METHODS OF OCEAN CURRENT OBSERVATIONS NOW USED BY THE HYDROGRAPHIC DEPARTMENT, TOKYO, AND SOME RESULTS OBTAINED TO DATE

(From a study by COMMANDER S. KISINDO, I.J.N.,
communicated to the International Hydrographic Bureau.)

Most of the existing current charts and descriptions are by-products of navigation, based on currents reported by seamen from dead reckoning.

But when it is a question of construction of truly reliable current charts, entirely satisfactory for navigation, the necessity naturally arises of securing the basic data by special survey ships.

The Hydrographic Department began a detailed investigation of ocean currents in 1929. Since only one ship is engaged in ocean current investigation the area investigated each year is limited. In 1929 it was the Tosa offing; 1930 the area from Taiwan to Nansei Syotô; this year (1931) investigations from the Sio Misaki offing to Inuboyegasaki were commenced.

The surveys are twice a year, summer and winter; summer from July to September inclusive, winter from January to March inclusive.

The methods of survey may be classified under the following 5 heads :-

1. Direct measurement of surface flow by means of current floats.
2. Measuring the current by means of current indicators.
3. Measuring the temperature and salinity of the water and calculating the current dynamically.
4. Studying the water system by examining the physical and chemical nature of the sea water.
5. Studying the changing conditions of ocean currents.

Besides the above, depth measurements and investigations of wind currents in the higher strata are carried on at the same time but this has nothing to do with ocean current survey.

1. DETERMINING THE DIRECT SURFACE FLOW BY MEANS OF CURRENT FLOATS (OR FLOATING BUOYS).

The Hydrographic Department uses the method of putting out a large number of current floats at the same time, covering a wide range, and examining the ocean currents by following up their movements.

By this method a line of 40 to 50 miles is chosen and on this line the aforesaid floats are placed at intervals of about 4 miles, the survey ship following their movements during the day and by night (with light buoys) during about a day and a half.

This method is applicable only when weather conditions are favourable.

However, because of the present day knowledge in weather forecasting it is very often possible to forecast the weather at sea for one or two days in advance.

By using a good telescope, and provided the current does not change discontinously, the floats can generally be discovered easily in their order.

The advantage of this method is in being able to know the condition of ocean currents over a wide area at the same time, which is exceedingly convenient when determining the width of an ocean current.

Again, arrangements are made by which the current floats, after the location has been completely determined by the survey ship, are arranged to be picked up just as they are by fishing boats engaged in fishing.

This may be regarded as something of an improvement on the ocean current bottle.

In the case of the current float, since it is practically unaffected by wind and can be picked up so readily at sea the data thus secured is the best of all for ocean current surveys.

The line for laying out the current floats is as a rule determined by knowledge of existing currents. In the survey of the Tosa offing in the summer of 1929 by the *Mansyû*, 15 lines were designated, 12 of them being actually surveyed.

2. CURRENT SURVEYING BY THE CURRENT INDICATOR.

When we make ocean current surveys in the open sea we use the current indicator while drifting. The method is to lower current indicators simultaneously into a layer near the surface (10 to 20 m.) and into a deep layer (500 to 600 m.) where there is supposed to be no current, and by combining the vectors of the two currents measured to compute the surface current.

By observing all sorts of layers with the current indicator and from other known data it is not so difficult to decide the stillness layer in each locality.

The point of advantage in this method, as in the case of observations by the current float, is that it is not necessary to determine accurately the position of the ship.

Another advantageous point is that current observations can be made in a very short time. If it is only a surface current which is to be determinated, probably it can be done within an hour.

The disadvantage of this method is that where the current is swift the angle of slant in the suspending wire is so great that the measurement cannot be taken, and in case of a week current of less than one knot the result is generally bad.

Again, in this method there are two assumptions, *i. e.* that the 10 to 25 meter layer has the same flow as the surface, and that at a certain depth there is no ocean current. Naturally if these assumptions are erroneous the result will be erroneous. And when there is a drift current caused by wind the assumption that the 10 to 25 meter layer has the same flow as the surface is irrational.

3. MEASURING THE TEMPERATURE AND SALINITY OF THE WATER AND CALCULATING THE CURRENT DYNAMICALLY.

In Japan, BJERKNES' dynamical method has been tried several times, but generally good results were not obtained.

