THE EQUATORIAL CURRENTS IN THE WESTERN PACIFIC OCEAN

by

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As is shown by the four annexed charts which constitute the basis of the whole substance of our work, our investigations extend to the waters situated between latitudes 15° N and 5° S and also between Longitudes 125° and 160° E. From the land level rise up notably in the North western portion of the Philippine Islands, the east coast of Mindanaos and further north, the islands of the much frequented straits of San Bernardino; to the north we find Guam and to the East the high island of Ponape in the Caroline Islands. The south boundary is a part of the Bismarck Archipelago as well as the northern coast of New Guinea. The Moluccas and Halmahera (Djilolo) with the adjacent waters close the frame in the South-West. Within this area we also find the Palawan group and the isle of Jap which are important from a descriptive point of view. The area of the region under consideration is moreover considerably greater than that of the Mediterranean and Black Seas.

Today, unfortunately, these waters are almost completely outside the horizon of our sea routes. After the world's war and for several years the two Norddeutscher Lloyd steamers "Friederun" and "Bremerhaven" maintained a regular connection between Hong Kong, the Bismarck Archipelago and Sydney; today only the "Friederun" still sails at intervals of about six weeks between Hong Kong and the Bismarck Archipelago, as the Australian Government have put a stop to any further traffic from the Bismarck Archipelago to Sydney on the plea that it constitutes foreign shipping between Australian territories (!) If, notwithstanding, a detailed German description of the very remarkable surface currents of this ocean area can be given, it is thanks to the plentiful available German observation material obtained through prewar navigation. It has been collected from the 12 original Charts of C. PULS (1) which are to the same scale as the two charts annexed hereto and were in the custody of the Deutsche Seewarte. A comparison of the 12 current charts compiled by C. PULS, eight of which are particularly small, with his working charts had years ago proved to me that specially in view of the latest theoretical conceptions, from an oceanographical stand point, considerably more can be obtained from his observations than was possible 44 years ago, so valuable was his first work. The very fact that the mislocations he made, although carefully noted and critisized, were judged quite adequate for a new study of the western part, speaks for the excellency of his effort. The fact that these mislocations were made from sailing vessels which as a rule only travel over small or middling distances, was lucky for Puls' work at the time. It can therefore be assumed that the mislocation observed for a day's reckoning corresponds mostly to the actual "average" current, which naturally is not at all always the case with fast power propelled vessels. Under these conditions, there is some justification in omitting from the new worked produced today any material arranged and recorded in one degree fields. I have nearly always been able to dispense with unreliable calculations in connection with currents for spaces of time largely in excess of 24 hours.

From a mapping point of view, I followed a different course from that of PULS by combining in a single sheet the results of each of four months' observations and dividing them by means of colours only. With regard to the northern hemisphere winter the translations for December, January, February and March have been compiled together (Table 26)

(1) Upper surface temperatures and current conditions in the equatorial zone of the Pacific Ocean, from the Records of the Seewarte, Vol. 18, Hamburg 1895.

and similarly with regard to the Northern hemisphere summer those for June, July, August and September (Table 27). The two intervening months are of great importance, particularly as they supply the richest material. This method may be supported by technical considerations in the case of a special study, but whoever studies accurately the results given in the charts will agree that the illustrative representations are made more reliable by an accumulation of current arrows on account of the peculiarities of the current in our region which are quite of a special nature and are often strongly influenced by the neighbourhood of land. Except in rare cases, viz, when space is completely lacking, all the four main months separate translations — which was of course of importance — have been introduced into the 1 degree fields. Moreover, as is shown in the charts, it is a matter of hardly more than two dozen current arrows which fully bring out the directions diverging from the other "train of waters" (Zug der Gewässer) especially in June and also in March on the East Coast of New Mecklemburg. Errors in calculating the current or registering on board are naturally not altogether excluded. *The actually overwhelming uniformity of the current directions during various years is the peculiar feature of Nature's phenomena in that part of the world.* Moreover it is possible at any time, as the months are differentiated by colours, to proceed to a new grouping of results or even to refer back to the results of any particular month. PULS's manuscript charts also give and make use of the reckonings made by the German warships which often used to sail in these waters before the war.

