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And God made the firmament, and divided the waters which were under the firmament from the waters which were above the firmament, and it was so.

WHAT is this scene doing on the cover of Oceanus? Well, they are water buffalo aren't they? And to have water they need rain. And to have rain they need the monsoon. And to have a monsoon they need the interaction between the ocean and the atmosphere: and it is so.

COVER PHOTO BY: MUNNS

The Monsoons

VOL. XII, No. 1, October 1965

THE Indian Ocean, landlocked to the north by Asia, bounded to the south by the frozen mass of Antarctica, was criss-crossed by a busy maritime traffic a thousand years before seamen ventured beyond sight of the shorelines of other oceans. Great civilizations developed around the borders of the Indian Ocean, their peoples and cultures intermingling and interacting, linked by floating caravans. Life was sustained and trade grew through the beneficient agency of the monsoons copiously watering summer crops, obligingly producing fine weather for autumn harvests, and blowing simple sailing vessels on year-long-round trips across the ocean. Farmers and sailors doubtless comprehended the reliability and occasional vagaries of monsoon weather. On the other hand, weather never seemed to interest intellectuals of the littoral civilizations. No oriental Aristotle codified or tried to explain the vast monsoon lore of peasant and fisherman.

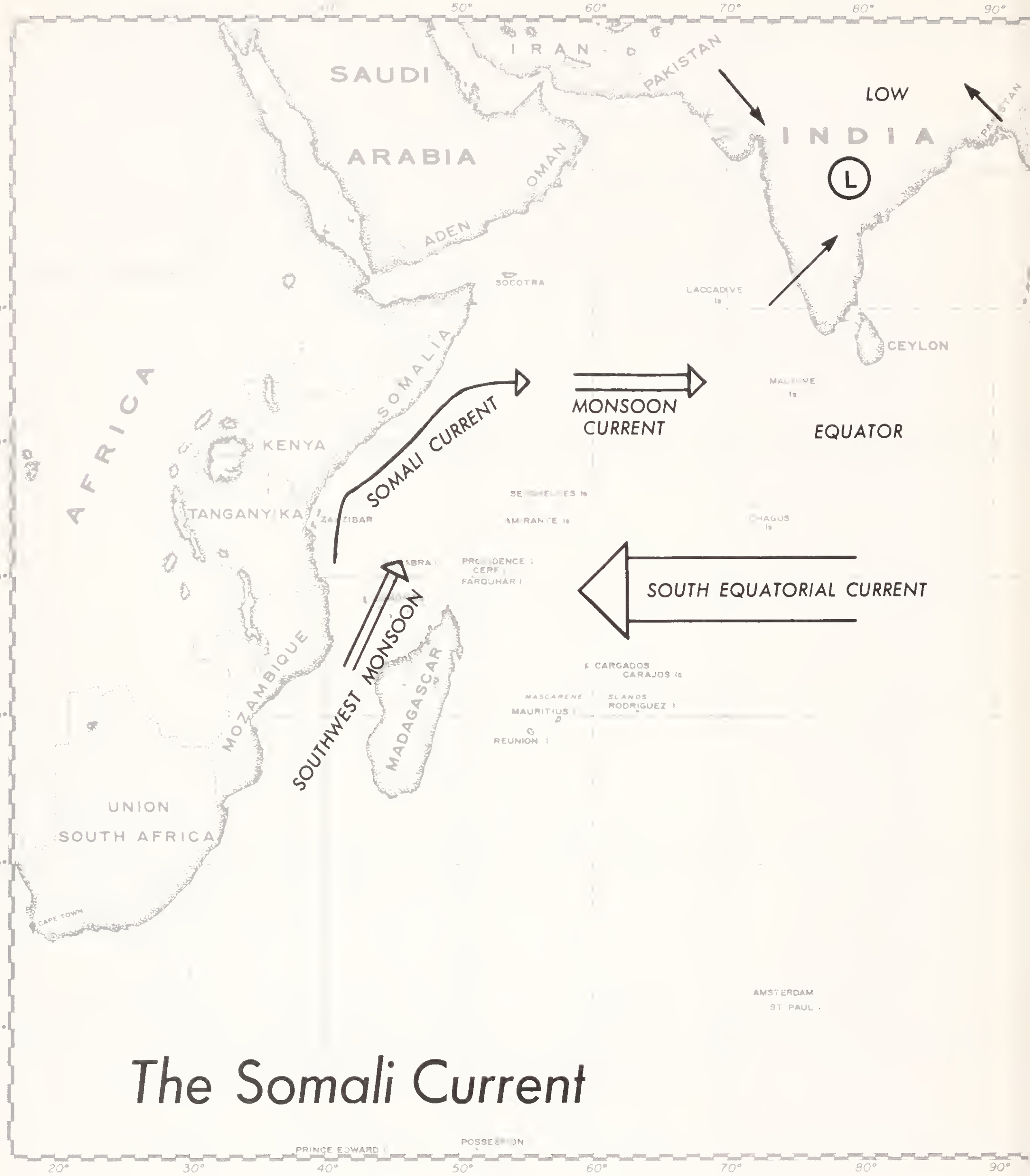
The centuries passed, with the inhabitants philosophically taking their weather for granted. Then, in the sixteenth century, voyagers from the west appeared, heralds of modern science, restlessly determined to observe, measure, and understand their environment.

(From: "Meteorology in the Indian Ocean", World Meteorological Organization, June 1965)

But much remained and remains to be learned. The International Indian Ocean Expedition was described in our March 1964 edition (Vol. X, No. 3). The huge mass of data obtained by the many ships and aircraft from many nations will take years to analyze. In this issue we report on a few results. The discovery of the 'Chain' Ridge and other geophysical findings and more information on the biology of the Indian Ocean will appear in future issues.

Monsoon system

Monsoons are winds which reverse with the seasons. During the northern summer Asia is hot causing a low pressure area over India. The southwest monsoon winds coming from near the Equator over the ocean are warm and saturated with moisture. As the land cools in the autumn high pressure is established (right) causing the generally cool and dry northeast monsoon.



The Somali Current

DURING the southwest monsoon the Somali Current flows as fast—and sometimes faster—than the Gulf Stream, but disappears during the northeast monsoon in the northern wintertime. The Somali Current appears to be an extension of the South Equatorial Current which at all times of the year flows westward in the Indian Ocean, somewhere between 5°-15° South. Around 6°-10° North, the Somali Current turns eastward into the so-called Monsoon Current which continues roughly eastward.

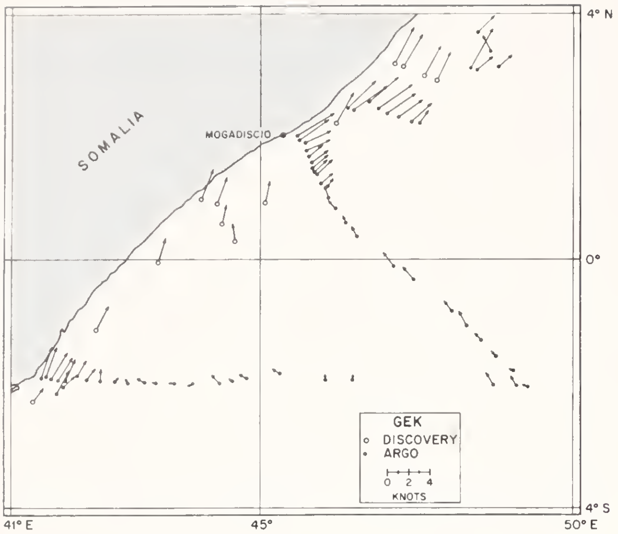
by B. WARREN

THE surface circulation in the northwest Indian Ocean undergoes drastic changes with the seasons, due to the reversing wind systems described elsewhere in this issue.* Ships' reports have indicated that during the southwest monsoon, in the northern summer, there is a strong northeastward current flowing for a distance of about one thousand miles along the coast of East Africa, chiefly the coast of Somaliland, before it turns eastward. Flowing at a speed of several knots, the Somali Current disappears completely during the northeast moonsoon in the northern winter (Sept.-March) and seems to be replaced by a fairly weak flow to the southwest.

