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WOODS HOLE OCEANOGRAPHIC INSTITUTION

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WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

R 6391

Reference No. 52-11

OCEANOGRAPHIC RESEARCH

conducted during the period

October 1, 1951 - December 31, 1951

Periodic Status Report No. 22
Submitted to Geophysics Branch, Office of Naval Research
Under Contract N6onr-27701 (NR-083-004)

January 1952

APPROVED FOR DISTRIBUTION ____________________
Director

[redacted]

According to the terms of Contract N6onr-27701 (NR-083-004), the work to be performed by the Contractor shall consist of the following:

1. The Contractor shall furnish the necessary personnel and facilities for and, in accordance with any instructions issued by the Scientific Officer or his authorized representative, shall

(a) conduct research, analyze, and compile data and technical information, prepare material for charts, manuals, and reports, and foster the training of military and civilian personnel in the following fields of oceanography:

(i) permanent currents;
(ii) interaction of the sea and atmosphere (including wind waves, swell, and surf);
(iii) the distribution of physical properties;
(iv) the distribution of chemical properties;
(v) the distribution of organisms;
(vi) the characteristics of the sea bottom and beaches;
(vii) tides, tidal currents, and destructive sea waves; and
(viii) the physics and distribution of sea and terrigenous ice.

The research shall include, but not necessarily be limited to, the following:

(1) studies of North Atlantic oceanography;
(2) wave observations and analysis;
(3) current measurements;
(4) studies of Arctic oceanography;
(5) development of unattended instruments;
(6) thermocline studies; and
(7) studies on inshore oceanography.

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INTRODUCTION

During the past year observations made by our ships, by air plane, and by drift bottles again brought us much nearer to being able to describe the actual temperature distribution in the Atlantic Ocean. We have come a long way to show that the actual conditions differ markedly from the statistical ocean. The inter-connected studies of the major currents, coastal and Arctic currents, and estuarine effluents, as well as the model studies and the development of unattended and new shipboard instruments, all are bent to the ever-nearing goal: the reliable description of the system with which we are dealing. The field investigations have shown that the old picture of the ocean, based on statistical information is entirely inadequate.

The increasingly detailed observations of actual conditions made it possible to describe rather adequately the behavior of the Gulf Stream between Cape Hatteras and the Grand Banks. A new hypothesis, proposed in the first quarterly report this year, concerning the manner in which the Gulf Stream breaks down into more than one current in mid-ocean, was strongly supported by observations made on Cruise A-41 of the research vessel ALBATROSS III. As usual, however, the observations showed that the system was more complex than had been thought and posed more questions than had been answered. It is increasingly apparent that one ship at a time cannot hope to deal with the details of the large scale phenomena to be investigated.

During the same cruise, the Gulf Stream was followed as far as longitude 23 W. and was shown to remain narrow and meandering, but well-defined, to that longitude. Although the vessel was plagued by bad weather and other difficulties, she obtained a larger number of observations than have been made on any other single-ship cruise.

The planning of the Trade Wind cruise, a two-ship investigation of the Equatorial currents, went rapidly forward during the last quarter. The physical, chemical, and meteorological data to be collected during this cruise will close the ring of the North Atlantic observations.

Theoretical studies of G.E.K. measurements have led to a better understanding of the capabilities and limitations of the G.E.K. It now appears that several new measurements may be obtained by electromagnetic observations, including the estimation of the mean volume transport of strong permanent currents.

Meteorological studies of the Bermuda-Azores High cell also showed the dangers of the statistical approach. It was shown that the mid-ocean wind patterns could be classified into various, more or less permanent, systems, none of which resemble the mean winds. Further study of the high pressure cell, the relation between the Trade Winds and the Equatorial currents, and the air transport from and to the Arctic may shed light on the fluctuations of the permanent currents.

The model studies of tidal flushing were encouraging and led to an understanding of many phenomena in two-layer systems. A major report on these studies is in preparation. The model study of oceans appears promising, although the type of model is so unusual that a thorough investigation of both the scaling laws and experimental variables has to be undertaken.

The efficiency of the salinity titration and thermometer calibration departments was increased again during the past year so that there is no backlog in either department.

Additional oceanographic observers were trained during Cruise A-41 of the ALBATROSS III, and during a course given at the laboratory in preparation for the Trade Winds cruise.

As of January 1, 1952 it is proposed to re-name these quarterly reports from "Oceanographic Research", to "North Atlantic Oceanography under Task Order I".

STUDIES OF NORTH ATLANTIC OCEANOGRAPHY

The Gulf Stream System. Cruise #41 of the ALBATROSS III was concluded 31 October. During this cruise which started 6 June, 3,122 bathythermograph observations were made, nearly all to a depth of 200 meters; 1,131 current fixes were obtained with the G.E.K.; and 26 hydrographic stations were occupied.

Considerable trouble was given by the pressure elements of the 900-foot bathythermographs. In most cases the bellows developed leaks at the soldered joints and filled with water. Of twelve 900-foot instruments used on this trip, all became malfunctional at some time but some could be repaired at sea. It was found that sometimes a leak developed in the "pigtail", (the length of lead tubing used in evacuating the bellows). This condition can be rectified by removing the pressure element and extruding the water from the bellows by compressing it manually. When all the water has been pumped out, the "pigtail" is removed and the aperture soldered. However, all repairs at sea are undesirable as they may affect the instrument's calibration. As a result of this cruise a representative of Wallace and Tiernan came to Woods Hole for a detailed examination of the instruments with our engineers. He and they are confident that future trouble of this nature can be minimized.

The processing of the bathythermograph data is nearly completed and study of the corrected values has been started. On the basis of uncorrected data, the chart (Fig. 1) has been drawn showing the temperature at 200 meters for the northern parts of the cruise. It appears from this data that the current remains narrow and meandering but well-defined as far as longitude 23 W. It must be emphasized that while the 200-meter temperatures give a clear definition of the location of the current, the crosscurrent surface temperature gradients are negligible. Apparently wind circulation and air temperatures flatten out the surface values.

During this cruise, for the first time, marked disagreement took place between the G.E.K. current directions and the 200-meter temperature contours. In some cases, they ran counter to each other and in one case a consistent current in excess of 20 cm/sec (about 1 knot) was found where no temperature change in the upper 200 meters was found. It is hoped that detailed examination of the data will throw some light on these discrepancies.

Of further interest is a large anti-cyclonic eddy centered at 50°30'N, 44°00'W. The ALBATROSS III had circumnavigated this eddy when she had to return to St. John's to land a sick man. When she returned to the same area eight days later the eddy had rejoined the Stream.

East of 23 W. no clear definition of the current was found. It appears to have broken up but this impression may be due to the ALBATROSS' being forced away by bad weather from the area of most interest.

There is some evidence of a northerly current in longitude 26 W. During the investigation of this area, winds of force 6 or more were experienced for four out of seven days with a maximum wind of force 10. Wave heights were estimated at 35-40 feet. Further work in the northern area was not permitted by the Captain of the ALBATROSS III.

Attempts to trace more southerly branches of the current on the return trip were not wholly successful. Currents were in evidence in some cases in excess of 50 cm/sec., but their complexity was such that several interpretations of their nature are possible. In effect it was not possible to study such a large area with a single ship to the extent desirable. Between the Azores and Bermuda about four days were lost while running away from the path of a hurricane, and another two days were spent hove to in a westerly gale.

