marking. The difference of temperature this time of year on the two sides of this marking are as much as 10 degrees Fahrenheit. In both cases shown above, the cold inshore water is on the left hand side; the warm Gulf Stream water is on the right.

he Gulf Stream

An ambitious program just completed may give us a better idea of the "best known" ocean current system.

THE sea observations for the most ambitious study of the Gulf Stream system ever undertaken were completed by mid-June with the return of our research vessels ATLANTIS, (Captain A. D. Colburn, Jr.) CRAWFORD, (Captain D. F. Casiles) and CHAIN, (Captain S. H. Hiller). Extensive observations were made during the past 2½ months in an area between the 52nd and 69th meridians, and between latitudes 45° North and 33° North.

Since the days of Ponce de Leon, the Gulf Stream has fascinated laymen and scientists alike and many studies have been made in attempts to understand the Stream. Yet, we are far from having an accepted theory of the stream's nature and operation.

Most of the studies — starting in 1844 with the work done by the U. S. Coast and Geodetic Survey under the direction of Franklin's great grandson, A. D. Bache — have been of the survey type. Generally these surveys were carried out between the Straits of Florida and Georges Banks.

Over the years the portion of the Gulf Stream System east of New England has received little attention. The Canadians have studied the area adjacent to the continental shelf while the Woods Hole Oceanographic Institution and the International Ice Patrol have worked on the western and eastern extremities but the main body of the system has been generally neglected.

In June, 1950, a short but intensive study (Operation Cabot) was made of the Gulf Stream in this area. Six ships were used to follow the Stream. Meanders in the current and the formation of a huge cyclonic eddy were observed. Unfortunately, this study which followed the Stream from Cape Hatteras to the Grand Banks lasted only seventeen days. Most of the work was confined to the study of a single current. The whole concept of the operation and even the interpretation of the data was based on and influenced by the concept of a single, continuous and uninterrupted current, the Gulf Stream. Time did not permit a study of the environment of this current nor, consequently, of what is now referred to as the Gulf Stream System.

Aside from this six ship operation, the only other sources of information on this area under discussion are charts showing average conditions and profiles from occasional lines of hydrographic stations. It is known that the average charts give no inkling of the abrupt gradients and swift, narrow currents and countercurrents that exist in the area. The sections of hydrographic stations, on the other hand, have been so dispersed in time and space that although they show quasi-synoptic conditions they do not give a three dimensional representation of the system.

Multiple currents

We know that more than one current is involved in the system and that the Gulf Stream System may be more complex than is generally supposed. There is good evidence that the so-called branching of the Gulf Stream to the east of the Grand Banks actually starts before the current reaches that longitude and that this "branching" is not a simple dividing of the Stream but is much more complicated. The program discussed here was planned and carried out, not as a survey but to test the multiple current hypothesis.

In order to obtain, for the first time, a three dimensional picture of the physical properties of this portion of the Gulf Stream System it was planned first to make a systematic series of hydrographic stations from the surface to the bottom over the whole area. Three lines of stations were run concurrently and nine sections, reaching from the continental shelf south to the 33d parallel of latitude were occupied. At each station, Nansen bottles were lowered to obtain water temperatures, salinities, oxygen values and various other chemical data at 25 different levels. Frequent or continuous temperature observations of the near surface layers were made with the bathythermograph and the thermistor chain, while continuous echo sounder profiles of the ocean bottom were also made. The U. S. Coast Guard cutter EVERGREEN (with oceanographers of the International Ice Patrol stationed at Woods Hole on board) occupied two shorter lines of stations south of the Grand Banks.

This part of the study took about three weeks, whereupon the ships made a rendezvous at Bermuda. The enthusiasm and zeal of the scientific parties and crews of our ships not only had caused the vessels to keep to their tight schedules — although several storms were encountered — which enabled as close a synoptic survey as possible of this region; but also the scientific data had all been analyzed, a process which normally takes many months in the laboratory after the return from a cruise. This was due to various circumstances.