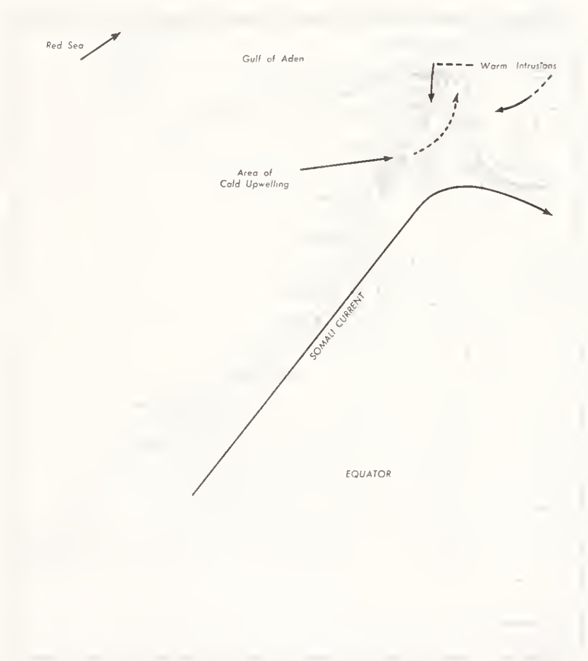
Current charts based on the collected ships' reports seem to suggest that the Somali Current is a western boundary current of the same sort as the Gulf Stream and the Kuroshio, only with the important difference that it appears during the southwest monsoon and disappears during the rest of the year.

This interpretation seems to agree with the theory of wind-driven currents, because only from April to September is the pattern of wind stress over the tropical Indian Ocean theoretically suitable for intense northerly flow along the East African coast.

*see: page 8



Vectors of the surface current as obtained by the GEK. The lengths of the arrows indicate the speed of the current in knots. The Somali Current is shown right up against the coast with an abrupt offshore edge. Surface speeds are about equal to those of the Gulf Stream, ± four knots.



The ocean surface temperatures in degrees centigrade are represented by the lines on this chart showing the general area of the survey. Hydrographic stations were made at the locations shown by dots. The current shows up as the rather cool, banded zone near the Somali coast, and turns abruptly eastward at about 6°-8° North.

One of the basic, general problems of the ocean circulation has to do with the way the ocean adjusts to changes in its driving mechanisms. In particular one would like to know what structural fluctuations the ocean shows under a changing wind stress and how long it takes the ocean to response to such variations. The most spectacular regular changes in wind stress occur over the north Indian Ocean and it has been hoped that detailed study of the Somali Current—both when it exists and when it does not exist—might provide significant general information about this process of adjustment. Thus, partly because of this unique role of the Somali Current with reference to theoretical inquiry and partly because it is a virtually unexplored major ocean current, it was arranged that the R.V. 'Argo' of the Scripps Institution of Oceanography, and the R.R.S. 'Discovery' of the (British) National Institute of Oceanography should carry on a joint five-week survey as part of their contribution to the International Indian Ocean Expedition. The aim of the survey was to observe in detail the pattern and structure of the current flow at the height of the southwest monsoon—or at least during one particular monsoon. This was an exploratory cruise because we had so little idea of the type of current system we would be investigating. We did not really know what surface velocities to expect, how wide the current was and how deep, whether it was associated with countercurrents as the Gulf Stream seems to be, etc.

It turned out that the pattern of flow in the near-surface water and in the deep water showed up quite clearly in the distributions of temperature and salinity.

High speeds

In addition to the hydrographic stations we also made approximate measurements of surface velocity by von Arx's Geomagnetic Electrokinetograph (GEK) system wherever possible.* Some of the resulting surface velocity vectors prove

*Impossible to describe in a footnote. Suffice it to say: a method to measure ocean currents from a ship underway.

that there really is a Somali Current. Unfortunately, the magnetic Equator lies at around 8°-10° North. This makes the GEK method impractical in the northern part of the area. We found the Somali Current a well defined current running right against the coast with quite an abrupt offshore edge. Maximum speeds ran about four knots, rather like the Gulf Stream, but the width of the current is something like 90 or 100 miles, half again as wide as the Gulf Stream. Apparently there is considerable inflow to the current from offshore waters. Farther downstream the 'Discovery' obtained additional velocity measurements by taking radar fixes on prominent coastal features. Near 7° and 8° North they found surface speeds close to seven knots,** which is somewhat more than anything I have ever heard reported for the Gulf Stream.

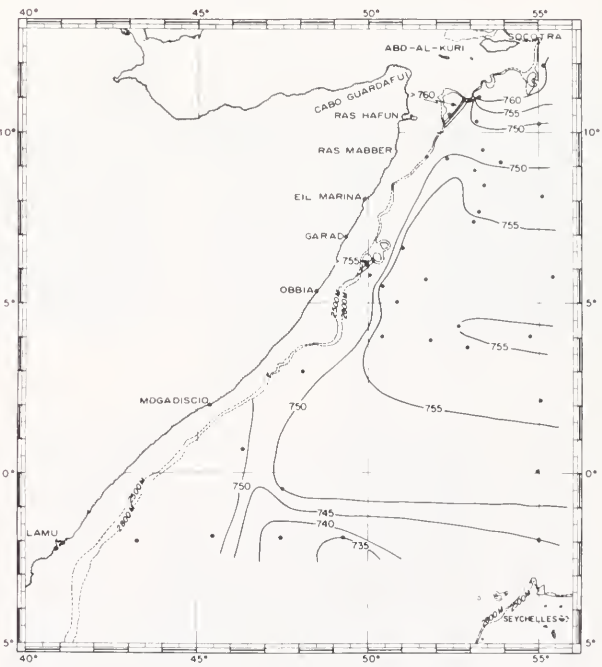
Water bodies

On the chart showing the distribution of surface temperature the Somali Current shows up as the rather cool, banded zone near the coast—although rather indistinct near the Equator. The current turns abruptly east—away from the coast—at around 6°-8° North. To the north of the current a body of warm water appears to be moving westward into the Somali Basin from the Arabian Sea; and another body of warm water moving southward from the Gulf of Aden.

Mr. Bunker mentions the upwelling which occurs along the Somali coast during the southwest monsoon. The surface temperature chart also shows this area last summer: a large body of cold water, which according to our observations seemed to have risen from depths of 200-300 meters near the shore and then spread offshore. The lowest isotherm shown here is 14°C., just north of Ras Mabber. The 'Argo' found surface water just colder than 13°C. within this area—certainly a striking feature only 500 miles north of the Equator. Some of the upwelled water appears to be entrained

**Almost 13 kilometers per hour, or ± 8 satute miles. Quite a current!

The surface salinities show the current somewhat more distinctly than the surface temperatures. Note the banded zone of relatively low salinity along the coast, again turning abruptly eastward at about 6°-8° North. The warm water intrusions in the north are quite saline.



The deep current in the Somali Basin is shown on this corrected salinity chart. (34. has to be placed in front of the decimal parts). A narrow, deep flow runs along the coast and turns eastward at about 10° North, some 100-150 miles north of where the surface current turned eastward. The bottom contours of 2500-2800 meters show the boundaries for this chart.

into the northern edge of the Somali current to form the remarkable narrow tongue of water colder than 20°C. Some of the water also seems to be moving northward toward the Gulf of Aden, part perhaps turning eastward north of the intrusion from the Arabian Sea.

DR. WARREN, Assistant Scientist, has been with the Institution since 1955, when he was awarded a summer fellowship. He is the author of "Topographic Influence on the Path of the Gulf Stream."

More distinct

On the chart showing the distribution of surface salinity, the Somali current is somewhat more distinct. Again we see a banded zone parallel to the coast, on the whole, a zone of relatively low salinity. The current turns eastward between 6° and 8° North. To the north of it we see again the intrusion from the Arabian Sea, now identified as a most saline body of water and also the southward intrusion from the Gulf of Aden, also high-salinity water. The upwelled water appears as a fairly uniform layer of low salinity, spreading offshore, some in the Somali Current, some moving northward between the two intrusions, part probably moving eastward north of the water from the Arabian Sea—though that is questionable. There is a complex system of movement in the northern part of this area. Apparently it was changing while we were there. I suspect that things probably are always this complicated during the southwest monsoon, but considering the unsteadiness of the flow, no doubt the actual pattern of flow varies considerably, both from one southwest monsoon to the next and even within a single monsoon, so that one should not regard this particular pattern as typical except in a rough overall way.

Below the near surface water at intermediate depths it is hard to infer anything definite about the flow pattern from the distribution of properties, but in the deep water below about 2500 meters, the situation is clear. The deep water is a uniform body showing only small horizontal variations, and it is plainly evident from temperature-salinity relationships that all the deep water in the Somali basin is essentially Circumpolar water which has spread northward from Antarctica. Nevertheless, there is a perceptible systematic gradation in water mass properties such that at any given temperature, the water right beside the continental slope is slightly less saline than that in the central part of the Basin. To show the shape of this fresh zone we have made up several charts giving the distribution of salinity on surfaces of constant potential temperature. Potential temperature is the temperature a parcel of water would take on if raised adiabatically from its observed depth to the sea surface. This is a more useful parameter for tagging water masses than temperature in-situ because it is insensitive to the effects of compression and rarefaction which are necessarily associated with vertical movements.