It is felt that in spite of many difficulties the cruise contributed substantially to our knowledge of the Gulf Stream System and that further cruises can now be wisely planned to observe its less known features in more detail.

200-Meter Temperatures Studies. Unfortunately, it was possible for Mr. Metcalf to devote only little time to a continuation of the 200-meter temperature studies described in the preceeding report in this series. Several more profiles from other mid-North Atlantic areas disclose that in 75-80% of the cases studied the depth of the 27.2 isopycnal and the 200-meter temperature increase and decrease together, though not necessarily proportionately.

Attention was then turned to the more northern areas. Here, the situation was complicated by the fact that in many cases the greatest interest is in the cold currents, and these generally are shallow and lie close to shore, so the 200-meter temperature is frequently unobtainable. Also, in these cold currents, the 27.2 sigma-t layer is so shallow as to come under the influence of surface warming and cooling and mixing by high winds.

However, in a series of sections across the northern half of the Labrador Current, it appears that the relationship between the 200-meter temperature and the 27.2 isopycnal is vague. (The 27.6 isopycnal was also used but the results are virtually the same.) In about half the cases, the two factors increased and decreased together, and in the other half they did so in opposition to each other.

In a group of sections across the southern half of the Labrador Current, the increased effect of the North Atlantic water from mid-latitudes made the relationship between these two factors lie about midway between the relationship found in the northern portion of the current and that found at mid-latitudes.

Although this study has not been carried far enough to demonstrate this feature fully, it is felt that interesting possibilities are suggested by the information gained so far.

Trade Wind Cruise. Considerable time was spent during the quarter in preparing for a two-ship survey of the Trade Wind area of the North Atlantic. The ALBATROSS III and the

ATLANTIS will take part in the cruise which will last approximately three months starting in mid-January 1952. Figure 2 shows the tentative tracks of the two ships with approximate distances and days at sea.

The objectives of the survey are to:

1. Cross the central North Atlantic where the preliminary Sonar Charts indicate "best" conditions.

2. Cover the West African area to locate the sources of the Northern Equatorial Current, and study Sonar conditions in that area.

3. Study in detail the North Equatorial Current and its relation to the Northeast Trades.

4. Make four long sections crossing the North Equatorial Current, the Countercurrent, and the Guiana Current.

5. Collect numerous bathythermograph observations to 900-foot depths in the southeastern North Atlantic.

6. Test new oceanographic instruments.

7. Obtain data of the distribution of oxygen, nitrate, and phosphate.

8. Make Sofar bomb drop tests.

Comparison of Winds, Tide Gauge Readings, and Surface Currents. As reported for the previous quarter, the work on the Bermuda-Azores High Pressure Cell led to the measurement of wind vectors in the Trades and Westerlies around that cell. Some comparisons of wind vectors, tide gauge readings, and surface currents were mentioned and of these the fourth; namely, a comparison of Trades plus Westerlies with the difference in sea level between Bermuda and Charleston, seemed most promising for further study. It was noted that while this relationship is close for long-time averages it breaks down to about half-time agreement when data from any single year are used.

Since comparison number three; namely, that between the Trades plus Westerlies and the height of mean sea level at Galveston, is in agreement with number four, Mr. Chase continued the work on both relationships. Comparison number three also breaks down for single year data.

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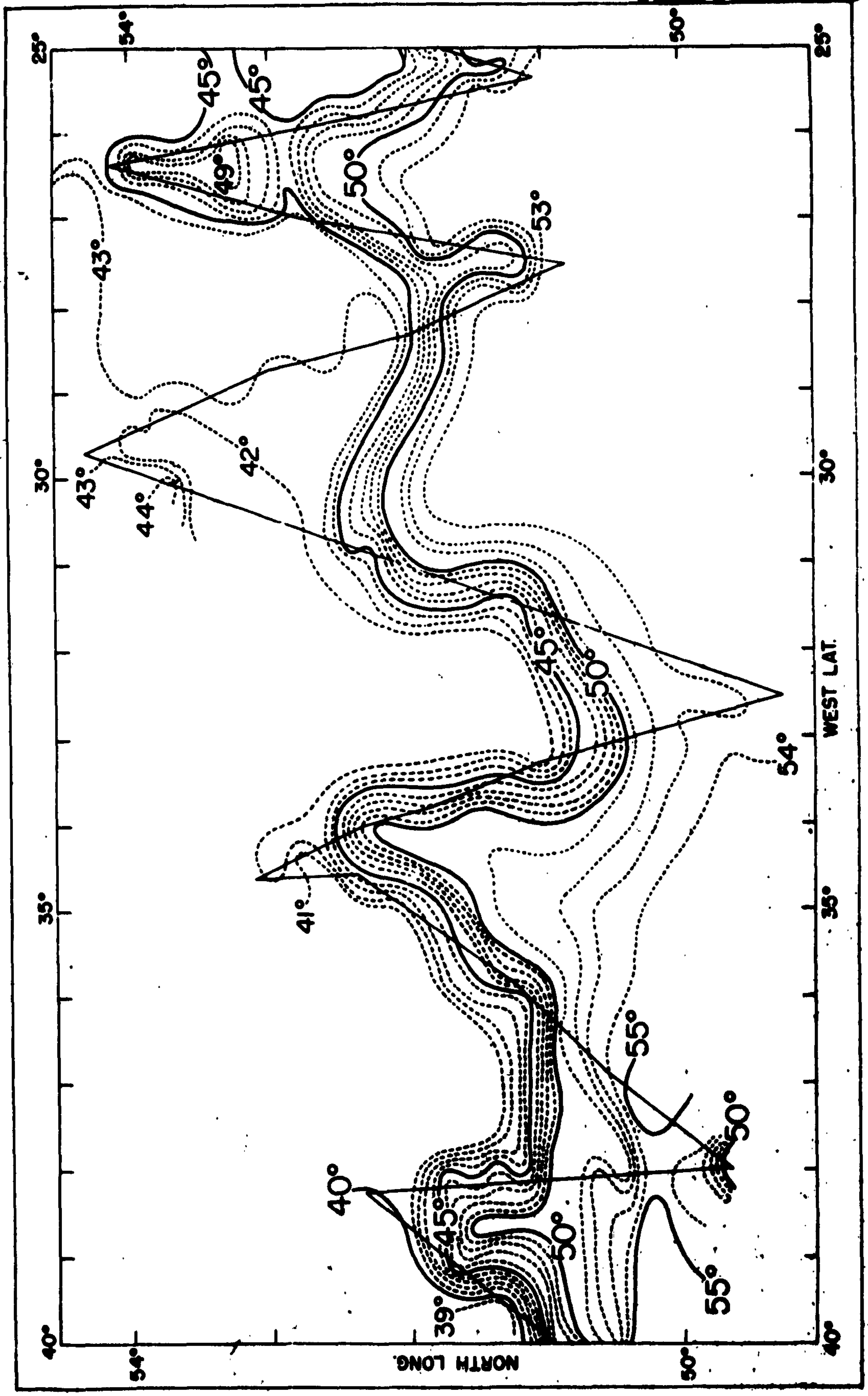

Fig. 1

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TRADE WIND CRUISE
WINTER 1952

	ATLANTIS ———			ALBATROSS - - - - -		
	MILES @ 8 kt.	STA. @ 2 hr.	DAYS	MILES @ 10 kt.	STA. @ 2 hr.	DAYS
WOODS HOLE - BERMUDA	650	0	3½	650	0	3
BERMUDA - DAKAR	4320	30	26	4140	30	20
DAKAR - DAKAR				1680	22	9
DAKAR - RECIFE	2160	22	14	2400	22	12
RECIFE - TRINIDAD	3900	4 days + 11 sta.	25	3600	4 days + 26 sta.	22