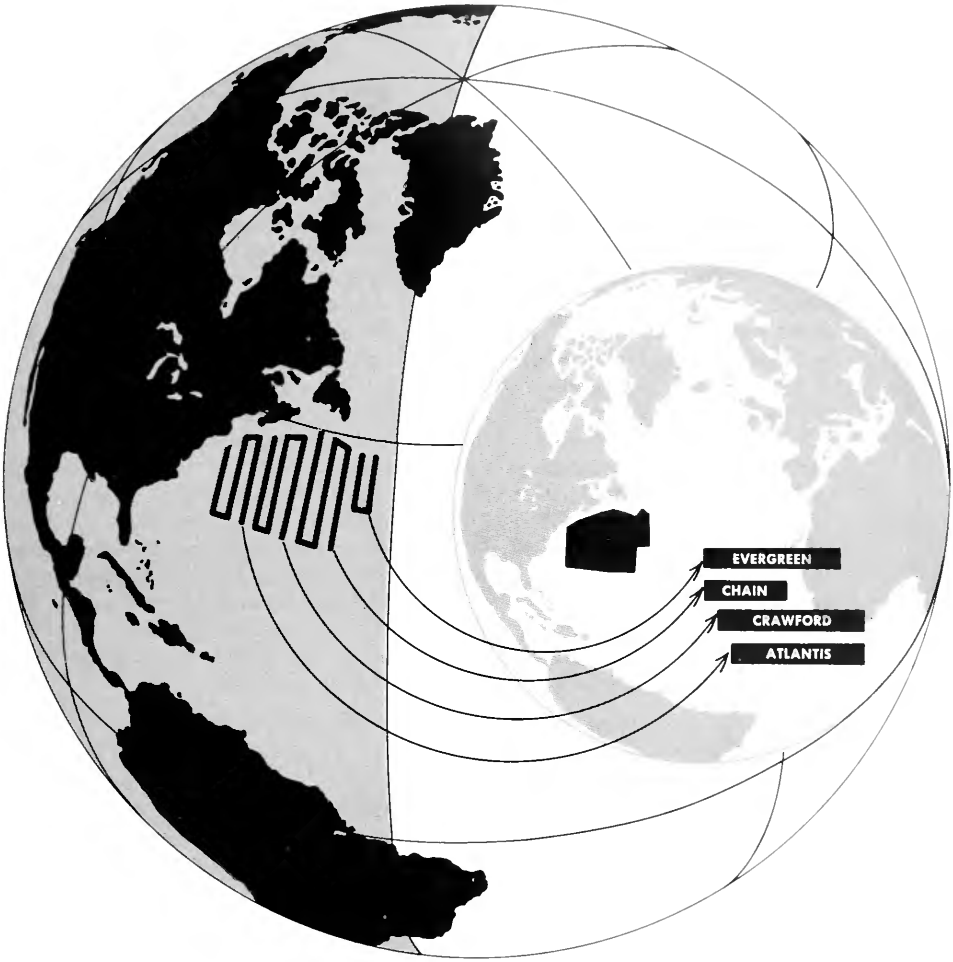
1. The competition between the parties on the ships particularly on the ATLANTIS, as both scientists and crew were doing all they could to prove that the ATLANTIS, regardless of impending retirement, is more fit than any other ship to do this type of work.

2. The salinometer (Oceanus, Vol. VI, No. 3) which has made it possible to work up the salinities after each station rather than bringing thousands of water samples back for titration at Woods Hole.

And girls!

3. Last, but not least, the presence on board the CHAIN of two old "hands" at working up data at Woods Hole; Eloise Soderland and Lorraine Barbour. The girls worked some 10-14 hours a day to keep up with data radioed in from the other ships and those taken by the CHAIN.

The relatively dense network of observations in the first part of the cruise delineated the major currents



The first part of our Gulf Stream Survey covered an area of about one half million miles.

Inserted is the general area covered while testing the multiple current hypothesis.

and showed the general distribution of physical properties in the area. However, it is certain that the results will raise many more questions about existing conditions than will be answered. There is the question of the time rate of change. There are areas of uncertainty where the correct interpretation of the data is in doubt.

There are anomalous observations that may or may not be valid. In spite of the relatively dense network of stations there were areas where a need was felt for more closely spaced observations. Apparent meanders in the currents and eddy-like structures demanded further investigation.

The second part of the study was planned at Bermuda on the basis of the results of the first cruise. This second cruise, which was also approximately three weeks long, was quite different in character from the first. On the basis of the knowledge gained, the three ships were concentrated in the most interesting areas. With the use of towed thermistors and with the bathythermograph and a knowledge of the environment, hundreds of miles of currents were followed and mapped in a relatively short time. The movements of eddies and meanders were followed. Time consuming, deep observations were only made at certain critical points.