I shall only show one of these charts, because it turns out that the pattern is essentially the same all the way from 2500 meters to the ocean bottom. This is the distribution of salinity on the surface of potential temperature 1.8°C., and, as I stated, this pattern is representative of the entire body of deep water. On our stations the average depth of the 1.8°C. potential isotherm was 2600 meters, with a range in depth from 2500-2800 meters. The 2500-2800 meter bottom contours are included here to show the lateral boundaries of the Somali basin at this temperature. The dots show the positions of the hydro stations which reached to these depths. Here is the fresh zone I mentioned, 50 or 60 miles wide, lying close against the continental slope, except in the south. It is most markedly developed south of the Equator, and grows less intense toward the north. We interpret this distribution of course as indicating a narrow deep flow northward and northeastward along the western boundary of the basin, then turning eastward with the bottom contours at around 10° North. As far as I know these represent the first observations of this deep flow.

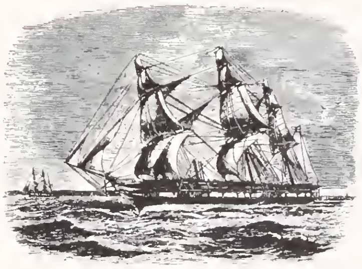
Certainly none of us had anticipated it, and we were rather surprised to find such a distinct feature. Notice that the deep flow turns eastward some 100 to 150 miles north of where the surface current turned—this seems a little puzzling although it may be that in the near-surface water the shallow intrusion from the Arabian Sea and the offshore movement of upwelled water combine in some way to keep the surface current farther south than it would be otherwise.

There are a number of basic things we have not learned about the deep flow; these will have to await future cruises for investigation. Since we did not make any direct current measurements in the fresh zone we do not know what sort of velocities and volume transports characterize the flow. And, as I stated before, the property distributions at mid-depths are rather ambiguous with regard to the flow pattern, so we do not really know whether the deep current is connected vertically with the Somali current in the near-surface waters, or whether it is an entirely separate current. And perhaps, most fundamental of all, we have very little notion as to whether the deep flow is a more or less permanent feature of the Somali Basin, or whether it reverses seasonally like the surface current.

There are many questions of this sort, which is not surprising, since this was the first attempt to take a close look at the flow in the Somali Basin, but I think we did get a fair idea of what conditions are like during the southwest phase of the monsoon. Last fall, the German F.S. Meteor also did extensive work in the Somali Basin, I have not heard yet exactly where their observations were made, but they were done during the northeast monsoon, when there is not supposed to be any Somali Current, so we are looking forward now to compare their results with ours to find out just what did happen to the ocean during the monsoon changes.

Dr. Warren's article (first presented to the Board of Trustees this summer) was re-written in his absence. The editor takes full responsibility for any ommissions or commissions.





'ATLANTIS', 'Beagle', 'Challenger', 'Discovery', 'Galathea', 'Meteor'. Ah, what gallant names in the history of oceanography. These names were remembered recently by being given to the first unit of six dormitories to house undergraduate students at the Revelle College of the University of California, San Diego.

This is not the first time that famous vessels are so honored. Or should we say rather: that buildings are honored by being so named. In 1948 when our Institution acquired the complex of buildings at Little Harbor, Woods Hole, the larger buildings were named 'Challenger', 'Meteor', 'Fram' and 'l' Hirondelle'. Later, a new building was named 'Blake'.

On the same property the 'Walsh cottage' and the 'Barn' were not renamed. Possibly these buildings were found to be too insignificant, although there may have been a sound New England reason. Old timers hang on to names. A nearby house is still referred to as the "Luscomb house", although the property has changed hands quite a few times since the Luscombs lived there. The house was torn down recently to make place for a new church building but we should not be at least surprised if someone said: "Oh, you mean the Sunday school on the Luscomb lot."

INTERACTION between the SUMMER MONSOON and the INDIAN OCEAN

by A. F. BUNKER

It has been realized for many centuries that the Arabian Sea has a strong influence on the temperatures and winds of the atmosphere above it. Similarly, the atmosphere has a great influence on the waters beneath it. In spite of the great interest of meteorologists and oceanographers in these interactions, the details never were studied adequately, primarily because of the magnitude of the job. The International Indian Ocean Expedition with its many oceanographic ships and meteorological aircraft was equal to this job. Studies of the interdependence of the sea and atmosphere became one of the Expedition's many goals. With data now coming in from many ships, the details of the interaction are becoming clearer.

The observations that I am depending upon most heavily for this discussion are those taken with the Institution's C-54 aircraft. This airplane has been equipped with psychrographs, radiosondes and Doppler radar so that temperatures and winds could be determined from 30 meters (100 feet) to 5,000 meters (15,000 feet) over many areas of the Arabian Sea. On the third trip of the C-54 aircraft to India we made trips out of Bombay to Aden and the Somalia coast where the interactions of air and sea reach their greatest development. After studying the data obtained from these flights and other sources, it became apparent that the sea and air complete two cycles of influencing each other, starting on a global scale and ending with a highly localized low level jet embedded in the monsoon wind system.

Global Scale

The series of cycles begin with the return of the sun to the northern hemisphere in the spring. At that time the air over Asia is cold and a high pressure center is located over the land. The cold air moves out in all directions including down over India and across the Arabian Sea. As the sun warms the land and in turn the land warms the air, the air becomes lighter, the pressure drops and a low pressure is established over the land. Over the Indian Ocean the pressure is changed only slightly because of the small changes in the temperature of the sea water. Under the influence of this new pressure field, the air starts moving northward across the equator and the Arabian Sea. This motion completes the first half cycle of interaction.

Regional Scale

The motion of the air across the equator and the Arabian Sea sets up a drag on the surface waters. Those surface waters move off to the east. To replace these waters cooler water from below comes to the surface over a large region of the western Indian Ocean. By early summer the water in this region is several degrees cooler than the water farther to the east. Thus another half cycle of interaction is completed on a regional scale.

Now with cooler water in the western region, the air is cooled by contact with the water. This cooling increases the density of air and increases the surface pressure. Since there already is a surface high pressure center south of the equator the increase of pressure in this area forms a ridge extending out from the center above the African coast.

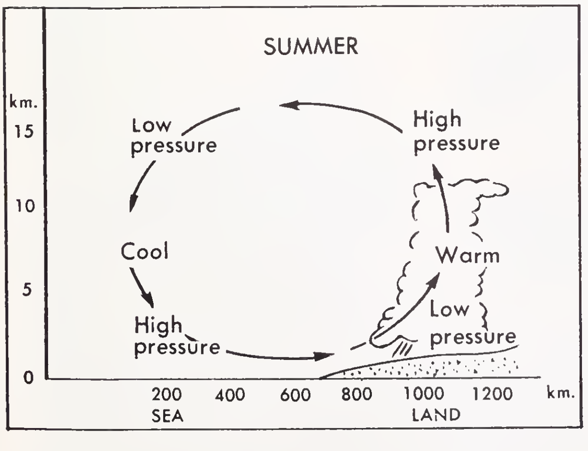
With this pressure field we can show that in the region off Somalia the winds blow strongly in a rather narrow belt. This completes the next half cycle of interaction.

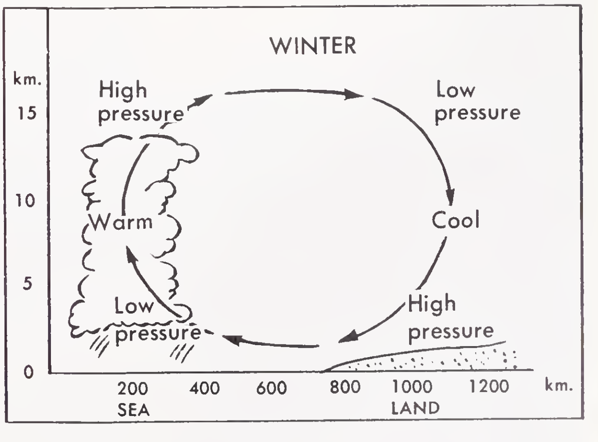
Local Scale

Now the strong winds in this narrow belt cause a large drag on the water beneath. This pushes a narrow belt of water off to the east. The only source of replacement water is the deep, cold water and that water rises up to the surface. This cold water forms a localized pool of water with a temperature as low as 13°C.