To this foundation which certainly includes from 85 to 90% of all the current arrows. I have added the valuable observations taken from new material and supplied by the two above mentioned Bremen steamers "Friderun" and "Bremerhaven" for the years 1932 to 1938. Their courses always run across the area in a N.W. — S.E. direction, they are sometimes sharply traced, although with discretion on the strong currents and (or) on certain points in the Philippine Islands but at all events are very useful for the filling up of the charts. Finally the particular translations drawn from recent Dutch chart work (2), and given in Tables 1-6 have been transferred, but current arrows which have been made out arithmetically from more than one text are quite exceptional and as such are brought out by putting between brackets the number of observations made. As may be seen, the data used for this work are the outcome of two thirds of a Year's experience. Only the transition months of April and May on the one hand and October and November on the other hand are missing. I may perhaps be in a position to give them later. These months will produce changes which are of chief importance as far as strength and direction are concerned only on the south edge of the north equatorial current at the expense of the counter current, as well as in the region to the North of New Guinea, but not in the Mindanao area, for instance, since this offers, so to speak, an ideal yearly stability of movement, as will be shown later.

Before we proceed to an examination of the results of our work, two introductory remarks should be made. 1°) A glance over the very instructive charts of current arrows which are grouped almost everywhere to illustrate water movements fills us more and more with a feeling of gratitude for the masters of the German sailing vessels who collected such valuable material in their ship's journal for the Deutsche Seewarte, under mostly very trying conditions and during long and toilsome voyages. Those regions of the so called "eastern passages", from the time of their discovery, have gained a very bad name on account of the frequent calms, poor or contrary winds and the greaat resultant current changes. It is a duty of honour to remember on this occasion those men of the last decade, as I endeavoured to do elsewhere some time ago. (3) The two black charts of current lines are based on many reflections, renewed efforts and investigations. It may be that another oceanographer could obtain quite a different picture from these data. Personally, I would not welcome such an undertaking. These charts can, each in its own way, lend themselves to many a scientific speculation, especially as regards the equatorial counter current, the formation of which in the three oceans, A. DEFANT (4) dealt with from a physical stand point, not very long ago.

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(2) Kon. Nederl. Meteorolog. Institut, Oceanogr. en Meteorolog. Waarnemingen in de Chineesche Zeeën etc... 's Gravenhage 1935/36.

(3) Geographie des Indischen und Stillen Ozeans, p. 354, Hamburg 1935.

(4) The equatorial counter current. Sitz-Bericht der Preuss. Acad. der Wissensch. XXVIII, Berlin 1935.

I. NORTHERN HEMISPHERE WINTER (CHART 26).

At this time of the year, the N.E. trade wind, which towards the asiatic side is generally described as N.E. monsoon, is mostly strong and steady at least as far as Latitude 10° North. Very few calms are encountered north of Latitude 10° N.; see month of January on fig. 1 of the text (5). On Jap Island (Lat. 9° 30' N., Longitude 138° 10' E.) 93 to 95% of all the observations made during the months of January and February come from N, NE and E. directions. It is only south of about Lat. 7° N. that the calms become more frequent: they reach their maximum of frequency before the N.W. side of New Guinea, where, as is well known the N.E. winds south of the line usually turn to the N.W. and are called N.W. monsoon.

During the four winter months, the velocities of the north equatorial current are peculiar, in a few isolated cases they actually vary from 0 to 50 nautical miles per 24 hours ship's run, but in the large majority of cases, these velocities lie between 15 and 22 miles and are therefore considerable. In any case the water movement is then considerably stronger and particularly steadier than during the Northern hemisphere summer. This may incidentally be noted as an important peculiarity of the Kuro Siwo; Japanese observers and authors agree that the Kuro Siwo shows no noteworthy or positively perceptible change in its average speed in the course of the year, although the prevailing wind coming from the Riu Kiu Island, blows from the front in the winter and from the back in the summer. The cause of this is most likely the different seasonal strength of its main source; in the winter the Kuro Siwo assumes the character of a pressure current in the foreground but becomes more like a wind drift current in the summer.

The direction of the north equatorial current, the south edge of which, as a rule, is to be found in Latitudes 6° to 7° N. runs definitely towards W.N.W., and more northward, in its northern half, while in its southern half, it runs with a wave-like swing towards W.W.S.W. also towards W.N.W., but becomes strongly marked towards S.W. and South, when nearing the east coast of Mindanao. The resultant line of divergence runs from East to West in Latitudes 10° to 11° N. with a characteristic transfer movement to the North before the Leyte and Samar Islands in the Philippine group, so that still in the neighbourhood of the San Bernardino Strait the water turns off southward. The northward movement of the separation line up to Lat. 13° N. in the vicinity of the Islands is clearly shown every month by the direction of the current displacement.