At the conclusion of the second cruise the ships again met in Bermuda and the results were reviewed. Again, on the basis of these results, the third cruise was planned. At the time of going to press we did not know the plans for the final stages of the study.

At the end of the three month period a complete picture of this important segment of the Gulf Stream System should be available. It will only cover the spring season but valuable knowledge should have been gained on the rate at which conitions are changing during this period. The beginning of the seasonal cycle of warming in the surface layer was observed over a large area. The large number of traverses that were made in the region will certainly produce some new and interesting observations on the bottom topography. This type of multi-ship operation may be of extreme interest in defining the value of the single ship programs which have been carried out in the past.

A shock for our English friends

"THE Gulf Stream is not a river of hot water flowing through the ocean, but a narrow ribbon of high velocity water acting as a boundary that prevents the warm water on the Sargasso Sea side (right hand) from overflowing the colder, denser waters on the inshore (left hand) side.

There is scarcely any more firmly rooted idea in the mind of the layman than the notion that the Gulf Stream keeps the European climate warm. So long as it was believed that the Gulf Stream was a "river" of warm water, this idea did make sense. It is no longer possible to be so certain of the direct climatological influence of the Gulf Stream, for it now seems that it is not so much the Stream itself that is important, as the position and temperatures of the large mass of warm water on its right-hand flank.

In fact, Iselin went so far as to speculate, in 1940, that warming of the European climate might actually be least during periods of increasing transport of the Gulf Stream.

For all we know, the European climate might be warmer if the direction of rotation of the North Atlantic Eddy were reversed."

The above is quoted from: H. Stommel. "The Gulf Stream, a physical and dynamical description," Univ. of California Press, 1958. ($6.00). This book provides a survey of the technical aspects of the Gulf Stream System.

Some statistics:

R. V. ATLANTIS:	9 scientists, 19 officers and crew
R. V. CRAWFORD:	8 scientists, 15 officers and crew
R. V. CHAIN:	15 scientists, 29 officers and crew
U.S.C.G. EVERGREEN:	7 scientists, 55 officers and crew
P2V aircraft:	2-5 scientists, 4 officers and crew
	44 scientists, 122 officers and crew

Scientific observations:

1st part of cruise only

ATLANTIS:	54 hydrographic stations
CRAWFORD:	62 hydrographic stations
CHAIN:	67 hydrographic stations
EVERGREEN:	31 hydrographic stations

A total of 214 stations each occupying about from two to four hours time, collecting a total of 5200 temperature observations and 5200 water samples in an area of about ½ million square miles during twenty work days. It is interesting to note that ATLANTIS may have reached her 5000th "station" by the end of the cruise. This will mean that the ship in her 30 year career spent a total of some 2½ years hove-to on station. This does not take into account stations for bottom coring, etc.

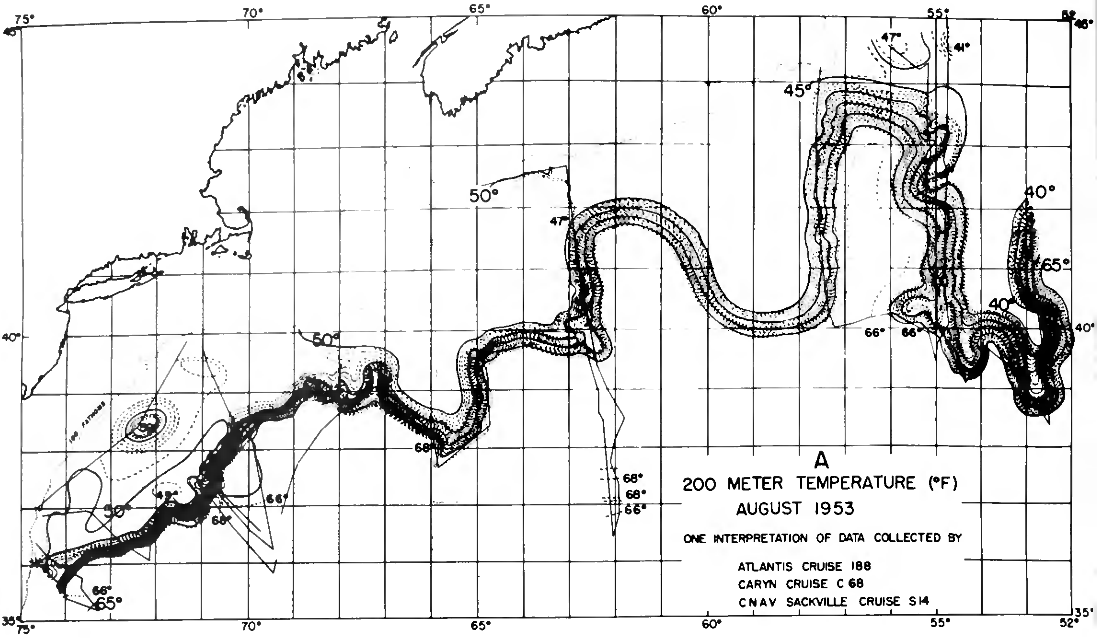
Intership voice communications were made twice a day and station results were forwarded daily to Woods Hole by radiogram.