This cold water rapidly cools the air flowing over it. Since the cold water is fairly localized it produces a rather small lens of cold air. To study this situation we flew a path out of Aden southeast across the strong wind system to 4°N., there we climbed to 5,000 meters and returned to Aden. En route, we made temperature measurements

The air circulations associated with the summer and winter monsoons (after: WMO-No. 166).





from the aircraft and while at high level we dropped radiosondes that radioed the air temperatures back to the airplane.

Now we come to the final cycle of interactions between sea and air—the smallest and most localized of them all. Such a cool spot in the atmosphere disturbs the pressure field at the higher levels and hence changes the wind velocities aloft. I shall not go into the theory of the thermal wind which predicts the change in velocity with height for a given horizontal temperature gradient. It is a very convenient tool of meteorologists because it allows determination of the winds aloft without a knowledge of the pressure field. You might call the thermal wind the poor man's pressure chart since he can find the winds aloft without the expense of observing the pressure fields.

Calculation from the horizontal temperature gradients show that the wind should increase about 15 meters per second (± 30 mph) with height to the top of the cool layer. Above this layer the temperature gradient reverses and the wind should decrease. To see if it does, let us look at the figure which gives the observed winds two days later a few hundred kilometers downwind of this cross section.

MR. BUNKER, Associate Scientist on our staff, is the author of "Turbulence Measurements in a Young Cyclone over the Ocean."

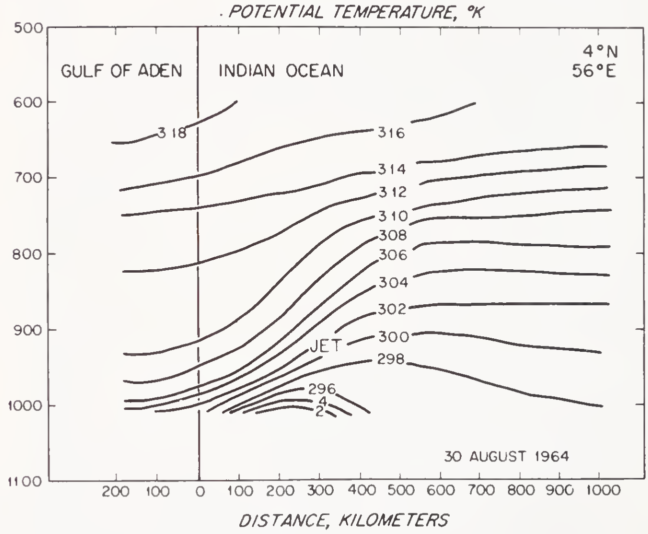
This thermal wind jet completes the cycles of interaction that started on a global scale. It is not, however, the end of the interactions between sea and air over the Arabian Sea. After the air leaves the region of cool Somalian waters, heat and water vapor are transferred to the cool air and the horizontal temperature gradients weaken. With the weakening of the gradients, the speeds of the jet diminish and by the time the jet reaches the Indian coast line it is just barely recognizable. The diminution of the wind as it crosses the Arabian Sea causes a convergence or piling up of air in the lower layers in the eastern part of the Arabian Sea. The accumulation of air is relieved by a rising of the air which in turn sets off cumulus convection in the air mass. As the clouds grow, scattered showers and general cloudiness are produced.

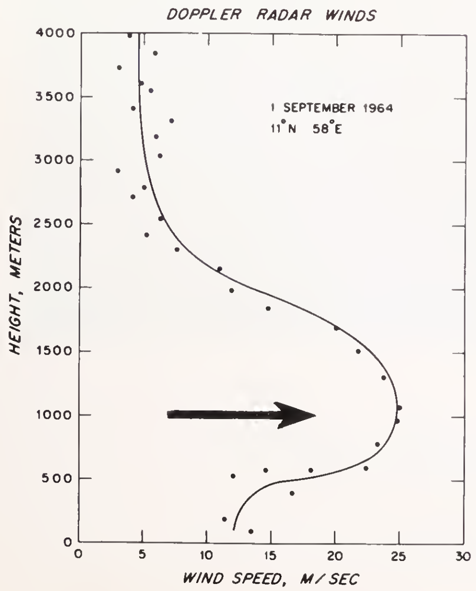
See: "Monsoon flight", by A. F. Bunker. Oceanus, Vol. X, No. 2.

DENSMORE (FROM A KODACHROME)

Dropped from our aircraft the parachute of the radio-sonde is beginning to open. This is a reversal of the more usual radio-sonde procedure when a sounding is made by launching the apparatus from the ground attached to a balloon.

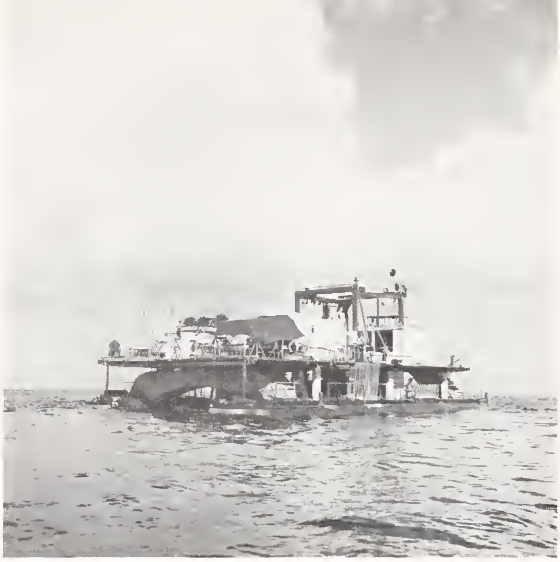
The observed temperatures show the cooling accomplished by passage of the air over 300 or 400 kilometers of cold water. The values given are degrees absolute. Potential temperatures are used to eliminate the effect of pressure changes with height in the atmosphere.





The diagram presents the wind speed observed at many heights from close to the water to a height of four kilometers. The effect of the horizontal temperature gradient upon the height variation of the wind speed is very apparent with the wind at 1,000 meters reaching a speed of 25 meters per second (± 50 mph).

The strong, low level wind jet (arrow) is caused by the cold upwelling waters off the Somali coast.



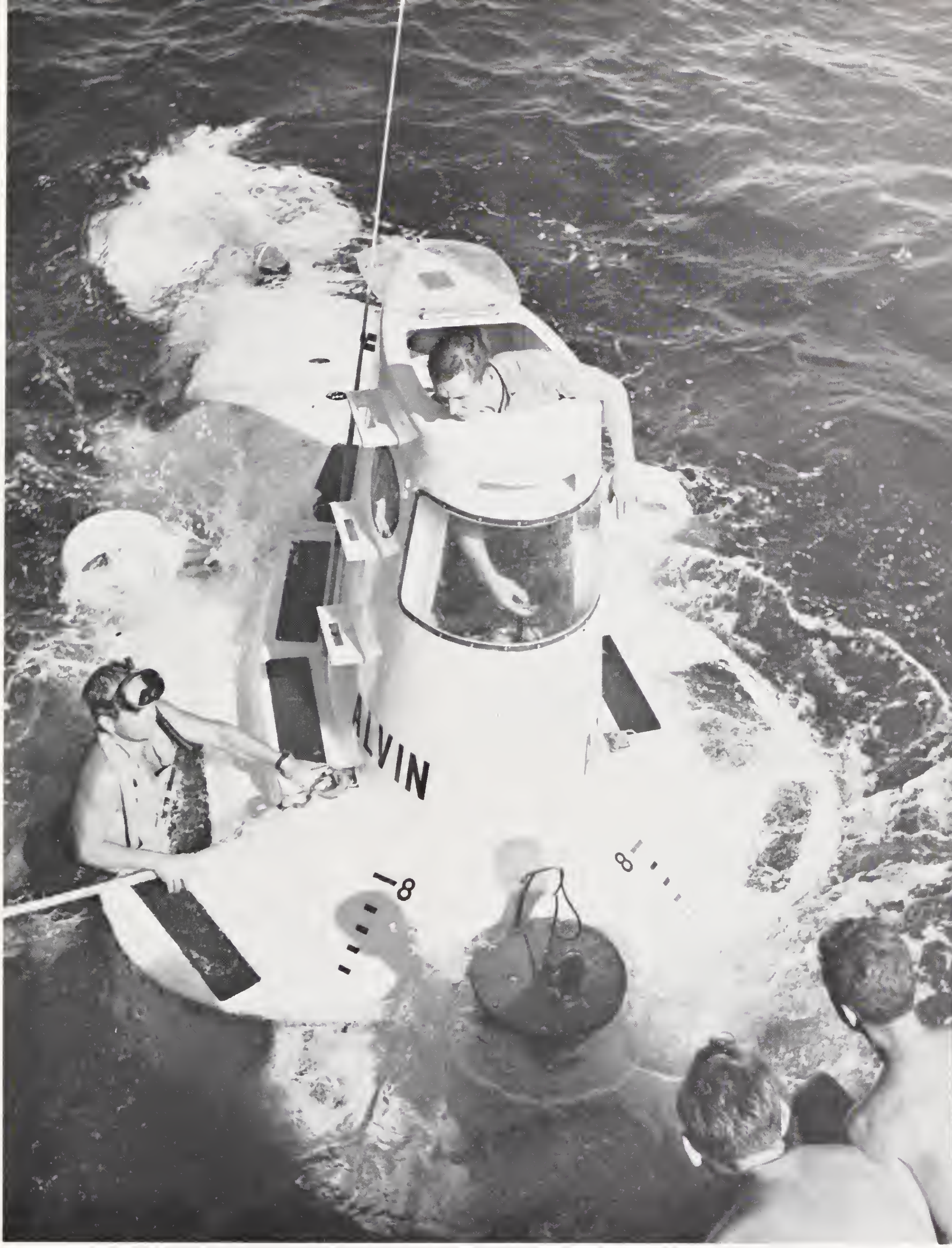
D.R.V. 'ALVIN'