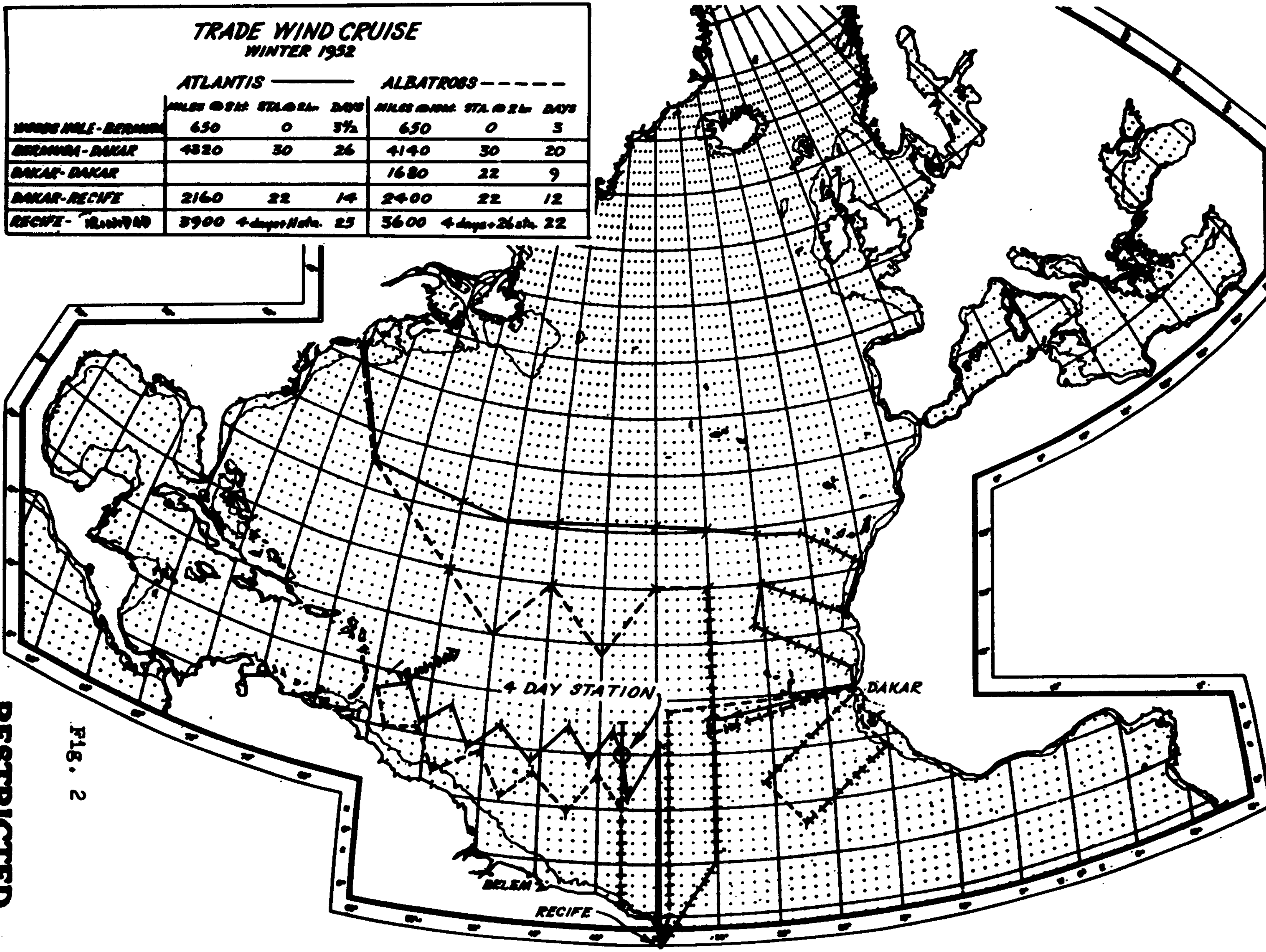

Fig. 2

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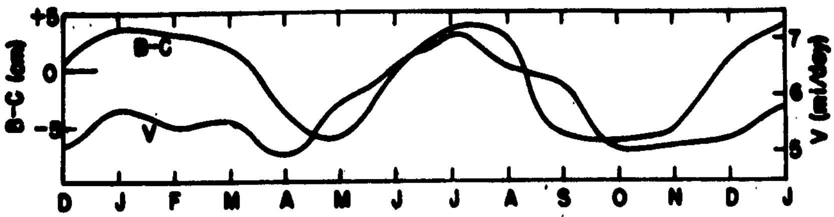
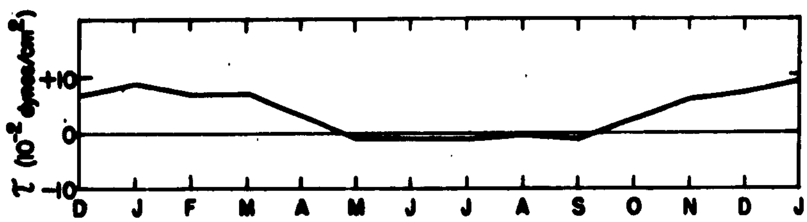


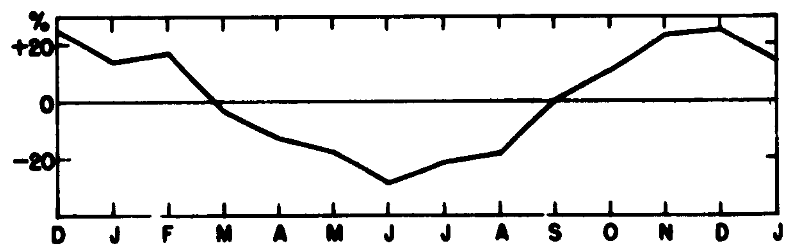
B-C = Difference in sea level BERMUDA-CHARLESTON.
V = Northbound components of surface current 29°-33° N. LAT.

A



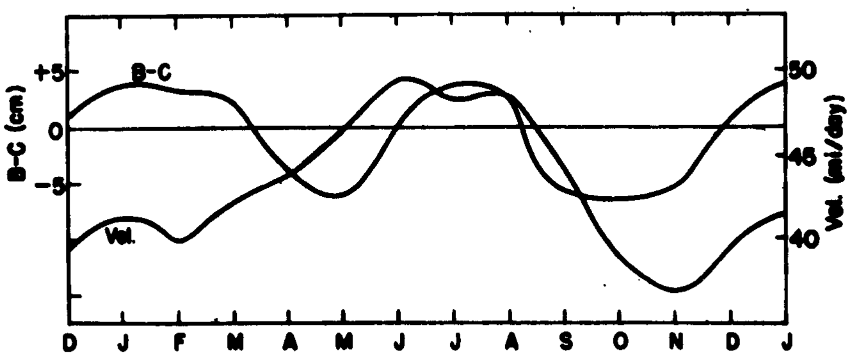
Offshore stress CHARLESTON area.