The airplane flew some 30,000 miles to obtain sea surface temperatures, to watch the Stream visually whenever possible and to locate buoys set out by the ships.

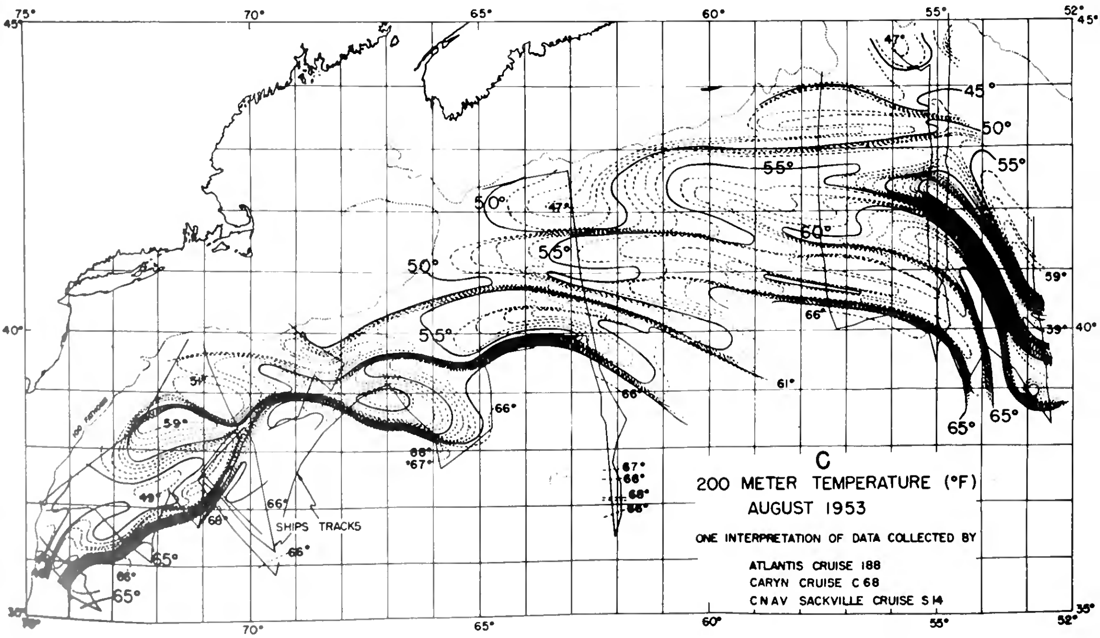
Personnel:

The program was under the overall supervision of Mr. F. C. Fuglister who has developed the multiple Gulf Stream System hypothesis. Others participating were: Messrs. L. V. Worthington, W. G. Metcalf, A. R. Miller, Henry Stommel and Drs. W. S. von Arx, and W. S. Richardson, all of our staff in addition to many others.

Dr. Paul M. Fye, our director, took part in the third cruise on board the R. V. CHAIN.