If the "Kurosio" flows mainly by the influence of an outer force, such as the Trade Wind, it is but natural to consider that the current cannot be determined by the investigation of the mass distribution of sea water.

But it can be assumed that the main cause of the insufficient results obtained when the dynamical calculation of the ocean current was formerly tried in this country may be attributed to possible deficiencies in observation, as well as to the inadequate application of the theory to the practice.

In actual fact, the result obtained in 1929 off the coast of Tosa shows that the currents determined by means of dynamical calculation compare well with those obtained by direct observations by means of current floats and other means.

Method of taking samples of sea water and of temperature measuring.

Taking the samples and measuring the temperature are made in regard to the following layers: surface, 10, 25, 50, 100, 150, 200, 300, 400, 500, 600, 800, 1,000 and 1,500 meter layers.

For taking the samples of sea water from every layer between the surface and the depth of 300 meters, KITAHARA's heat-insulated water bottle is used.

The temperature of the water is measured by the immersion of an ordinary thermometer into the tube immediately after the bottle has been hauled in.

In this Department the RIGO's reversing water bottle (EKMAN type bottle with reversing thermometers by NEGRETTI & ZAMBRA) is used for temperature measurements of the layers deeper than 400 meters.

For taking a sample of sea water at a given depth, a water bottle is lowered by a steel rope and the depth is determined by the counter which shows the length of the rope run out. However if the rope is not in a vertical line, the length of the rope run out does not show the exact depth. Therefore at present the method of using an unprotected thermometer which indicates the depth by the water pressure is in general use.

In the case of twin-screw vessels, as our surveying vessels are, the use of the unprotected thermometer is not necessary, since it is easy to manœuvre such vessels so as to keep the rope vertical.

Though the steel rope appears to stand vertically in the layers near the surface it may have more or less inclination from the vertical line in deeper layers due to the difference in currents. But the error in depth caused by such inclination is very small and it is questionable whether this error is greater than the errors of the unprotected thermometer.

Determination of Salinity.

The sample of sea water taken is subjected to titration with silver nitrate to examine the quantity of chlorine contained, and the salinity is obtained from KNUDSEN's tables.

Dynamical calculation of the current. (1)

If the current of a certain region is to be determined by means of dynamical calculation, a great number of observing stations must be selected, the dynamic depth at each station must be observed, and then, examining the distribution of dynamical depths, lines connecting points of equal dynamic depth (isobaths) are drawn, and finally the velocity and direction of the current must be determined therefrom.

A chart showing the currents dynamically calculated according to this method has been compiled by means of the results of the observations made by H.I.J.M.S. *Mansyû* off the coast of Tosa in the summer of 1929 (Fig. 1).