Two drift bottles dropped into the sea (6) by Japanese investigators produced decidedly concurrent results; after starting respectively from points situated in Latitude 12° N. and Longitude 129°5 W. and Latitude 13°2 N. and Longitude 127°5' W. they both landed at the Palau Islands.

On account of its uninterrupted and so to speak hundred per cent, steadfastness during the whole of the year in the vicinity of the eastern side of Mindanao, the current flowing southward deserves to be described as the Mindanao-current. Translations with north components, as a rule, are not reported. Ships sailing from North to South make frequent use of the current, as inside an area extending to within 50 miles of the coast, it runs at the rate of at least 1,5 knot or 0,8 m./sec. When sailing on the Dutch steamer "Tjimenteng" in May 1929 in a south direction in the vicinity of Cape S. Augustin which juts out far away to the south, we were favoured by a current of over 2 knots. Enclosed between Mindanao and a large eddy area appearing clearly on the chart in Latitude 7° North and Longitude 130° East, the Mindanao current reaches W.E. width of 150 miles and supplies mainly from this front the bodies of water, which, about this time of the year, constitute the foundation of the equatorial counter current. That the Mindanao current with a S. - S.S.W. direction really increases in strength every month is shown in the Dutch atlas quoted above (foot Note 2). The following summary is based on this information and some further data.

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(5) In fig. 1 of the text the illustrative representations of winds have been given beyond the eastern limit of the current charts as far as Longitude 180°, in order to permit eventually the estimation of the driving forces encountered at the back of the currents.

(6) S. YONEMURA. — Note on oceanogr. works. Hydrogr. Department, Imp. Jap. Navy. Records of oceanogr. works in Japan, Tokyo, 1928.

East coast of Mindanao, level with Cape S. Augustin (Latitude 6°16' N. Longitude 126°12' East. — The current direction remaining always S.S.W.

MONTHS	Mean Movement	Number of Observations	Maximum	MONTHS	Mean Movement	Number of Observations	Maximum
January ...	49 Milles	3	72	July	48 Milles	3	75
February ..	46	2	88	August	39	9	?
March	36	3	76	September .	41	4	?
April	33	2	76	October ...	37	4	?
May	39	4	80	November .	46	3	80
June	38	4	64	December ..	48	6	80

If the Mindanao current, about Latitude 7° North., were compressed by a group of coral-islands situated in the East, in the same way as the Florida-Current is narrowed by the Bahama Banks on a 45 to 50 mile front width, its average upper surface speed would no doubt approximate that of the Florida current while the bodies of water rushing from the N.E. would collect together as if driven into a water pipe (6'). Only smaller portions of the Mindanao current penetrate the North Celebes Sea, particularly as in the southern part along the Minahassa the movement is directed towards N.E. and E. A great deal more of the Mindanao current mainly through a violent turn to the left and current displacings finds an outlet at the Talaud Islands and further north towards the East and North East. A current ocming out of the Moluccas Sea, west of Halmahera flows towards the ocean in the same direction. In this way, the East current through the junction of the two branches settles down in Longitudes 127° to 128° East and we have in Longitude 130° East a width of about 300 nautical miles in round figures between Latitude 7° and Latitude 2° North, for the counter current resulting from the junction of roots coming from N.W. and S.W. Obviously it is the north hemisphere water of the North equatorial current that supplies the larger share at this time of the year. The convergence line between the north equatorial current and the counter current lies somewhere in Latitudes 6° to 7° North. Both currents join here into a left turning eddy of bodies of water. In Longitudes 135° to 136° East, may be assumed the existence of a neutral zone; thus, for instance, in February 1933, south east of Palau, between Latitude 5°30' North, Longitude 137°34' East and Latitude 8°3' North. Longitude 135°42' E. and for a midnight position somewhere in Latitude 7° North Longitude 136°5' East, the steamer "Friderun" experienced a movement of only 1 nautical mile from the south and this in spite of a N.E. trade wind with a strength of 4 to 5. Moreover strong deviations from the general current are to be expected close to all large islands such as Palau, Yap, Guam, Ponapé, etc. The observations made by sailing vessels in this respect report a special acceleration of the movement caused mostly by the islands.