B



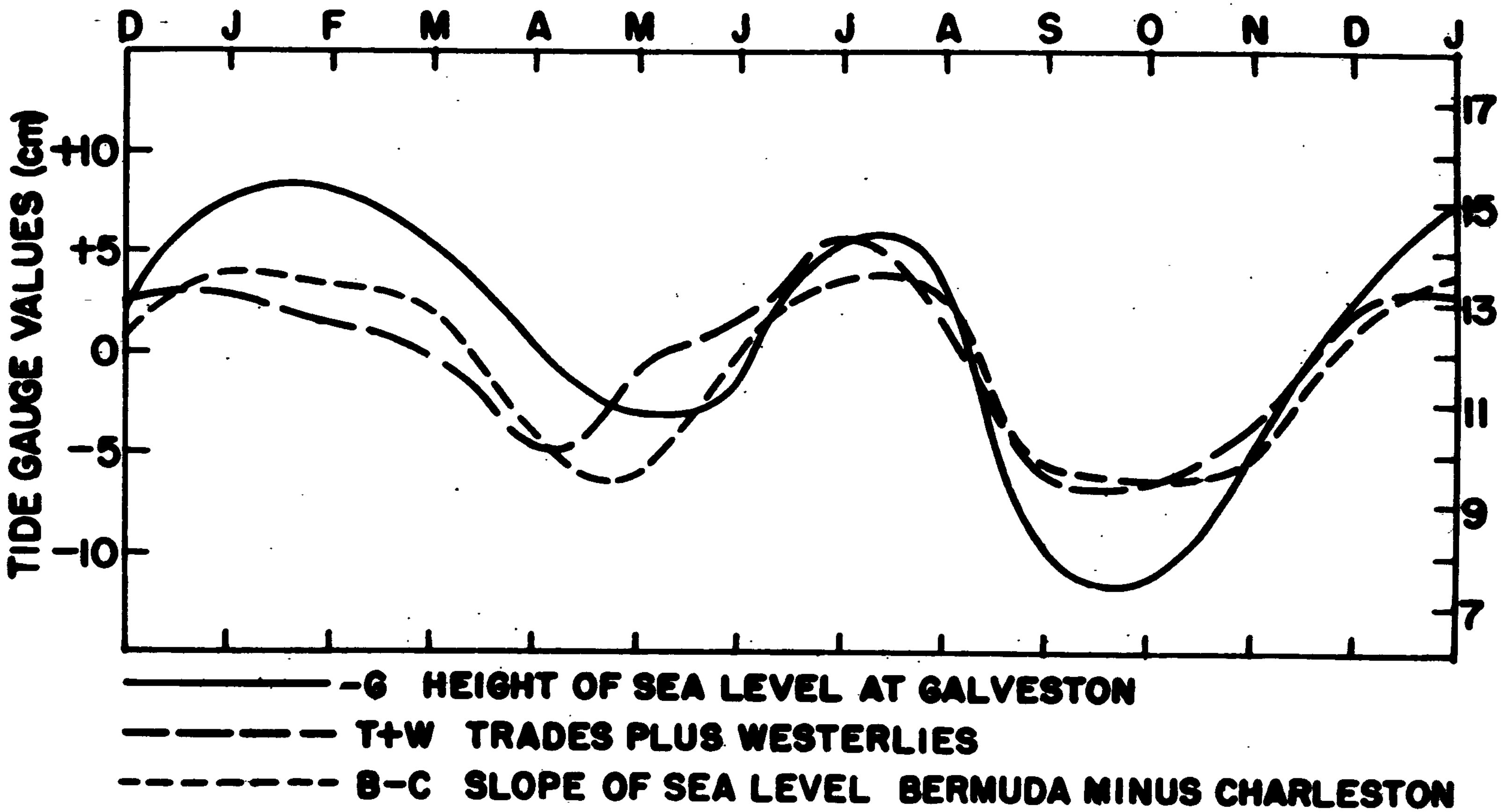
Percentage frequency of net offshore winds at CHARLESTON 1931-1938.

C



B-C = Difference in sea level BERMUDA-CHARLESTON
Vel. = Velocity of surface currents south of HATTERAS. (after Fuglister)

D



LONG TIME AVERAGES

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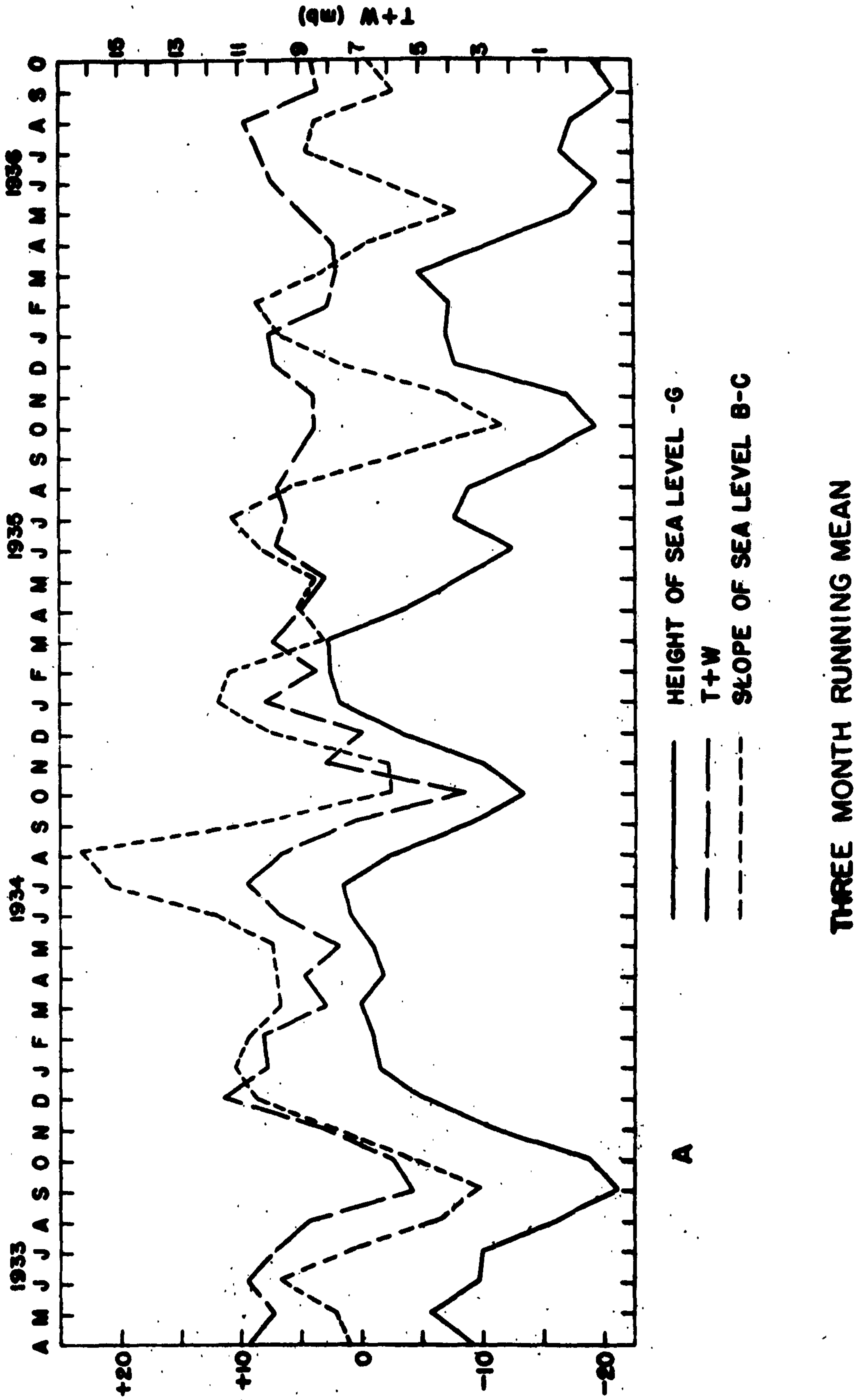

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These breakdowns suggest the short period influence of extraneous variables. Such variables might be:

a. The effect of local winds at the tide gauges.

b. The location of the template relative to the varying positions of the center of the Bermuda-Azores High.

c. The ratio of geostrophic wind to surface wind and to stress.

d. Rainfall and runoff in the vicinity of the tide gauges.

e. The effect of currents below the wind-driven layer.

f. The effects of radiation and evaporation on the density of small patches of water advected to the gauges.

g. The effects of water from the South Atlantic and from the coastal waters to the north.