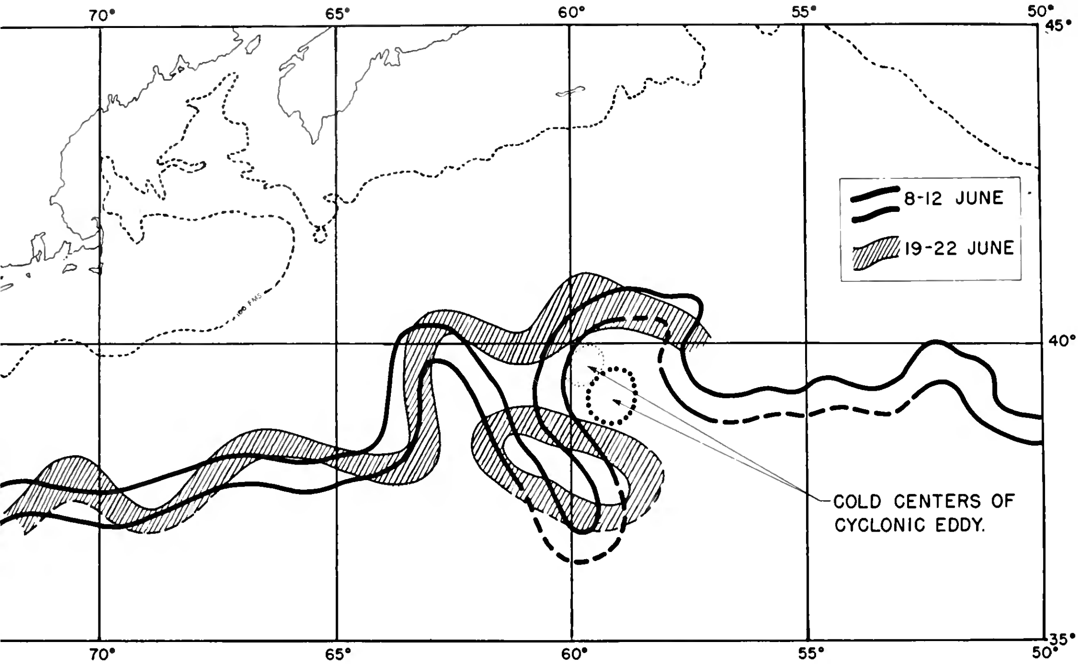
These two views of the Gulf Stream System were drawn from the same set of observations. At the depth of 200 meters the temperatures are not influenced by seasonal fluctuations. The single current idea is shown above. The current often appears to follow the ship's tracks, indicated by solid lines. Below: the multiple current hypothesis, showing a series of currents overlapping like shingles on a roof. The temperatures are in degrees Fahrenheit.



Fuglister

Hahn

"In sight!" With this warning to the winchman to slow down, a wet and miserable observer has just sighted the next Nansen bottle coming up on a hydrographic station.



The rate of change in the Stream was indicated during a two week period when six ships were investigating the current in 1950. The long loop broke off and formed an eddy which moved counter-clockwise.

The Gulf Stream System

BY C. O'D. ISELIN

ALTHOUGH the scientific history of the Gulf Stream was reviewed by Stommel in 1950, so much field work has been carried out since then that there is a good deal that can be added to his excellent account of the gradual evolution of our understanding of the problems presented by this most spectacular of ocean currents.

Since the pioneering study of Benjamin Franklin, there have been three main observational approaches to the problems of the Gulf Stream. The first was the statistical approach and, until very recently, this was limited to surface observations. Through the leadership of Matthew Fontaine Maury, surface temperature observations and reports of surface currents experienced by navigators have been collected during the last century in ever-increasing quantities. These data were averaged by season and later by month, and also, as they increased in quantity, by smaller and smaller units of area. The most modern example of such a statistical picture of the surface characteristics of the Gulf Stream was published by Fuglister in 1957. This is the sort of information shown in atlases of the ocean and is the basis of the generally accepted view that the Gulf Stream gradually broadens and weakens as it flows northeastward from Cape Hatteras toward the southern limits of the Grand Banks. As we shall see, and as was indeed pointed out by Fuglister, there are serious limitations to the statistical approach, for northeastward from Cape Hatteras the average Gulf Stream bears little resemblance to the one existing at any given time.

The second approach, which was employed vigorously during the 1930's, was to observe in cross section the distribution of temperature and salinity down to depths of 2,000 meters or more. The net result of these temperature and salinity profiles was to show that the current was considerably narrower and swifter than indicated by the statistical surface charts, that it varied in transport seasonally, and perhaps over longer periods, and that major disturbances, possibly large eddies, were commonly present on either side of the current.