IN June and July 1965, the Deep Research Vehicle 'Alvin' made her first deep dives off the Bahamas. Leaving the pleasant anchorage at Coral Harbour, New Providence Island, the small craft (called "ocarina-shaped" by the Wall Street Journal) first was lowered gingerly on a polypropylene line from her attendant catamaran to a depth of about 2340 meters, (7700 feet), and retrieved during a long day's work. The up-and down speed was about ten meters per minute.

A series of successively deeper dives, without a line, ended on July 20th, when the 'Alvin' made a free dive to her designed depth of some 1825 meters (6000 feet), with pilots W. Rainnie and M. McCamis on board.

The three pilots who made the series of deep dives, including V. Wilson, concentrated on the vehicle's performance, although they did have an opportunity to observe rugged cliffs, plant and animal life.

Mariners may well have rubbed their eyes seeing the catamaran, a cross between a houseboat and a dredge. When the 'Alvin' surfaces she is attended by aqualung swimmers who guide the craft between the floats of the mothership until the 'Alvin' is lifted out of the water on a cradle. The photograph at bottom left, taken during the hoisting procedure, clearly shows the two maneuvering propellers and the large driving-steering propeller.



OWEN PHOTOS

Deep Research Vehicle Alvin

Two kilometers down!

INSTITUT FÜR MEERESKUNDE

The 'Meteor' in the Indian Ocean

by P. KOSKE

ON DECEMBER 16, 1964, we left the port of Aden bound for Mombasa, Kenya, with about thirty days of work ahead in the region of the Somali current off the coast of East Africa. We, that is, the F. S. 'Meteor' (with a length of 82 meters and a displacement of 2700 tons, comparable to the 'Atlantis II'), a crew of 55 (including a group of nine scientists and technicians who are on the boat continuously), and 25 scientists from nine different universities with Prof. G. Dietrich from Kiel University as chief scientist. All with much enthusiasm, not all with the same amount of experience with the element, and everyone convinced, as is the rule with sea-going scientists, that his field is the most important one of the whole cruise.

We had spent the last four weeks in the Red Sea, mainly in the southern part of it, doing current measurements in the Straits of Bab el Mandeb, the "gate of tears", while a team of eight biologists stayed ashore for a fortnight, on Sarad Sarso, an uninhabited island of the Farsan group (Saudi Arabia), for littoral work. During this time, which was sort of a shake-down cruise we had started to like our new bucket. She is big enough for many different aspects of basic research in oceanography, the individual labs are well placed around the main working-deck, and because of their special suspended construction they are free from vibration which made it possible even to make micro-photographs while under way. Apart from the working facilities we started to reflect on the long tour of sea-duty ahead of us, working around the clock, and having the unusual feeling on this new ship—of not being uncomfortable at sea. On December 24 we were at 7°.50′ North, 52°.02′ East, about 120 miles off the coast of Somalia, 'Meteor' Station 112, at a depth of 5070 meters.

Work—work—work

Contrary to the former days with northeast winds of force 6-7 it was rather calm. We started off with the "Bathysonde", our in-situ instrument for the measurement of conductivity, temperature and pressure. While it was lowered down to 2000 meters, the plankton people did their shallow cast with 5 liter bottles to study productivity and routine vertical hauls with the Indian Ocean Standard Net. At noontime someone mentioned Christmas. It was a strange feeling. At home Christmas means icy winds, snow and long dark nights and here we were in shorts without shirts and the temperature outside was as high as 28°C. After two hydro casts, a shallow one and deep one, the chemists lowered their oxygen-sonde down to 500 meters and finally our geology group worked with a small bottom-grab.

We stopped working at 17.00. At dinner time in the messroom there was a real Christmas tree with lighted candles and we had a quiet meal. Prof. Dietrich said a few words and read a chapter from the Bible. Some received telegrams from home. Later in the evening, in our quarters, we played some tapes with Christmas music and celebrated with a bottle of wine. It is at such moments that even tough, bearded oceanographers feel somewhat uncomfortable and want to be at home. At midnight we went back to work again. On December 31 we got a telephone call via Norddeich Radio from our local newspaper "Kieler Nachrichten". They were sending best wishes for the New Year.

We had just finished our hydrographic section 4 and were steaming to the starting point of section 5. About 200 miles to go with only a few under-way instruments working: the echo-sounder, the counter for gamma-radiation, the recorder for surface temperature, salinity and transparency, two thermopiles for long and short wave radiation and the magnetometer. So everything was set for a big party and it sure became wild during this night. Next morning only 14 people out of 80 asked for breakfast, the absolute minimum for the whole cruise.

The more we approached the Equator the more our meteorology team became excited. We were in the region of the jet-stream. Two daily balloon ascents were part of their routine work, at 12.00 GMT and 24.00 GMT. These balloons with their "radio-sondes" were tracked automatically by the wind-weather-radar, sometimes to heights of 30.000 meters and more. And while one could follow every movement of the balloon on the dials of an analogue computer the sonde was transmitting information about temperature, humidity, and air-pressure. Apparently the results were really exciting because during these days there were only happy faces around the meteorology lab.

Land—at last

Then finally after more than thirty days at sea and after a big initiation ceremony on the line with 58 dirty pollywogs and only 22 honorable shellbacks, we approached Mombasa on January 16. The white beaches with palm trees and the beautiful tropical vegetation seemed to us like a paradise. The work at the Somali coast during the time of the northeast-monsoon lay behind us.

MUNNS

New Sources of Seafood

AMERICAN scientists have discovered two more areas of the Indian Ocean that may be rich sources of seafood for the oftentimes hungry peoples of parts of Asia and Africa, according to a recent announcement of the National Science Foundation.

The researchers, who operated from the Foundation's R.V. 'Anton Bruun', said that "indications of the presence of fishery resources available to trawling" were found off Delgoa Bay, Mozambique, and off Formosa Bay, Kenya, north of the Mozambique Channel.

This was the second announcement regarding the possible presence of untapped fishery resources in the Indian Ocean. The first report, also from scientists aboard the 'Anton Bruun' was made in May, 1964. Fisheries experts from the Bureau of Commercial Fisheries (BCF) of the U.S. Fish and Wildlife Service then found evidence suggesting the existence of a fishery perhaps several hundred miles in extent off the coast of the protectorates of Muscat and Oman in eastern Arabia. The evidence indicated a fishery containing a large concentration of bottom fish and crabs.

The presence of the new fishery resources consisted of large quantities of market-size red shrimp and lobster from Delgoa Bay and very large shrimp from the vicinity of Formosa Bay.

Mr. Springer, also of the BCF, was chief scientist aboard the 'Anton Bruun' during the latest discovery. The shrimp from near Delgoa Bay, he said, were a small, red, relatively soft-fleshed variety of the type now fished off the coast of Argentina and to a lesser extent, off Florida. A deep-water type (1350 feet), they need refrigeration and special handling in order to be marketable.

The shrimp from the Formosa Bay area were from shallower water (about 750 feet) and were especially large, running about six or eight shrimp per pound. "There would be no problem in marketing these," Mr. Springer said.