To average out some of the effects of these variables three-month running averages for Trades plus Westerlies, Bermuda minus Charleston and minus Galveston were computed and plotted. The agreement is generally good between the three curves. The long-time average values of Bermuda minus Charleston differ from the values for:

1. the northbound component of surface currents in the area between Bermuda and Charleston and

2. the velocities of surface currents in a segment of the Gulf Stream south of Hatteras,

by amounts which correspond generally with on- and offshore wind and stress data from the Charleston area.

The curve of northbound currents (1 above) is very similar to those for the Trades area currents, the center pressure of the Bermuda-Azores High, and the Trade Wind components.

It might be expected, then, that a three-month running average of the Trades would compare favorably with that for Bermuda minus Charleston when allowances were made for on- and offshore winds at Charleston. This proved not to be the case. One cannot be sure, then, which of the two (Bermuda minus Charleston or Trades), if either, can be used to follow surface current values in the Bermuda-Charleston area.

The work on these comparisons will be discontinued for the next quarter due to the participation of Mr. Chase in the Trade Wind Cruise.

File of Historical Weather Maps. Daily maps for the quarter have been added to the collection. None of the gaps listed in last quarter's report have been filled.

Current Measurements with the G.E.K. Recently, theoretical study of the errors and meaning of electromagnetic measurements has been taken up by Messrs. M. S. Longuet-Higgins, Melvin E. Stern, Henry Stommel, and Dr. Willem V. R. Malkus. Their results are in general agreement with the large numbers of observations obtained in June and October-November 1950 in the Gulf Stream, (see WHOI Reference No. 51-96) and shed new light on the capacities and limitations of the G.E.K. Their work suggests that the integrated errors of electromagnetic measurements along the surface represent the mean velocity of flow through the vertical plane containing the line of observations, provided the currents are sufficiently parallel and the observations transect the current system. In mid-latitudes in the regions of strong "permanent" currents, the errors may be large enough to be measured with useful precision by existing navigational and G.E.K. equipments, and if the depth of water is also measured, the mean volume transport may be obtained. Preliminary trials of the method based on existing Gulf Stream data have yielded credible results in approximate agreement with those obtained by the method of dynamic sections. If means can be developed to make precise the necessary measurements of small differences between large integrated quantities, work with the G.E.K. in both shoal and deep water may assume a changed significance.

Malkus and Stern have investigated some further properties of the induced electric field in ocean situations which suggest new kinds of measurements that may be useful especially in low latitudes and which make use of the horizontal component of magnetic flux.

STUDIES OF ARCTIC OCEANOGRAPHY

Arctic Field Observations. In October the Hydrographic Office disclosed plans for an Arctic cruise early in 1952 to the Greenland-Iceland area. Mr. Metcalf went to Washington to discuss these plans in late October. Much of the rest of the quarter was spent preparing for this cruise and further visits were made to Washington and Boston. By the year's end, final preparations were completed and the cruise was scheduled to start on 7 January 1952.

In the meantime, Mr. Holmes and Mr. Worthington were preparing for another phase of Operation SKIJUMP for the purpose of obtaining oceanographic information in the Arctic basin. They plan to operate out of Point Barrow, Alaska, and to land on the Arctic pack in an R4D aircraft. On this operation, the Navy is providing a P2V aircraft to support the oceanographic plane and transport gasoline and other supplies to the polar pack stations. It is hoped that the scope of the operation can be increased materially over last year's program.

Early in November, Metcalf and Holmes attended an Arctic Conference in Washington called by the Office of Naval Research. The results of the past twelve months of Arctic oceanographic studies were reviewed and discussed.

Relation between North Atlantic Ice and Arctic Weather.

A. Relation of the surface temperature in the area of the North Atlantic warm drift to the following ice in the Greenland Sea.

In an attempt to determine to what extent, if any, the surface temperature of the North Atlantic warm water is related to the following ice conditions in the North Atlantic-Arctic, Mr. I. I. Schell computed correlations between the mean April-July ice cover of the Greenland Sea and the mean annual surface temperature in areas: E, F, G, H, I, J, K, L, M, N, after Smed (1948-1950), 1, 2, 3, and 4 years before. The areas chosen (Fig. 3) may be assumed to lie totally or in part in the path of the North Atlantic warm water moving in a general northeasterly and northerly direction.

The correlation coefficients obtained (Table 1) are quite small and suggest that the rise in the surface temperature of the North Atlantic warm water would seem to be overshadowed by other factors affecting the ice of the Arctic. Yet, it may be noted that the correlation coefficients of the ice with the temperatures 3 and 4 years earlier are mainly negative in sign which may be considered an expression of the normal tendency of above average temperatures, for example, to be followed by a lesser than usual amount of ice. The assumed interval of 3 to 4 years for the warm water south of Iceland to reach the Greenland Sea by way of Spitsbergen is not inconsistent with the 2 to 3 year interval claimed by Zubov (1945) for North Atlantic warm water off the Lofotens to reach northeast Spitsbergen.

That the surface temperatures of the warm North Atlantic water may play only a minor part in the extent of the ice cover is not surprising, because a greater than usual transport of this water northward is probably more important for