After World War II, when field observations could again be resumed, two new tools were available, which permitted a quite different approach. The greatly improved navigation afforded by Loran made it possible to estimate continuously the direction and velocity of the surface current being encountered by the research vessel. Thus, it was possible to maneuver in and out of the current on short tracks so as to track some features of it for considerable distances in the downstream direction. Furthermore, the development of a diving thermometer that could be used underway permitted the continuous observation of temperature down to a depth of 900 feet. The usefulness of these new techniques was first reported by Iselin and Fuglister in 1948. It was soon shown that a major and hitherto unexpected feature of the Gulf Stream northeastward from Cape Hatteras was its meanders. Moreover, the current was again shown to be narrower and swifter than had been generally believed possible.

Almost simultaneously, von Arx developed a new and powerful method of observing surface currents from a ship underway. This depended on the electric potentials induced by the movement of the water through the earth's magnetic field.

Operation Cabot

In June 1950, it became possible to employ six ships simultaneously during a three-week period for a coordinated survey of the Gulf Stream between Cape Hatteras and the Grand Banks. All three new techniques; namely, Loran Navigation, the bathythermograph, and the geomagnetic electric kinetograph, were exploited to the utmost. Some of these results were reported by Fuglister and Worthington, and by von Arx. The six-ship survey, known as Operation Cabot, which was organized and directed by the U. S. Hydrographic Office, besides confirming the general conclusions of the previous single-ship surveys showed that the waves forming just east of Cape Hatteras as they develop into meanders move slowly downstream and the details of the detachment of a large offshore meander south of Halifax were observed during a twelve-day period. Perhaps even more significant was the indication that two distinct Gulf Streams passed the tail of the Grand Banks.

Puzzles

By this time the modern students of the Gulf Stream had become thoroughly puzzled. On theoretical grounds, Stommel and Munk had been able to show that narrow swift currents were to be expected in the western part of each ocean, and Haurwitz and Panofsky were more or less able to account for the development of the meanders eastward from Cape Hatteras, but none of the available theory in any way suggested that a second warm current might develop north of the primary Gulf Stream.

In June 1951, this new feature was followed from off southern New England eastward to the Grand Banks area so that there is no longer any doubt that it is a continuous warm current, rather than a series of clockwise eddies, which one encounters along the Nova Scotian continental slope. In fact, the 1951 observations suggest that a third and similar filament of warm water develops inside this one as it crosses over to the Grand Banks. Thus, it is now thought that eastward from Cape Hatteras the warm water does not flow as a single current, but as a series of overlapping currents arranged somewhat like the shingles on a roof. In some manner, as yet by no means fully understood, the countercurrent along the inshore edge of Gulf Stream No. 1 drains off warm water and momentum, and transfers it to Gulf Stream No. 2, just to the north. Further eastward this in turn supplies Gulf Stream No. 3. Data gathered last summer by ALBATROSS III east of the Grand Banks indicate that this process may continue to at least mid-ocean and possibly farther. Thus, it is indeed fortunate that of recent years we have begun to speak of the Gulf Stream System, for the old statistical Gulf Stream is not one gradually widening and weakening current, but a series of overlapping, narrow, swift streaks of flow.

The original need for the term Gulf Stream System was that on a statistical basis the Gulf Stream appeared to branch after passing the tail of the Grand Banks. Three main branches seemed to be involved. We now see that this process has its origins well to the westward of the Grand Banks and that it is not really branching in the ordinary sense, but the development of a series of new currents, each to the north of the older ones. Much the same phenomena seem to be present in the jet streams found at high elevations in the great belts of prevailing westerly winds of mid-latitudes, although each atmospheric jet has greater dimensions than the overlapping subdivision of the Gulf Stream System.

Interpretation

It must be admitted that considerable uncertainty still exists in the proper contouring of the recent temperature surveys. Proceeding at the rate of about 200 miles a day, and without any clear picture of what lies ahead, the oceanographer cannot so choose his courses on the basis of the observed temperature and surface current that there can be but one interpretation of the survey. If he follows each minor loop encountered, he cannot develop the larger picture. On moving from warm water to colder water and then back to warm water again, he does not know for certain that he is back in the same warm current. He may have found a new warm streak or an isolated eddy. To overcome this basic difficulty, it is hoped that in the near future means can be developed to observe surface temperature from a plane.* At 1,500 miles a day, the interpretation of Gulf Stream temperature surveys should be much less uncertain, especially if a plane and a ship can be used together. Once the basic pattern of the Gulf Stream System has been worked out and once we know more about the rate of change of this pattern, the ship can be used again with confidence to develop details and to extend the survey into the third dimension.