Though the extent of the two fisheries is not known, Mr. Springer pointed out, the catch rates for the hauls from the 'Anton Bruun' suggest fisheries of commercial concentration. "If we could do this well on a ship not designed for the purpose, a properly rigged commercial boat could do much better."

Existence of the fisheries would be of great importance to the peoples of countries bordering the Indian Ocean. Large populations in the area suffer from chronic food shortages and from health problems due to protein-poor diets.

The cruises of the 'Anton Bruun' were part of the International Indian Ocean Expedition, an investigation involving some 40 ships and 28 nations. The field investigations, carried out in the spirit of the International Cooperation Year recently announced by President Lyndon B. Johnson, were largely completed in 1964, though some additional work will be done in 1965. Scientists involved in the IIOE are expanding the presently scanty knowledge of the Indian Ocean, a body of water covering 28 million square miles.

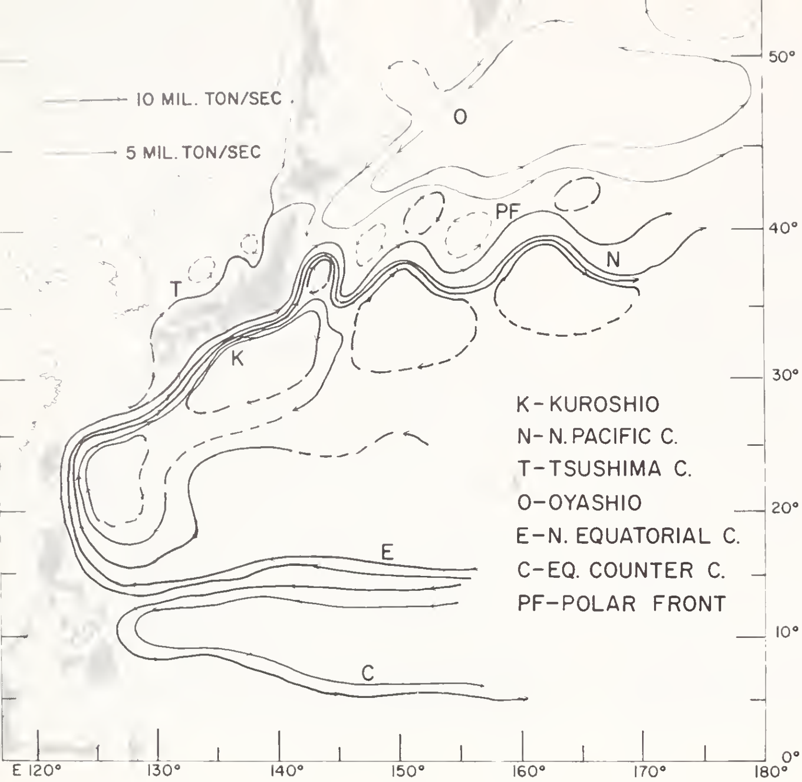
The National Science Foundation has planned and coordinated the U.S. participation in the IIOE. The U.S. biological program is headed by Dr. J. H. Ryther of our staff. As far as we know the 'Anton Bruun' was the only foreign based ship to remain in the Indian Ocean during the entire program. When the expedition ends, some 15 ships and five aircraft of the United States will have participated in the program.

MEDEIROS

We had a rather unusual visit at Woods Hole in October. Two newly built research vessels both destined for the west coast came alongside, prior to their shakedown cruises. The ships are the last of a class of ten AGOR-type vessels built by the U.S. Navy. The 'Thomas Washington' is for the use of the Scripps Institution of Oceanography, University of California, while the 'Thomas G. Thompson' (naturally) is operated by the University of Washington's Department of Oceanography. The 209' vessels both will make observations in the Caribbean area prior to sailing for their homeports. Co-incidentally both chief scientists, Dr. F. A. Richards and M. Silverman, are old Woods Hole hands.

———meanwhile the R.V. 'Atlantis II' visited our Scripps friends and is on the final leg of her circumnavigation. She is expected at Woods Hole in November.

MUNNS



by T. ICHIYE

The Kuroshio System

The 'Atlantis II' has just taken part in an international survey of the Kuroshio before continuing on her circumnavigation. The Pacific counterpart of the Gulf Stream influences the climate and fisheries of Japan.

DR. ICHIYE is Physical Oceanographer on the staff of the Lamont Geological Observatory, Palisades, N.Y. He was at our Institution for a year or two when he first arrived in the U.S.A.

THE name Kuroshio (Kuro = black, Shio = current) appeared first in the 13th century in some Japanese historical stories of the struggles between the two largest military families in which the current of this name was described near an island colony for political exiles about 150 miles south of Tokyo. The name is due to the extraordinary transparency of the water which makes it look black. The first scientific report on the current might be that of the French navigator De Tessan who cruised in the North Pacific on board the corvette 'La Venus' between 1836 and 1839. Thus for some time in western countries, the current was known as Tessan's current, a name which was gradually forgotten due to the lack of continuing studies by the French. A more detailed study was made by Lt. S. Bent who participated in Commodore Perry's expedition to the Far East in 1853-54. He noticed the warm current in the western North Pacific from surface water temperatures and named it the Japan current. In his paper read in 1856 before the American Geographical Society Lt. Bent said: "The Japanese are well aware of this current and have given it the name of Kuro-Siwo or Black Stream, which is undoubtedly from the deep blue color of its water". In 1873

Schrenck also described the current system in the western north Pacific from surface water temperatures collected by Russian warships between 1857 to 1867. His nomenclature, such as Tshushima Current, Liman Current and Kurile Current still is in use.

Large scale oceanographic exploration in the area were initiated by the 'Challenger' in 1875 and by the Russian 'Vityaz' from 1886-1889. In the 20th century the R.V. 'Carnegie' occupied extensive hydrographic stations during her 1928-29 cruise in the North Pacific. Ships of the Japanese Hydrographic Office, including the 'Manshu', the 'Komahashi' and the 'Koshu' started extensive surveys of the entire Kuroshio system in 1930, although most of these data were classified and not available until after the war. Research vessels of the Japanese fishery stations including the 'Soyo' made simultaneous surveys near Japan during every summer from 1933 to 1940, occuping hydrographic stations on ten or more transects across the Kuroshio between Longitude 130° East and 150° East. Some of these results were discussed in comparison with the Gulf Stream in a paper by Wüst (1936).

Since 1950 the area south and east of Japan was surveyed almost synoptically at least four times a year by five to eight vessels from the Japanese Meteorological Agency and the Japanese Hydrographic Office. Seasonal and year to year changes of the Kuroshio have been obtained from these studies. In the summer of 1955 an international survey was carried out with seventeen ships from the United States, Japan and Canada to obtain an overall picture of the circulation in the North Pacific Ocean. (Operation Norpac).

The System

The Kuroshio is the counterpart of the Gulf Stream in the Pacific Ocean. Wüst in 1936 applied the name "Kuroshio System" to the western and northern parts of the clockwise gyre in the North Pacific. The system consists of three major divisions. From east of Luzon in the Philippines the Kuroshio proper flows northward, turns to the northeast from north of Taiwan and runs close to Japan as far as 35° North where it turns nearly east to form the Kuroshio Extension. The North Pacific Current continues from the Extension, flowing eastward as far as 150° West. The Tsushima Current which has no counterpart in the Gulf Stream System, is a branch of the Kuroshio which enters the Japan Sea and flows west of the Japanese islands to the north.

Rice Crops

Catastrophies of an economic nature often have stimulated scientific research. The failure of the rice crops throughout northern Japan in 1931 and 1934 and changes in the fisheries stimulated cooperative surveys of the Kuroshio. A cold eddy some 300 kilometers long, which has appeared and disappeared since 1934 and changed the course of the current also added to the eagerness to study the current in detail and continuously. Our knowledge about the fluctuations of ocean currents and their relationship to changes in climate and weather is still fragmentary. Years of expensive and careful observations are needed to produce only an approximate description of such fluctuations.

The source region of the Kuroshio is east of Luzon where a part of the North Equatorial Current turns to the north close to the Philippine Islands. This area was not surveyed until recently, but the information obtained between 1932 and 1936 suggested that the current east of Luzon runs at about one to three knots with a width of about 150 km. with one or two clockwise eddies to the right hand side of the current. Japanese oceanographers estimate that some 20 to 30 million tons of water per second—from one half to three quarters of the 40 million tons of water per second transported in the North Equatorial Current —becomes the source of the Kuroshio. Just south of Japan the volume of water transported by the Kuroshio is fifty million tons per second so that from 20 to 30 million tons must have been entrained from the Philippine Sea east of the current, a counterpart of the Sargasso Sea.