Two separate branches of the counter current can be observed within the area under review. The first, which is the western part reaches as far as Longitude 140° East; while remaining as broad as at the start, the current bends distinctly southward from its course, as the geographical latitude diminishes to the S.E. and South and through a regular wheeling round, immediately at the spot where flowing eastward from Halmahera and Morotai it reaches the open Pacific Ocean: this accounts for the southern movements in the Jildo Strait and at Waigeo which at that time caused a lot of trouble to north bound sailing vessels during the N.E. Monsoon; movements of about 40 nautical miles per 24 hours' ship's run are frequent in this first area; in isolated cases they reach 60 miles. The curve to S.E. and S. down to the neighbourhood of the Equator is assisted by many calms and light changeable winds coming from the northern semi-circle (N.W. Monsoon). Even in the areas to the North of Latitude 5° N. a calm or only light trade wind often prevails, so that the

(6') It is known that from 45 to 50 miles only off the Mindanao East Coast and parallel to it stretches the so called Mindanao deep-sea trench, with depths of over 9000 and 10.000 metres. It should be noted that the strong current has made somewhat difficult the wire soundings of H.M.S. "Planet" and the serial measurements of the "Snellius" Dutch expedition carried out in those great depths.

counter current pursues its course at a reduced speed also in its second, that is, its eastern sector, in any case from Longitudes 140° to 143° East and on a considerably narrower front, as it then only occupies the sea surface between Latitudes 7° and 5° North.

We come across the south equatorial current exclusively in the S.E. portion of our chart (Table 26). From the vicinity of the Equator, we have many and mostly strong movements to the West, plainly evident as far as Longitudes 140° and even 137° East. The west stream prevails also north of the Admiralty Islands. East of New Mecklembourg (New Ireland), entangled movements lead to the assumption of a neutral zone, yet, in March, seasonable S.E. Coast currents have not been observed (see above).

If the counter current were not so plainly and strongly delineated in the eastern half of our area, we could still describe the movements just mentioned between Latitudes 5° and 0° North as "North equatoriail current". For, there is no doubt, judging from wind conditions, that the N.E. trade wind which now prevails southward, is responsible for these Westward movements. PULS has already established this fact. S.E. trade winds are almost completely absent within the sea area under consideration and this is so almost as far as Longitude 180° E. The south equatorial is therefore, in our area, so to speak, a north equatorial current in disguise.

There remains the question which it is difficult to answer from an oceanographic stand point of the relation which necessarily exists somewhere, between the waters of the south equatorial current and those of the south branch of the counter current. I have located it in a westward bending line somewhere about Long. 140° E. We may also assume the presence of the south hemisphere waters of the equatorial current considerably further westward. The drawing in table 26 shows decidedly that only very weak and changeable drifts are reported from the western half of the north coast of New Guinea, while on the eastern hald of the same coast strong South eastward movements are prevailing, which may well have been looked upon as branches of the south equatorial current.

II. NORTH HEMISPHERE SUMMER (Table 27).

In August and, in many areas in September only, the counter part of the North hemisphere winter currents reaches its maximum. To a considerable extent this sudden change is directly connected with wind conditions. This is particularly true of the southern half of our area, south of Latitude 5° North, where the E.S. trade wind prevails and which did not come into the picture of wind conditions in January, or certainly only with frequent intervals of wind calms. In addition to this and within reach of Halmahera-Mindanao, is to be recorded the intervention of the S.W. Monsoon with its asiatic features which turns from South to South west (see Fig. 1). This summer monsoon still includes Yap, but as regards Guam, it must at this time share with the N.E. and E. trade wind, as indicated by the two lines for August.

PERCENTAGE OF WIND FREQUENCY. — AUGUST.

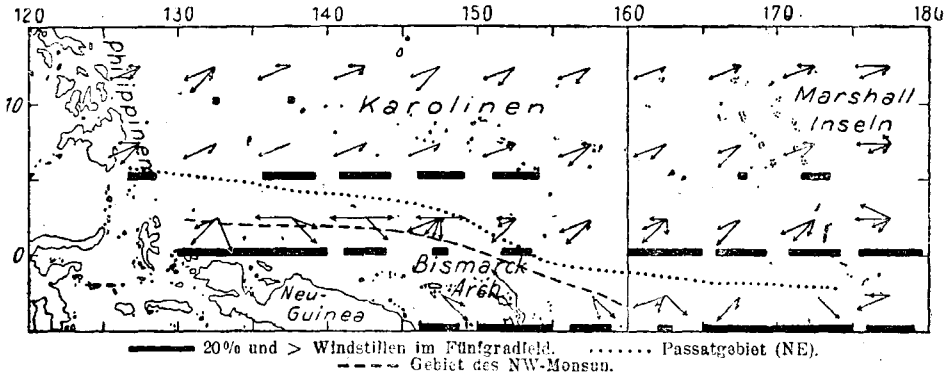
	N	NE	E	SE	S	SW	W	NW	Calms
Yap (1906-1930)...	6	7	4	4	8	8	22	5	16
Guam (10 years)...	5	19	11	14	17	17	6	4	5