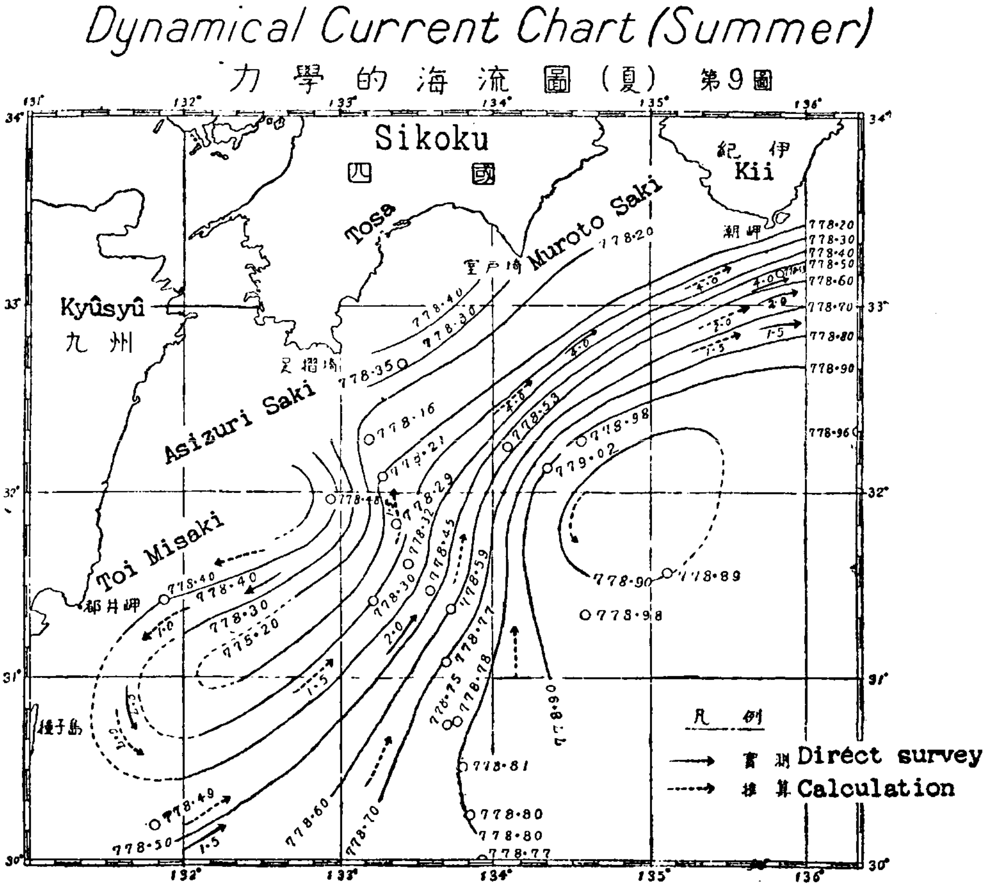

Fig. 1.

4. STUDY OF THE "KUROSIO".

This Department has been carrying on a detailed investigation of the Kurosio since 1929. Up to the present time several oceanographic elements between the sea surface and depths varying from 800 to 1,500 meters have been observed at approximately 300 stations in a region extending from the approaches to the Luzon Strait to the Izu Islands. It is the intention of the author to give here a brief outline of the general characters of the current.

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(1) *The explanation of the method for dynamical calculation of the current which Commander Kisindo has developed for the benefit of Japanese oceanographers is not reproduced here.*

It is to be regretted that up to now no boundary is established between the Kurosio and the bordering oceanic waters.

If the sea water is observed merely from a qualitative view point there is no clear distinction between the current and the bordering water. For instance the Kurosio is treated in such articles as if it differed only in having a higher temperature and a higher salinity than the bordering water. However, not only the outer boundary of the Kurosio cannot be determined merely by the differences of the temperature and salinity, but also the temperature and salinity generally become higher near the boundary. Such being the case, to discuss the Kurosio by a mere qualitative investigation of the sea water with no reference to the boundaries leads to errors. Therefore, let us first give a definition of the Kurosio and then discuss it.

Heretofore the Kurosio has been considered generally as a stream current which flows like a large river from off the east coast of Taiwan (Formosa) to the sea east of the "Sanriku" district (Rikuzen, Rikutyû and Mutu provinces of north-east part of Honsyû), and that the water flowing off the coast of "Sanriku" is the same water which flowed off the east coast of Taiwan. However, that the Kurosio is not such a simple stream current can be easily determined by an investigation into the breadth, depth and velocity with reference to the principal profiles in the Kurosio area, and by the estimation of the quantity of water passing through the main channels in the area as well as by an examination of the trend of the isobaths of the dynamical current charts.

It is true that there is a northward flowing current off the east coast of Formosa, a generally north-eastward flowing current in the west side of the South-western Islands, a current running from the east coast of Kyûsyû to Sio Misaki, then running in the direction of Mikura Sima in the sea south of Japan, and a generally north-eastward current off the east coast of the Sanriku district. It is also true that the breadth of these currents is about 30 miles at the narrowest and 60 miles at the broadest parts, and the water making up these currents is partly, if not entirely, of the same origin.

These currents of oceanic water which exist in a region between the eastern sea area of Taiwan and the eastern sea area of Sanriku district, flowing in a direction varying from north to east (through north-east), are called the Kurosio *en bloc*. The most important fact concerning the Kurosio lies in that it has a remarkable velocity. Since it is a current which takes its origin in oceanic water, it is but natural that it has qualities similar to the oceanic water in its vicinity. Although the water is qualitatively similar to that of Kurosio, it cannot be called the Kurosio if it is not flowing in a direction between north and east (in the north-east quadrant). Mariners in general have been accustomed to consider the Kurosio as stated above. Neverthless this statement is made purposely for the benefit of those who treat the Kurosio as a body of water without taking due account of its direction and velocity.