The water mass of the Kuroshio consists of Western North Pacific Central

Water. In the upper 200 meters this water mass has a temperature above 20°C. and a salinity of 34.8 to 35‰. At depths from 200 to 600 meters the temperatures range from 20°C. to 8°C. and salinities from 34.8 to 34.1‰. Still lower from 1000 to 2000 meters the temperatures are from 4° to 2°C. with salinities of 34.6 to 34.3‰. Like the Gulf Stream the Kuroshio in not a "river of warm water" but is situated on the edge of the warm central water and is distinguished by a sharp rise of isotherms from the right to the left, looking in the direction of the flow. One conspicuous difference is that the Kuroshio, as I reported in 1963, contains intermediate water from the cold Oyashio Current which flows southward like the Labrador current. The Oyashio water with a low salinity of 33.8 to 34.‰ spreads to the south below the warm, saline water of the Kuroshio between 400 and 1000 meters.

As the Kuroshio reaches the southern coast of Japan its surface velocity increases. The average velocities measured at the axis of the current with the G.E.K.* from the southern coast of Japan until the current bends offshore are from 2.6 to 3.7 knots. The width of the current in this area, defined as the flow with a surface speed of more than one knot, is about 100 kilometers. At a depth of 1000 meters the current flows in the same direction as at the surface with a speed of 9% or 30% of the surface velocity, depending upon whether one uses a reference level of "no motion" at depths of 1200 meters or 3000 meters.

Seasonal changes and meanders

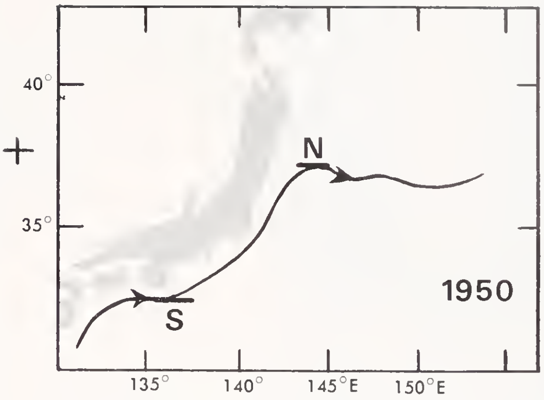
The total volume of water passing Japan in the Kuroshio has been calculated as from 30 to 60 millions tons of water per second with the maximum transport in the spring and fall and the minimum in winter and early summer. This is in contrast to the seasonal changes in the Gulf Stream between Long Island and Bermuda which Iselin computed to change from 60 to 75 million tons per second, with the maximum in the summer and the minimum in the fall and early spring. It must be understood that the oceanographer calculates geostrophic currents from the density field, which in turn, has been obtained from measurements of temperature and salinity—both vertically and horizontally—taken at hydrographic stations. Meteorologist compute winds aloft from observed density fields but they have the advantage of sitting at the bottom of the pressure field. Oceanographers rely upon an arbitrary choice of the "level of no motion". This is meant by the "1000 meter (or 2000 meter, etc.) reference level". The smaller mass transport of the Kuroshio, compared with the Gulf Stream may be due to the choice of the shallower reference level.

The Kuroshio changes its course from northeast to due east at about 142° East, separating from the coast of Japan and the narrow shelf around it, unlike the Gulf Stream which roughly follows the bathymetry of the continental shelf as far as the Grand Banks. After leaving the coast, the current shows multiple structure and meanderings like the Gulf Stream. Also, to the north of the Kuroshio there are clockwise eddies of warm water and counterclockwise eddies of cold water with dimensions of 100 to 200 kilometers and lifetimes of a few months to nearly one year. The warm eddies seem to be cut-off meanders of the Kuroshio and the cold ones may be of Oyashio origin.

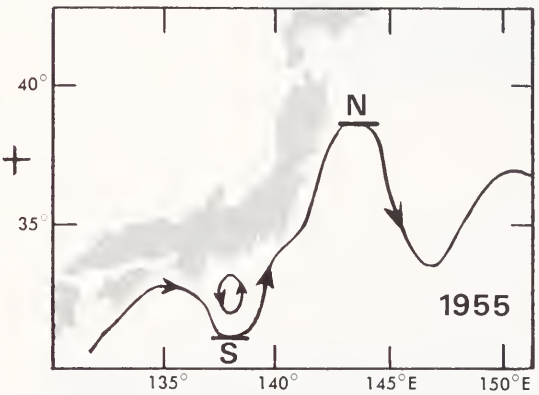
Large fluctuation

Another feature of the Kuroshio which has no counterpart in the Gulf Stream is its detour around a counterclockwise eddy of cold water to the south of Japan between 136° and 140° East. This eddy lasted for several years while its shape and extent changed considerably. The eddy first appeared in the fall of 1934 with it center at about 32.5° North and 136° East and a major diameter of 200 kilometers. By the spring of 1938 the eddy had reached its maximum extent of 300 kilometers with the center at 32° North and 137° East. The eddy diminished in size and moved eastward suddenly after 1941 and completely disappeared in 1947. Then it appeared again from 1954 through 1955, disappeared again in 1956, returned during the summer of 1959 and has continued since with a slight weakening in 1963.

There are many speculations on the cause of this eddy and the detour of the Kuroshio around it. The detour of the current may be due to a topographic effect of the Bonin Ridge which lies across the path of the Kuroshio just downstream of the detour. Growth and decay of the eddy seems to have a period of eight to ten years, while the amplitude of the first northward ridge of the meanders, east of 142° East, fluctuated with a period of four to five years. The frequent surveys of the area south of Japan from May 10 to June 9, 1959 showed the process of growth of the detour which started west of 133° East and within a month became steady between 135° and 137° East.



The location of the northern limit (N.) of the first meander east of Japan fluctuates over a period of 4½ to 5 years, while the location of the southern limit (S.) shows fluctuations of about eleven years due to the generation of a counterclockwise eddy off Japan.

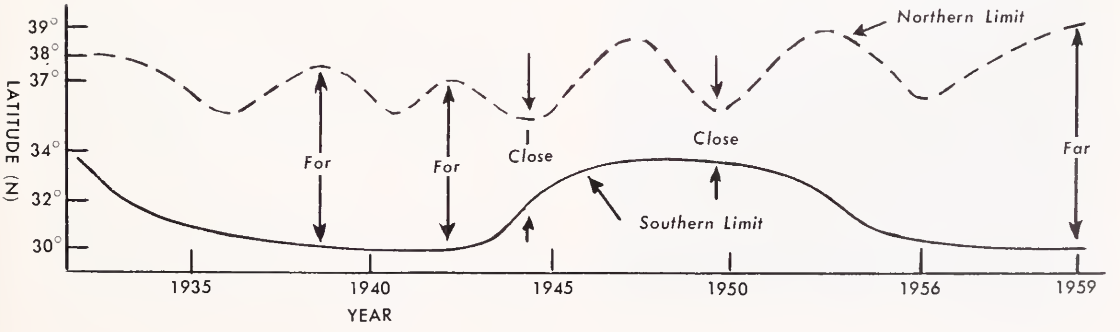


The Tsushima Current

The Tsushima current, a branch of the Kuroshio, has no counterpart in the Gulf Stream system. This current is believed to separate from the Kuroshio, southwest of Japan at about 30° North but is not recognized as a strong current until it reaches the Japan Sea, where it flows close to the western Japanese coast with a maximum speed of one to one and a half knots and has a width of 50 to 100 kilometers.

The greater part of the Tsushima flows into the Pacific through the Tsugaru Strait, the remaining part flowing further north is dissipated by mixing with cold water. Two or three eddies, a few hundred kilometers across are usually present on the offshore edge of the current between 35° and 40° North. The current is about 300 meters deep. Below that depth the water is cold (0°-1°C.), fresh (34-34.1‰) and almost homogenous. It remains an enigma how such water is formed.

The northern limit (dotted line) and the southern limit (solid line) of the Kuroshio, as shown in the above drawings, move toward or away from each other over a period of about eleven years. The farthest separation started in 1959.