It may be pointed out beforehand that the N.E. trade wind as E. or even E.S.E. wind extends as far Latitude 5° North in the eastern half, so that it blows over the Caroline Area even in the summer, but that, as we shall show later these islands and the sea area likewise are surrounded by the eastern counter current of the upper surface, in the North hemisphere summer. On the whole, the E. winds are then weak or moderately strong.

In comparison with what it is in the winter, the average speed of the North equatorial current is considerably reduced, this is clearly due to the moderate force of the trade wind which we have just referred to, As a rule, movements of more than 30 nautical miles per 24 hours ship's run are not reported, they mostly lie between 10 and 15. Their steadiness is also very much relaxed. This is disclosed by the many more or less retrograde movements which appear at once in the chart (Table 27); these divergent local movements are absent from the North hemisphere winter chart. We find the divergence area between the Northern

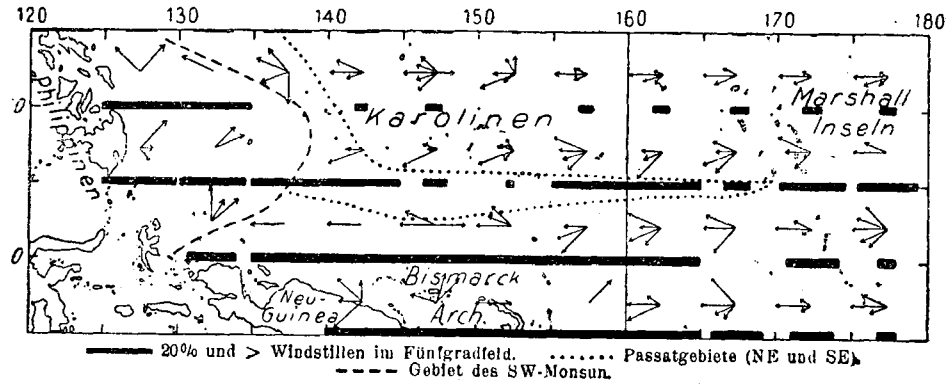
branch which ultimately joins the Kuro Siwo, and the southern branch which becomes the Mindanao current, in exactly the same place as in the North hemisphere winter; this is a fact worthy of notice, for it leads us to look upon as its cause, the effective and steady influence of the Philippine Islands' nearness to the current separation. Considering that south winds are prevailing in the Philippine Islands, a different result might have been expected.

JANUARY.



— 20% and more wind calms in 5° field — trade wind area (N.E.).

JULY.



— 20% and more wind calms in 5° field — trade wind area (N.E. and S.E.) S.W. monsoon area.

Prevailing winds according to the Deutsche Seewarte Atlas, Hamburg 1896.

The S.W. Monsoon is so little effective from an oceanographic standpoint that there is no objection to hardly referring to a notable decrease of its speed in connection with the Mindanao current. According to the first table giving movements abreast of Cape S. Agustin for every month, we actually find, for the four winter months an average movement of 44.7 nautical miles per 24 hours' ship's run and 41.5 nautical miles for the four summer months. But the number of isolated basic observations (in all 14 and 20 respectively) is definitely not yet sufficient; so that 41.5 nautical miles per 24 hours or 89 cm./sec. against the wind constitutes quite a considerable performance. In this respect, should be noted the more striking fact that even far off Mindanao, in the area comprised between Longitude 30° East and Palau-Jap, in spite of predominating southward breezes mostly south west current movements are reported, with retrograde actions, of course, as already stated above; the upper sea surface currents are quite weak in that area and it must still remain doubtful whether our diagram has struck the right way everywhere.