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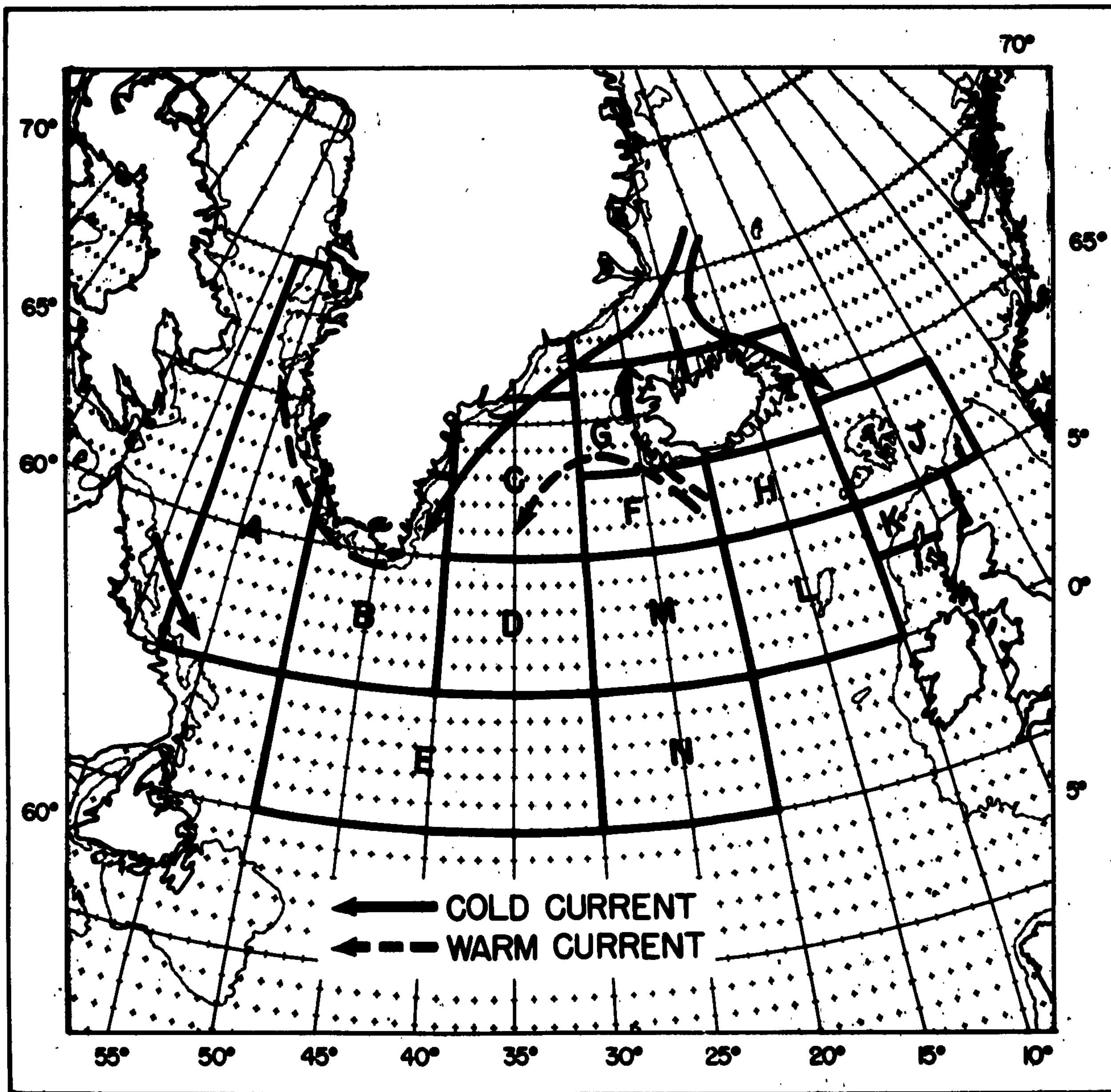

Fig. 3 Areas E, F, G, H, I, J, K, L, M, N (after Smed) lying totally or in part in the path of North Atlantic warm water bound northward.

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the ice development, than a lessened transport of warmer than usual water.

The implication from the above that a decreased transport of warm North Atlantic water may be accompanied by above average temperatures lends some weight to Iselin's conclusions (1940) that a weaker than normal circulation in the area of the Bermuda High leads to a diminished banking of the North Atlantic warm water to the right, allowing warmer than usual water to spread northeastward. A consideration of the northeastward water transport, together with the northeastward transport of warm air in the northern North Atlantic, may therefore well form the next phase of investigation of the relations with the Arctic ice.

TABLE I. Correlations of Greenland Sea Ice with the Average Annual Surface Temperatures of Northern North Atlantic Areas, E, F, G, H, I, J, K, L, M, N (after Smed) 1, 2, 3, and 4 years before (1879-1939).

Areas:	E	F	G	H	I	J	K	L	M	N
r	-.09	.16	.25	.10	.01	.07	.01	.08	.03	.10
r	.03	.10	.10	.13	.02	.04	.00	.02	.06	.12
r	.09	-.08	-.11	-.05	-.22	-.03	-.16	-.11	.04	.18
r	.01	-.12	-.09	-.17	-.25	-.14	-.30	-.24	-.10	-.03

B. Annual march of air transfer from and to the Arctic in relation to ice development in the Arctic.

Because of the possible bearing the annual march of air transport from and to the Arctic, and from and to the northern hemisphere as a whole, may have on the circulation and ice in the Arctic, an attempt was made to determine the monthly inflow and outflow of air, respectively, from the Arctic and the northern hemisphere from a consideration of one month's to the next month's changes in the normal mean monthly northern hemisphere sea level pressure distribution. Values of the net change in the mean monthly pressure from one month to the next for each 10° zone of latitude based on data 1899 to 1939, inclusive, were made available, thanks to the cooperation of Professor H. C. Willett of the Massachusetts Institute of Technology. From these values, the change in the average pressure for the northern hemisphere as a whole (north of 10° N.) and for the sector 60° - 90°N., which takes in most of the area containing the Arctic ice, were subsequently computed, due allowance being made in the computation for decrease of the total mass of air in each circumlatitude zone with increase in latitude. The values obtained for the northern hemisphere as a whole in millibars are shown in Table 1.

TABLE I. Mean monthly net air transfer from and to the northern hemisphere (10°-90°N) from one month to the next expressed as the average pressure change (mb.).

Jan.*	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0.4	-0.6	-0.3	-0.9	-0.7	-1.4	-0.4	0.3	0.9	0.9	1.0	0.6

* The month to which the change is reckoned. Thus, the change from December to January.

It appears that the net outflow of air for the hemisphere as a whole begins in February and the net inflow in August. This is the same as with the results previously obtained by Shaw (1936). However, the new figures exhibit a somewhat greater regularity in the rise and fall of the month to month air inflow and outflow, respectively, than Shaw's values. This may be ascribed to the more extensive material on which the recent results are based. (The inclusion by Shaw of data also for the sector 0 - 10°N. adjacent to the equator is unlikely to be a factor in the comparison here as the mass of air in that zone probably changes very little from season to season). It is of interest to note in connection with the results discussed here that the time of beginning of the outflow of air, for example, for the northern hemisphere as a whole in February is earlier than could have been expected from a consideration of the upward trend in temperature of the earth's surface which occurs in March.

Because of roughness of the data north of 75°N., the values for the sector 60° - 90°N., which includes the Arctic, were first smoothed as running means of 3. The average change in pressure from one month to the next for this sector turns out quite differently than for the hemisphere as a whole. Comparing two sets of values together (Table 2), the inflow of air into the Arctic appears to continue through March, which is the month of the year with the greatest ice cover in the Arctic, while for the hemisphere as a whole the inflow we have seen ceases with the month of January. Similarly, the return inflow of air into the Arctic does not begin before the end of September, which coincides with the month of the least ice cover in the Arctic. Thus, the return flow for the Arctic is again about two months later than for the hemisphere as a whole. The apparent relation between the development of ice cover in the Arctic and the march of air from and to the Arctic sector (60° - 90°N.) suggests that there may also be a relation between the changes in the ice cover and air transfer from year to year.

TABLE II. Mean monthly, month to month, net air transfer from and to the Arctic sector (60°- °N) compared with the transfer for the northern hemisphere as a whole (10°-90°N) expressed as the average pressure change (running means of 3).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
60-90°N	1.1	1.0	1.0	0.0	-1.8	-2.2	-1.8	-0.5	0.0	0.9	1.4	1.4
10-90°N	0.0	-0.2	-0.6	-0.6	-1.0	-0.8	-0.5	0.3	0.7	0.9	0.8	0.6

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STUDIES OF INSHORE OCEANOGRAPHY

Surveys of Atlantic Coastal Waters. Analyses of the drift bottle returns from the ALBATROSS III cruise of May 8-20, 1951, extending from Woods Hole to Cape Hatteras (see WHOI Reference No. 51-91) has been completed and a report by Mr. Miller is in the finishing stages. This will be submitted as a technical report during the next quarter.