(A) *Surface temperature.*

Until recently when a detailed investigation had not yet been made the sea water in the Kurosio area was considered to be higher as regards surface temperature than the water bordering it. In addition the part of the highest temperature had been thought to be the axis of the Kurosio. However, it is an ordinary phenomenon that in winter the surface temperature of the Kurosio at the northern or western edge is higher than that of coastal water, while in summer, as the temperature of the coastal water increases such differences in temperature disappear. Sometimes it is noticed that articles which deal with the Kurosio from the point of view of temperature only, say, that when the temperature of the coastal water increases from the spring to the beginning of summer that the Kurosio is nearing the shore. This is not correct. (It is also incorrect to consider that the Kurosio approaches the shore in summer and recedes in winter).

In most cases throughout the year the southern or eastern boundary of the Kurosio is not only distinguishable by the difference in the surface temperature, but the temperature of the water outside the Kurosio is even higher than that in the current itself. Of course at a considerable distance off the southern boundary of the Kurosio the temperature falls, that is in the region where a westward flowing current exists. However, at the southern boundary and in its vicinity the temperature generally does not decrease.

From the foregoing explanation it can be understood that it is incorrect to try to determine the Kurosio area from a study of the distribution of the surface temperature or to consider the part of the highest temperature to be the axis of the Kurosio.

(B) *Salinity of the surface.*

It is incorrect also to consider that the Kurosio is the water of especially high salinity, that the salinity at the surface is higher within the stream than outside, and that the part at which the salinity is maximum is the axis of the Kurosio. Some-investigators even go so far as to say that the salinity of the Kurosio at the surface is always about 35 ‰ and is higher by 1 or 2 ‰ compared with that of the coastal water. However, investigations in the Kurosio area show that in summer, in a region extending from the east coast of Taiwan to Hatizyô Sima, the salinity at the surface is generally less than 34 ‰, rarely exceeding 34.5 ‰, and on the northern side of the Kurosio the boundary between the Kurosio and the coastal water is not discernible. On the other hand, on the southern side the salinity is even higher outside the Kurosio area than inside. Therefore, the conclusion that the axis of the Kurosio can be clearly detected from the distribution of salinity seems to be a hasty assumption deduced from the preparation of a salinity distribution chart, without estimating the velocity and direction of flow, and assuming that the axis of the Kurosio is where the salinity is highest.

In winter when the salinity in the Kurosio area increases to 34.7-34.9 ‰ the salinity outside the stream also increases, so that it is impossible to determine any difference between them. In the other seasons the condition is roughly the same. Consequently it is a great mistake to consider that the Kurosio can be determined from the trend of the surface isopycnal lines or to consider the part of the highest salinity to be the axis. This is true as regards not only the surface but also as regards the middle and lower layers.

(C) *Temperature distribution below the surface.*

Below the surface in the area where the water is changing from coastal to oceanic there is a section where a remarkable change in temperature takes place. For instance in the vertical profile taken across the Kurosio off Onmae Saki, isothermal lines of 20° C. or less have remarkable inclination. Away from the coast these isothermal lines gradually decrease in inclination until they become horizontal. The parts where the isothermal lines have inclination are the places where the Kurosio flows. Now imagine an innumerable number of longitudinal vertical sections perpendicular to the above mentioned profile, and let dn be the distance between these sections and dT be the difference in the mean temperatures between these sections, then the section of which the value of $\frac{dT}{dn}$ is maximum can be obtained. Let this longitudinal vertical section of the maximum $\frac{dT}{dn}$ be called the *section of the maximum temperature gradient,* then this section represents the axis of the Kurosio. Consequently it can be concluded that in deeper layers too, the axis of the Kurosio is not where the temperature is highest, but is where the transversal gradient of the temperature is most remarkable.