Now, what can be said about the rate of change of the complicated pattern of flow making up the Gulf Stream System? Operation Cabot showed that a period of about ten days is required to produce as much change as occurs ordinarily in one day in the swift currents of the upper atmosphere. This is, of course, only one observation, but it seems reasonable in view of the huge amounts of momentum involved in ocean currents and their relative slowness compared with the winds, that changes in what might be termed "the weather map of the ocean" would be much slower than in the atmosphere. Thus, the synoptic oceanographer, when he comes into being, will perhaps have an easier or at least a more leisurely task than the weather forecaster.

To understand a phenomenon as complicated as the Gulf Stream, we must first be able to describe it accurately. Thus, for some years to come field observations must be continued and means must be developed to secure continuous data at a few critical points in the system, at least.

Obviously, physical oceanography still has a long way to go before oceanic circulation is thoroughly understood. Nevertheless, having recently broken away from studies of the unreal, average ocean, we can expect rapid progress to continue.

*This method was developed at Woods Hole. See: Oceanus, Vol. IV, 4.

This article was adapted from a paper by Dr. Iselin in: *"The Proceedings of the American Philosophical Society"*, Vol. 96, No. 6, 1952 and is reprinted with the Editor's permission. Some changes were made in this article and some technical details were omitted.

J. H.

NATO Advisory Committee on Oceanography.

Dr. Iselin returned from the first meeting of the NATO Advisory Committee on Oceanography, held at Paris. He reported that the meeting was interesting and exciting to the participants in that NATO support may be the means by which European oceanography will regain its pre-war vigor.

The forthcoming cruise of the R.V. "CHAIN" to northern Europe (see page 2) will give our European friends the opportunity to inspect our largest ship and the oceanographic methods and instruments developed at Woods Hole.

Currents and Tides

Oil pollution at sea is a grave problem, particularly for sea birds and bathers. Mr. R. G. Mackey of Texaco Oil Co., Chairman of the A.P.I. Oil Pollution Panel, visited the Institute to discuss the possibility of an oil slick "watch" off Nantucket this summer.

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Drs. Iselin, Ketchum, Redfield, Spilhaus, Carritt, Riley and Mr. Vine testified recently before a U. S. Senate Committee holding hearings on Bill No. S. 2692. Introduced by Senator Warren G. Magnuson and co-sponsored by 13 other senators the Bill proposes a national oceanographic program as outlined in the reports published by the NAS-NRC Committee on Oceanography.

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Mr. A. L. Downing, of the Water Pollution Research Board of the United Kingdom also visited Dr. Ketchum.

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Dr. Willem V. R. Malkus and his wife Dr. Joanne S. Malkus have accepted respectively the post of Professor of Geophysics and Professor of Meteorology at the University of California. They have accepted nine months appointments and plan to be at Woods Hole during the summer months.

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Dr. John M. Zeigler was appointed lecturer of the University of Chicago, Department of Geology. He will not teach a course for the present but will work to increase cooperation between the Institution and the University and will also act as student adviser.

As during the past four years, Henry Stommell and Jan Hahn will advise the Bermuda race participants on the location of the Gulf Stream. The 600 mile Newport—Bermuda race is held every other year.

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The Institution supplied a large number of photographs, graphs, charts and models, for an international oceanographic exhibit to be held at Trieste and at Bari, Italy. The exhibits are sponsored by the U. S. Information Agency.

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A forthcoming issue of LIFE magazine will contain a double page spread on the "Atlantis - Discovery" Gulf Stream investigation and other illustrations on oceanographic research. The preparations for this article have been going on for a year.

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Dr. Iselin flew to Paris late in May to attend the first formal meeting of the NATO advisory committee on oceanography.

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The "Spencer F. Baird" of the Scripps Institution of Oceanography, University of California, is scheduled to make a cruise to the Caribbean Sea in November.

We used to speak of our ocean and *their* ocean. Since "Atlantis" has been to the Peru-Chile region and in the Indian Ocean we suppose Scripps wants to retaliate.

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