N. Y. TIMES

Looking while listening

by W. A. WATKINS

THAT the Antarctic seal Leptonychotes weddelli (Lesson) 1826 produces a variety of calls underwater has been known at least since E. A. Wilson's account published in 1907. He described the calls graphically, recounted hearing the seals calling beneath the ship as well as beneath the ice, and supposed that the calls were communicative. Unfortunately his observations have been missed by later workers. More recent observers have seemed reluctant to consider that the calls were made underwater, and presumed that the seals were calling in air trapped under the ice. A. A. Lindsey recorded the in-air calls phonographically in November, 1934; his record was not published, but he has generously supplied copies of it to interested students. In October and November, 1963, underwater recordings were made at McMurdo Sound in the Ross Sea by Dr. Carleton Ray of the New York Zoological Society and Lt. David Lavallee, USN.*

*From: Schevill, W. E., and W. A. Watkins. Underwater calls of Leptonychotes (Weddell seal). Zoologica, 50, 1 pp. 45-47.

IN October and November 1964 we went to the Antarctic to study the underwater sounds produced by the Weddell Seal, Leptonychotes weddelli. These seals live most of their lives under the sea ice. They occasionally are seen when they poke their heads out of a breathing hole or when they come out on the ice to bask in the sun, — the rest of their existence is in the water under the ice, out of sight.

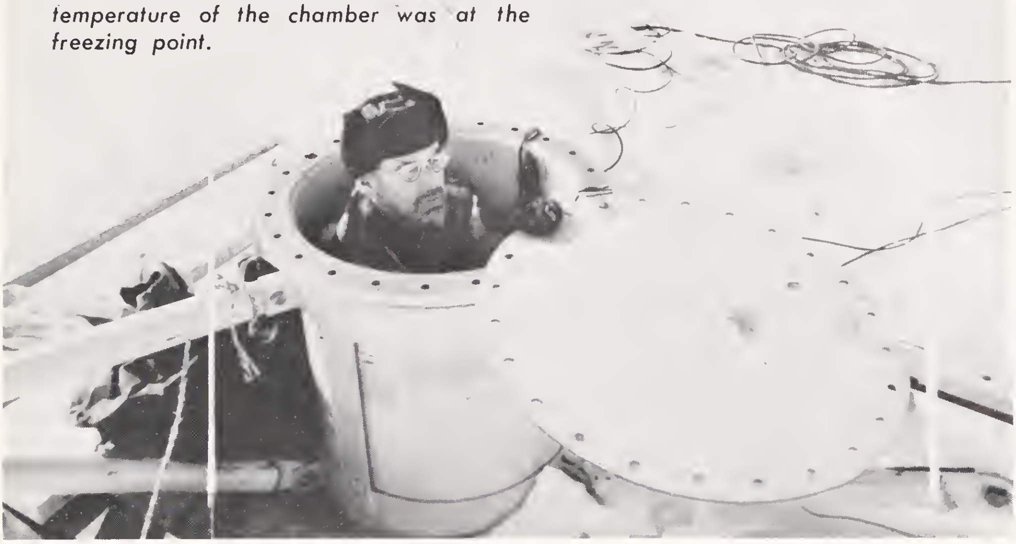
In 1963 a New York Zoological Society party made a recording of the underwater sounds of these seals at McMurdo. We analyzed the sounds for publication and as a result Mr. W. Schevill and I made preparations to go to the Antarctic in a joint operation with the New York Zoological Society group headed by Dr. Carleton Ray. This trip was made possible through a grant from the National Science Foundation. Their United States Antarctic Research Program arranged transportation and clothing for McMurdo Sound and provided food as well as excellent logistic support in the field.

Ice chamber

During the planning of the trip W. Schevill suggested a sub-ice observation chamber to take advantage of the unusual transparency of the water — 200 feet or better. The idea was presented to the USARP offices of the National Science Foundation, and both Schevill and Lt. D. Lavallee of the U.S. Navy submitted sketch designs. With USARP support, a chamber was built by Alpine Geophysical Associates. It is still at McMurdo Sound in the Antarctic according to plan, and was a very successful tool during this trip.

The sub-ice observation chamber was the outgrowth of an interest that has existed here at the Woods Hole Oceanographic Institution ever since the war.

Mr. Schevill prepares to go down into the "inside-out aquarium" to study Weddell Seas below the Antarctic ice. The inside temperature of the chamber was at the freezing point.



CARLETON RAY

W. Schevill, A. Vine and others have been interested in direct visual underwater observation. Many designs have been sketched for observation chambers to be used on submarines, on surface ships and independently. There has, however, been little success in getting them built until (with the support of several others) the bow chamber of 'Atlantis II' resulted. The 'Alvin' with its observation capabilities is another step in the same direction. And now we have the Antarctic sub-ice observation chamber, which Schevill calls an "inside-out aquarium".

The chamber turned out well worthwhile. It permitted underwater observation by the hour, instead of by the minute, as with divers. Moreover, unlike scuba divers, it made no noise to interfere with sound recording, and, once in place, it did not disturb the seals much more than a duck blind disturbs ducks. It became a part of the underwater landscape, and it enabled us to match observed seal behavior with the sounds heard.

Transparency

The extraordinary underwater visibility during the Antarctic springtime permitted us to see seals nearly 65 meters away. As the season wore on, the accelerating plankton growth made the water less transparent, and a few weeks after we left (about Christmas time), the visibility had deteriorated, we are told, to about 10 meters.

We did not heat the chamber, so that we had almost no trouble from condensation inside. With a loose lid on top, for darkness and warmth, the internal temperature stayed near 0°C. (the water outside was —1.9°C). No forced ventilation was necessary. An observer would stay a couple of hours at a time.

Mr. Watkins surrounded by listening and recording gear in a shack built on the ice. Curious seals occasionally came up through a hole in the shack to inspect his works.

CARLETON RAY

The builders did not entirely follow our plans, so that the chamber turned out smaller and longer than intended. We had hoped to have two observers in it together, but there was room for only one. We had planned internal ballast; the builders fitted outside ballast on a long extension, so that the total assembly was awkward to handle. The next one should be larger and shorter, with inside ballast, so that there would be more room for cameras and a second observer, and to make the chamber easier to handle from a ship or from the ice.

The chamber was held in place by three arms from which cables extended through the ice to toggled stops. The observer's head was about 2 meters under the ice (about 4 meters below the water surface). There were outside lights for photography.

Instrumentation

A fairly complicated instrumentation system accompanied the use of the under-ice chamber and was remarkable considering the logistics required for any Antarctic work. A hydrophone array was lowered with units at 300 meters (10 meters off the bottom), 150 meters, and 10 meters, plus a fourth unit used intermittently at 30 to 45 meters. Running voice commentary of visual observations from the recording shack as well as from inside the chamber was recorded on tape along with the hydrophone information. Two high-fidelity monitoring systems capable of listening to any of the hydrophone channels were located in the chamber and in the recording shack. An intercommunication system was maintained between the chamber and the recording shack. A visual monitor utilizing variable filters and a cathode-ray-tube read-out was used for receiving frequencies above and below the audio spectrum. Two large laboratory-type tape recorders (Modified Crown Series 800) were used for recording the signals and these machines as well as the portable equipment were synchronized together with a high-frequency precision timing system. A high-frequency echo sounder with a trainable multiple head was used in a number of frustrated attempts to follow seals acoustically as they came and went, and did give a good map of the local bottom conditions. Maintenance tools, equipment, and spare parts helped to fill up the left-over space in the recording shack. A shock-mounted gasoline generator provided the heavy-load power and was located 150 meters away to keep noise levels to a minimum; battery stacks provided power for really silent listening.

MR. WATKINS is in our Department of Geophysics and works with Mr. Schevill on the recording and analyzing of sea-sounds.

A four-foot hole cut through the ice occupied one end of the recording shack. It was through this hole that hydrophone cables and echo-sounder heads passed, and it was through this hole that many good observations of seal reactions were made. On several occasions the curiosity of the seals actually brought them up into the hole for a long look at the world of electronics. It was also into this hole that we continually reminded ourselves not to step! It was 310 meters to the bottom!

Three holes

There were three holes cut in the ice, some 20 metric tons of ice, all moved by hand. One hole was for the sub-ice observation chamber, another hole was for the instruments and a third hole was for the seals. The seals began to use their hole even before we had completed our installation.

The acoustic observations from this "cruise" included over 42.700 meters of sound on tape. Analyzing this promises to occupy much of this winter's effort. Besides a complete physical description of the sounds of the Weddell seals, we'd like to know how depth affects their calls, what significance the different calls have, and what sort of echo-ranging abilities, if any, they possess.

The coordinated combination of good visual as well as good acoustic observation provided a clear glimpse into part of the daily routine of the Antarctic Weddell seal. Looking while listening increased the chances of learning manyfold.

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