This conclusion is one of the valuable results obtained by comparing the distribution of velocities in the Kurosio area based on the direct observations and the distribution of velocities based on dynamical calculation with temperatures. This is the important point and shows that the assumption that because the Kurosio is a warm current it should have an area of high temperature as its axis, or, going even further, the trend of isothermal lines of a certain section alone, cannot outline the limit of the current. It was found that where the temperature gradient is large the Kurosio area offers the basis of successful dynamical calculation of the Kurosio. If the part of highest temperature is the axis of the Kurosio the velocity of the Kurosio cannot be obtained by dynamical calculation. This, of course, having a bearing on the salinity distribution, is mainly because the variation of the specific gravity of sea water is more affected by the temperature than by the difference in salinity.

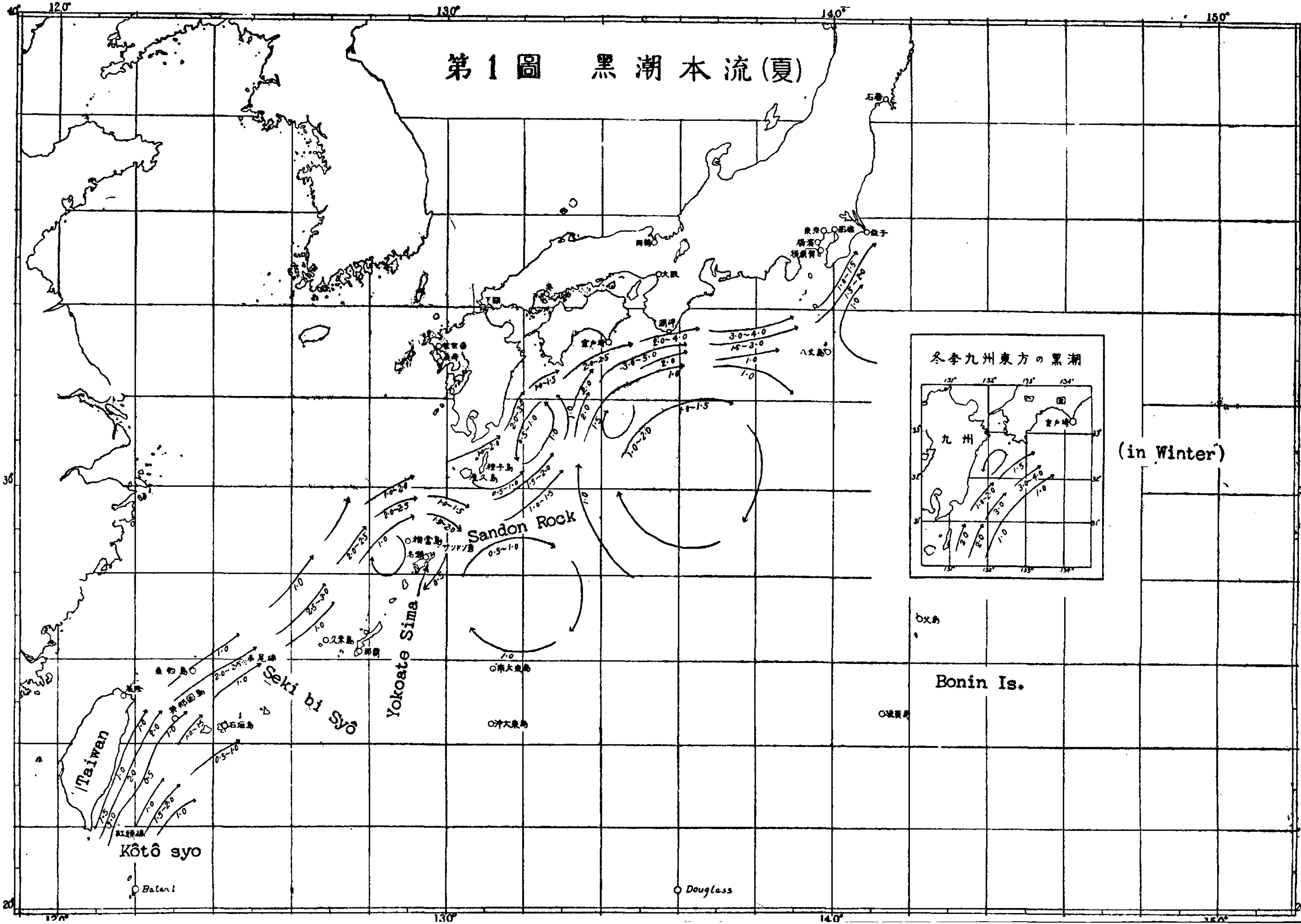
(D) *Salinity below the surface.*

Observations have shown that the salinity below the sea surface too, gradually increases away from the shore, and at the southern boundary of Kurosio no distinctive features can be observed.