Studies at St. Andrews, New Brunswick. Evaluation and analyses of observations made in the St. Croix River and exchanges of Passamaquoddy Bay by Dr. Ketchum in August of

1951 (see WHOI Reference No. 51-91) are now complete and will be the subject of a technical report which will be submitted during the next quarter.

DEVELOPMENT OF INSTRUMENTS

Unattended Instruments. Two conferences were held to determine the best way of recovering unattended instruments at sea. Following a suggestion of Mr. Iselin's, the main effort now is being directed toward the developing of a means of mooring buoys below the level of wave action in the deep ocean. Preliminary trials in Vineyard Sound, at a depth of 100 feet, have shown that such submerged buoys will survive severe winter storms and violent tidal currents for a long period, although moored with very thin wires (1/8" diameter).

It does not seem possible to locate them easily by sonar, but if they emit a small noise, such as the tapping of a hammer, they can easily be located and recovered (as we have shown by field tests), if their position is initially known within a radius of seven or eight miles. This should be an adequate margin, considering the uncertainties of deep sea navigation.

Several different types of noise makers are in production and we contemplate testing them all.

Five of the 400-day temperature recorders, designed by Mr. Klebba, are being built, and the shop is now equipped with jigs for rapid mass production, if necessary.

Drifting and Anchored Buoys. A provisional plan has been developed for the employment of both drifting and anchored buoys in current surveys of about a fortnight's duration. This plan is a radio signal adaptation of the acoustic gun-finding techniques well known to artillerymen. The three reference stations may be located either ashore, or at sea as anchored radio buoys, and the drift of free buoys may be measured, with respect to the reference stations, by separate pulsed interrogation initiated by the ship or a shore station. A ship may serve as a reference point itself thereby reducing the number of unattended reference stations to two, but since the ship may wish to move freely, a third reference point seems desirable. This will allow the ship to find its position with respect to the reference frame of the anchored buoys or shore stations, and to serve as the needed third point of reference should one of the anchored buoys break away, or cease to operate. Mr. Walden is designing the radio components for this system.

Tests, in miniature, of a number of free drift and anchored buoy designs have been made in the laboratory. A one-third dummy model has been built of the best of these for seaworthiness tests in local waters. Results suggest that satisfactory support for a 12 to 18 foot vertical antenna is provided by a cylindrical surface float (hot water tank) riding upright but nearly awash, provided it is suitably damped vertically to follow the undulations of the sea surface. While a damping disc was required in the model, it is thought that 200 meters of small chain in the full-scale float will provide the required vertical damping and suitable horizontal drag to reduce wind drift to a useful minimum. This same chain may serve to tether the buoy to a mooring buoy for anchored service, provided the necessary weight is added at the bottom on the catinary. The design of a deep sea mooring is under consideration.

WAVE OBSERVATION AND ANALYSIS

Cooperative research between the Department of Meteorology, New York University, and this Institution has been initiated during this quarter. The processing of wave observations obtained by Dr. Willard J. Pierson has been completed on the auto-correlation machine and the results were forwarded to him at New York University.

MODEL STUDIES OF OCEANS

The boundaries of oceanic basins have been set up in a rotating paraboloidal basin of 50 cm. focal length and the water within them driven by wind stresses alone. The best replicas of primary ocean circulation patterns have been obtained by applying a zonal wind stress pattern having the same form of distribution as that assumed by Munk ("On the Wind-Driven Ocean Circulation", J. Met., 7 (2), 1950). Since the experimental distribution of wind stress was arrived at by trial and error, the result provides some confirmation of the validity of the distribution he assumed. Results also suggest that lateral shearing stresses must exceed bottom friction, which also supports Munk's view.

The circulations produced in the rotating basin are necessarily laminar for the reason that the time and length scale ratios reduce the scaled Austausch to the order of magnitude of the kinematic viscosity of water. Thus molecular diffusion falls rather high in the spectrum of turbulence of the model and only the large scale mixing processes are produced. The rate of mixing by these processes is so slow that two or three "years" of operation is possible before the color contrast of dyed portions of the circulation pattern is lost. Since the shearing stresses of laminar flow penetrate vertical density gradients, attempts to introduce stable density structures or two-layer systems have been unavailing.

The wind velocities required to induce motion to scale are high enough to produce small waves and turbulent mixing at the coastlines. These waves, it is found, can be eliminated by covering the water surface with Aerosol (a detergent) which seems to have no measurable effect on the ratio of a given wind velocity to the water velocity produced. Keulegan (J. Res. Nat. Bur. Stds., 46 (5), 1951) reports similar results using Glim.

Since the circulations produced in the rotating basin do not allow significant vertical motions to occur, the importance of these motions in the real oceans becomes evident. Artificial provision must be made for the effects of the sub-Arctic convergences and regions of upwelling in low latitudes in order to obtain a satisfactory circulation pattern along the eastern portion, especially, the North Atlantic Ocean basin. The equivalent of this vertical exchange has been produced experimentally by draining water from the Arctic Ocean basin and discharging it in the Gulf of Guinea from which point it moves along an extensive reach of the African coastline to join the North Equatorial current.

Secondary circulations have been observed in the rotating basin which bear resemblance to the meandering of the Gulf Stream. Thus far, the meander motion produced is in the order of one-third of the current velocity rather than one-tenth as in nature, but this may be changed by the more faithful reproduction of the continental boundaries being attempted at present. The significant feature of this meander structure is that it is tied to a moving system of cyclonic eddies between the Gulf Stream and the edge coast. Eddies are generated in the bight northeast of Cape Hatteras. These move northeastward along the coast. The course of the Gulf Stream conforms to the cyclonic curvature of these eddies and here the water velocities are highest. In the anticyclonic curvatures between the eddies, the current velocities of the Gulf Stream are lower. This is in qualitative agreement with the results found in nature during June 1950 (von Arx, WHOI Reference No. 51-96, Dec. 1951) and suggests a mechanism for them. As these eddies in slope water approach the Grand Banks they are distorted and extruded as a swift current setting easterly immediately south of the Grand Banks and north of the Gulf Stream. During the intervals between the extrusions of these eddies, a tongue of Labrador current water courses westward around the southern tip of the Grand Banks, sometimes reaching a point as far west as Cabot Strait, before being expelled by the arrival of the next eddy. Fuglister (WHOI Reference No. 51-75, Sept. 1951) has suggested that multiple current systems exist in this region. An intermittent process of this kind may be involved.

MODEL STUDIES OF ESTUARIES

The results of the studies on tidal flushing have been encouraging. An understanding of many phenomena in two-layer systems has now been achieved. A major report of about 500 pages is in the process of preparation. This report will contain the results of many different types of experiments and theoretical investigations on the flow of two-layer systems. A copy of the preliminary table of contents of this report follows.

Mr. Farmer visited the Waterways Experiment Station of the U. S. Army Corps of Engineers at Vicksburg, Miss., during this quarter, and also attended a conference on Tidal Hydraulics at Galveston, Texas.

ON THE NATURE OF ESTUARINE CIRCULATION
by
Henry Stommel and Harlow G. Farmer

Preliminary Table of Contents.