If the water system were investigated under the simple assumption that the Kurosio consists of high saline water, without taking into account the distribution of velocities, the breadth of the Kurosio would be very great indeed. However, this does not show the Kurosio area at all, and the result is nothing more than an investigation of salinity distribution.

Kurosio Main Stream (Summer)

FIG. 2



Intermediate water (Zwischen-Wasser).

Observations have enabled us to ascertain the existence of an area of less saline content between the 500 and 1000 meter layers (near the coast the top of such water reaches as high as 200 meters), but that above and below these there are higher saline layers. This layer of small saline content is called the *Zwischen-Wasser.*

Some say definitely that the *Zwischen-Wasser* in the Kurosio is an under-current of the "Oyasio". However, this is a subject for future study, because the *Zwischen-Wasser* not only exists in the lower layers of the Kurosio or in regions where it is considered possible for the Oyasio to enter the Kurosio, but also according to the results of investigations of this Department, it exists almost everywhere to the north of the 10th parallel of north latitude in the western part of the North Pacific. (The Oyasio is also an ocean current with a considerable velocity).

In the vicinity of the Kurosio the upper surface of the *Zwischen-Wasser* exists in comparatively shallow layers near the coast and in deeper layers offshore. In other words, it is a phenomenon that the upper surface of the *Zwischen-Wasser* has a remarkable inclination.

5. MAIN BODY OF THE KUROSIO.

Based principally upon the data and results obtained from current investigations during the period from 1929 to 1931 (by direct observations employing current floats, current meters etc. and by dynamical calculation from the mass distribution of sea water) with additional information from former surveys and reports from vessels, the general aspects of the Kurosio between the east coast of Taiwan and the Izu Islands have been arranged into a chart as shown in Figure 2.

This chart shows the conditions of the Kurosio in summer.

There is no great difference between the summer and winter aspects of the Kurosio as regards either its direction or velocity. Where winter conditions differ greatly from summer conditions these also are given (see inset Fig. 2).

(1) *East coast of Taiwan.*

The breadth of the Kurosio between Garan bi and Kôtô syo is about 25 miles with its centre in lat. 22° 0' N., long. 121° 10' E. The direction of flow is nearly N.N.E. The rate is about 3 knots in the middle part, decreasing towards both edges until it becomes about 1 knot in the vicinity of Kôtô syo, and 0.7 knot at a point 7 miles off the east coast of Taiwan.

A north current with a speed of 1-2 knots and a breadth of about 30 miles flows eastward of a point 20 miles east of Kôtô syo. This current as it goes northward increases in breadth and greatly decreases in rate and to the south of Miyako Rettô flows easterly. At the parallel of 23° N. the Kurosio extends from the east coast of Taiwan to nearly 40 miles offshore and the direction of flow is nearly N.N.E. The velocities are 1.5 knot 5 miles off the coast, 2 knots (which is the strongest) in the neighbourhood of 25 miles off the coast, and 0.5 knot 40 miles offshore.

Between Suo and Yonakuni Island the current has a breadth of about 40 miles and a rate of approximately 2 knots and except near both edges flows north-north-east-north-eastward.

Between Yonakuni Sima and Isigaki Sima, the current flows north-eastward with a rate of roughly 1-1.5 knots, though this is affected by the tides.

While the current off the east coast of Taiwan in winter has no great difference from that in summer, it is generally a little stronger in velocity and the stream to the east of Kôtô syo is less remarkable in winter than in summer.

(2) *North-western side of the South-western Islands.*

In the north-western side of the South-western Islands the northern boundary of the Kurosio coincides roughly with the 200 meter depth-contour line in the Tung-hai and the current has a breadth of 50-60 miles flowing in a direction parallel to the Islands. Velocities of 2 to 3 knots are found in the parts which can be regarded as the axis and 1 knot or thereabouts at the northern and southern boundaries. Local references follow :-

In a line drawn south-east from Uoturi Sima the breadth is nearly north-east, and the velocity is 2 to 2.5 knots from Uoturi Sima to 40 miles south-east of that island, thence it decreases gradually until it becomes 1 knot or less at 60 miles. The axis of this current washes Sekibi Syo and proceeds north-eastward.