3.51 Experimental studies of effects of friction and mass entrainment
3.6 A theory of the salt wedge
3.61 Experimental studies of salt wedges

PART II Special topics

Chapter 4 - Mixing
4.1 Introduction
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4.3 Refinements of the tidal prism method
4.31 Exchange ratio
4.4 A mixing length theory of tidal mixing
4.41 Mixing in estuaries dominated by evaporation and precipitation
4.42 Uniform mixing along the estuary
4.5 Some effects of mixing in stratified systems

Chapter 5 - Offshore phenomena
5.0 Introduction
5.1 Effect of Coriolis force inside the estuary
5.2 The transition from flow in the channel to geostrophic flow along the coast
5.3 Effect of mixing on the offshore current regime: steep coast line
5.31 Shallow coast line
5.4 The dynamics of the fresh water "cloud"

Chapter 6 - Time-dependent phenomena
6.1 Effect of stratification on tidal currents
6.2 The salt wedge with tides
6.3 Transient solutions to the flushing problem
6.4 The weir effect in estuaries with small inlets

PART III Description and classification of estuaries
(A very brief, comparative description of about 30 different estuaries)

MISCELLANEOUS

Salinity Titrations. The following groups of salinity samples have been titrated:

Operation Blue Jay	408
USC&GS STIRNI (New York Harbor)	1,040
HAZEL III, Cruise #6 (Boston Harbor)	200
CARYN, Cruise #26	300
Miscellaneous	50
total	1,998

This work has been performed by two full-time technicians under the supervision of Mr. Bumpus.

Thermometer Calibration. During the fourth quarter of 1951, approximately 80 reversing thermometers were calibrated for various agencies (Hydrographic Office, U. S. Coast Guard, University of Miami, and W.H.O.I.). This involved the taking of 81 ice points (some 360 observations); 73 V_o determinations (some 300 observations and calculations); and some 500 odd tests at other points on the temperature scale(roughly 2100 observations).

Thirty pressure factor determinations were made (some 150 tests) and in addition, some fifty tests were conducted at 16°, 13°, 10°, and approximately 0°C. to determine the effect of temperature on the pressure of unprotected thermometers. This investigation is not yet complete. Results and conclusions will be written up at a later date.

During December, thirty-one reversing thermometers were ordered and received from the Kahl Scientific Instrument Co. for the account of the Office of Naval Research, chiefly to equip the vessels of operation "Trade Winds", as the then current complement of reversing thermometers available at this Institution was totally inadequate for the purpose.

As of the date of this report, the acceptable ones of these have been calibrated and are ready to go to sea, along with other thermometers previously on hand. Certain of the reversing thermometers shipped on this order were rejected as not meeting the specifications.

At present, all records are up to date, Statements of Examination prepared for all work completed, and all outside billings are up to date.

There are now on hand some thirty reversing thermometers to be calibrated for outside agencies and seven repaired instruments to be checked for this Institution. These seven are amongst those which were sent to the Kahl Instrument Co. for repair as mentioned in the third quarter report. The work seems to have been well and neatly done, and the Institution will be pleased to have these instruments back in service, as several of them are German thermometers of great excellence.

We are still awaiting delivery of certain thermometers now on order from Messrs. Negretti & Zambra and from the Taylor Instrument Company.

During the past year, certain serviceable reversing thermometers belonging to this Institution were lost or destroyed, as follows:

Richter & Wiese protected No. 3861	Lost on Operation SKIJUMP
Kahl protected No. 49-476	Broken while on loan to H.O.
Richter & Wiese unprotected No. U.4810	" " " " " "
" " " " No. U.4812	" " " " " "
" " " " No. U.4811	Lost on Operation SKIJUMP.
G. M. protected No, 370609	Lost on CARYN C-118.
G. M. unprotected No. U.46264	" " " "
G. M. protected No. 46261	Broken attempting repairs.
Richter & Wiese protected No. 2606	" " "

Negotiations are in progress with the Hydrographic Office to authorize transfer of three of their thermometers to this Institution in compensation for the three of ours lost or broken while on loan to one of their ships.

This work has been carried out by Mr. Whitney, Jr., under the supervision of Mr. Bumpus.

BIBLIOGRAPHY

Technical Reports. The following Technical Reports were submitted during the quarter:

Reference No. 51-96. Some Measurements of the Surface Velocities of the Gulf Stream. By W. S. von Arx. December 1951.

Reference No. 51-97. Baffin Bay Ice Conditions, June - July, 1951. By William G. Metcalf. December 1951.

Reference No. 51-98. The Exchanges of Fresh and Salt Waters in the Bay of Fundy and in Passamaquoddy Bay. By B. H. Ketchum and D. Jean Keen. December 1951.

Reference No. 51-99. An Experimental Study of Salt Wedges. By Harlow G. Farmer, Jr. December 1951.

Published Papers. The following papers were published during the quarter:

Ketchum, B. H., A. C. Redfield, and J. C. Ayers, 1951: The Oceanography of New York Bight. Pap. Phys. Oceanogr. and Meteorol. 12(1): 46 pp.

PERSONNEL

The following personnel were engaged in either full or part-time activity under this contract. Not included in this list but contributing to the work were shop-workers, maintenance personnel, crews of vessels, and the administrative staff of the Business Office.

Assignment	Name	Title
DIRECTION AND ADMINISTRATION	Ed. H. Smith	Director
	C. O'D. Iselin	Sr. Physical Oceanographer
	A. C. Redfield	Associate Director
	R. A. Veeder	Assistant to the Director
	Jeanne M. Backus	Secretary
HYDROGRAPHIC OBSERVATIONS AND ANALYSES	Nellie Anderson	Senior Technician
	A. B. Arons	Assoc. in Physical Oceanog.
	D. F. Bumpus	Oceanographer
	J. Chase	Research Associate
	P. C. Dalrymple	Research Assistant
	H. G. Farmer	Research Associate
	R. H. French	Junior Observer
	F. C. Fuglister	Oceanographer
	J. Hahn	Research Associate
	C. R. Hayes	Research Associate
	S. F. Hodgson	Research Assistant
	J. F. Holmes	Research Associate
	C. O'D. Iselin, Jr.	Junior Observer
	J. M. Kemp	Research Assistant
	B. H. Ketchum	Marine Microbiologist
	H. A. Kierstead	Physical Chemist
	W. V. R. Malkus	Research Associate
	W. G. Metcalf	Research Assoc. in Oceanog.
	I. I. Schell	Meteorologist
	Dorothy Schnabel	Secretary
	H. M. Stommel	Physical Oceanographer
	L. A. Thayer	Research Engineer
	Evangeline Tollios	Senior Technician
	W. S. von Arx	Oceanographer
	L. P. Wagner	Research Associate
	L. V. Worthington	Research Assoc. in Oceanog.
PHOTOGRAPHY, DRAFTING AND TITRATING	F. A. Bailey	Draftsman
	Marion O'D. Lane	Technical Assistant
	D. M. Owen	Research Assoc. in Oceanog.
	G. G. Pasley	Draftsman

Assignment	Name	Title
PHOTOGRAPHY, DRAFTING AND TITRATING, (cont'd.)	F. C. Ronne	Photographer
	Eva Shelnut	Draftsman
	J. W. Stimpson	Draftsman
	Phyllis Vail	Technical Assistant
	Doris M. Weeks	Multilith Operator
	Nancy H. Williams	Technical Assistant
	G. G. Whitney, Jr.	Research Assistant

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