In the north-west line of Kume Sima too, the breadth is about 60 miles, and the direction is a little north of north-east. The axis is about 45 miles north-west of Kume

Sima, the velocity there being 3 knots, which decreases towards both edges where it is about 1 knot.

In the north-west line of Yokoate Sima the breadth is about 60 miles beginning from a point 20 miles north of the island. The velocity attains its maximum of 2.5 knots at 40 to 50 miles north-west of the island. It decreases gradually toward each edge approximately to 1 knot. From this vicinity the current turns slightly to the east, and a part on the northern side turns towards Osumi Kaikyo, while the remaining part tends even farther east toward the channel between Yaku Sima and Amami-ô sima.

(3) *Tokara channels.*

In the Osumi Kaikyo there is generally an eastward flowing current of from 1 to 2.5 knots (which is the highest in the middle part of the strait). On the northern side near the coast of Osumi a weak counter-current is very often encountered.

Between Yaku Sima and Sandon rock to the north of Amami-ô Sima a south-westward flowing current of 1 to 2 knots is found, but to the south of the rock generally no current is observed.

(4) *In the sea south of Japan proper from the east coast of Tanega Sima to the Izu Islands.*

Hitherto, it has been generally considered that the water passing through the Tokara channels forms the main body of the current flowing in the sea south of Honsyû. However, considering the fact that the quantity of water coming through Osumi Kaikyo is very small and that the current between Yaku Sima and Sandon Rock always flows south-easterly, and in addition the trend of isobaths obtained by dynamical calculation, it has been discovered that a secondary vertical current, which has its central part nearly in lat. 30° N., long. 136° E., has great influence on the current flowing south of Honsyû. It is assumed that a part of the current which passed between Yaku Sima and Amami-ô Sima joins the northerly flowing part of the above-mentioned secondary vertical current and thus forms here the main body of the Kurosio flowing toward Tosa offing.

In the sea south-east of Tanega Sima, from 40 miles south-east of the island, the current flows north-easterly with a breadth of about 40 miles and at a rate of 1.5 to 2.0 knots. As the current prodeeds northward and its western side reaches a point about 60 miles south-by-east of Asizuri Saki, this western part begins to turn gradually to the left, forming a counter-clockwisely turning eddy current in the area between the main current and a current flowing northerly along the east coast line of Kyûsyû, which is referred to later.

The left half of this eddy current flows to the south-west at a rate of about 1 knot. It appears that this part has been generally considered to be within the main area of the Kurosio; however it is an area where the greatest care in navigation is necessary since the current in this area runs in an opposite direction to the Kurosio. In winter this eddy recedes within a line connecting Toi Saki and Asizuri Saki and becomes very small.

Off Toi Saki, the east coast of Kyûsyû, outside of the 200 meter depth contour, there is a northerly flowing current with a breadth of 10 miles. The velocity is 3 knots at its strongest part. This current gradually trends to the right as it proceeds northward running toward Asizuri Saki and joins the main body of the Kurosio off Tosa Bay.

To the south of Muroto Saki the main stream of the Kurosio flows from 10 miles south of the cape with a breadth of about 50 miles and a velocity of 2 knots or more toward east-by-north. At the so-called central axis the velocity varies from 2.5 to 5 knots, with a breadth of about 20 miles.

There is an easterly current running at a rate of 3 to 4 knots to the south of Sio Misaki, which extends from the cape as far as 20 miles to sea; the rate becomes 2 knots at points about 30 miles off the cape and decreases to seaward, while at about 70 miles offshore there is again an easterly current running at a rate of 1 to 1.5 knot with a breadth of about 20 miles.

The main body of the Kurosio off Sio Misaki flows eastward maintaining nearly the same breadth and velocity until it reaches a line drawn south-south-east from Onmae Saki; thence a part runs toward off Nozima Saki passing between Miyake Sima and Mikura Sima and southward of the latter island. The other part turns to the right becoming a southerly going current.