Here, the south equatorial current plays the dominant part, which is quite different from what obtains during the Northern hemisphere winter. It appears on the right side of

the chart (Table 27) in the field of vision, with strong westward movements from Latitude 4° North to at least Latitude 5° South; three eastward movements are of no importance considering the specially rich observation material available. In the vicinity of the Bismarck Archipelago the west current is now prevailing quite unopposed; maximum values of 60 nautical miles have already been recorded here on several occasions.

Gradually, the current transfers its northern edge more to the south, so that it is already to be found in Latitude 2° North by Longitude 145° East. Here begins a peculiar confluence with the branching out counter current, as well as with bodies of water, coming from it originally, as may be gathered from the chart. A small portion of the current pushes forward namely in Longitudes 141° to 144° East, in a northwesterly direction. The best account of the recorded movements can be depended upon in the sense of Sandström's current diagram (7), if a double line running to the left be assumed with a westerly convergence and easterly divergence, whereupon the occurrence actually ends and the current field becomes regular and uniform. The greatest portion of the south equatorial current is likewise forced away through the branching out of the counter current at the equator, to the left and in a south westerly direction. From there, the front width at its disposal is only from 125 to 130 nautical miles. The effect of the want of space begins to make itself felt to a high degree. The average speed increases to a considerable extent, here to the north of "Bird's head" in New Guinea, last June, a ship experienced a movement of 127 Nautical miles in 24 hours! at the same time, the general direction instead of being westward, becomes gradually W.N.W., N.W. and N. in the approach to Halmahera-Morotai.

Over the whole of its area the south equatorial current constitutes a considerable hinderance even for steamers, in the north hemisphere summer, for instance, when sailing from the Netherlands Indies, somewhere from Menado, in an easterly direction towards the Bismarck Archipelago, S.M.S. "Planet" our former surveying ship had some hard experiences during renewed expeditions along the northern coast of New Guinea towards Matupi. Accordingly voyages made by the S.S. "Friderun" also show that steering out of the Philippine Islands south of Mindanao and making straight for the New Guinea coast is only possible during the North hemisphere winter, while in the south hemisphere summer it is possible to enter the Ocean by the Bernardino strait and thus remain as long as possible in the favorable counter current; it is really impossible to avoid strong westward movements when approaching the Admiralty Islands. It is evident that in the case of voyages in a somewhat westward direction, it is quite the reverse.

Strong rips are very frequently observed in the south equatorial current, which is practically one hundred per cent stable. According to entries in ships' log books, the current often carries tree trunks, brushwood, quite small fragments of islands, as a drift contribution torn loose principally from the Admiralty Islands and North Coast of New Guinea.

The narrowed current seizes every opportunity to escape; thus a branch runs westward into the Dampier Strait south of Waigin Isl. and another flows in a S.W. direction into the two passages formed by the Waigin Isl. the small Gebe Isl. and a cape on the east coast of Halmahera.

The south equatorial current whose course, according to its name, should soon come to an end by this time, receives eventually another strong supply from bodies of water brought to it from the South West out of the broad Moluccas Strait between the N.E. head land of the Celebes and the west side of Halmahera. Here again the movement assumes definitely a N. and N.N.E. direction, being well supported by the South Monsoon. In this way, comes into existence in Longitudes 127° to 130° East, a north current radiating between Latitudes 2° North and almost 6°, which in many respects resembles the Florida current and which, through its steadiness and force, has been a source of wonder for seafaring people from the times of voyages of discovery. Its junction with the Mindanao current can be located in the vicinity of the Sandi and Talaur Isl.; the convergence line runs perhaps north of Talaur somewhat more northward than indicated by Chart table 27. In any case, the south hemisphere water takes now a far greater part in the counter current than the north

(7) I.W. SANDSTRÖM. — On the movement of fluids. Ann. d. Hydr. 1909 Table 27, Fig. 2, see also A. DEFANT, Dynamic Oceanography, p. 35, Fig. 8 g. Berlin 1929.

hemisphere water of the Mindanao current, which is quite the reverse of what takes place during the north hemisphere winter. But both kinds of water contribute their share and this definitely and mainly accounts for the extraordinary width and force of the

Counter current in the north hemisphere summer. In our part of the world even prevailing wind conditions do not much matter; they help developments, but rather indirectly inasmuch as breezes are mostly weak or enter zones of calms, and are therefore not obstructive. With a powerful turn, the counter current forces its way out of the two joining equatorial waters and flows forthwith in a E.N.E. and a E.S.E. direction. The branch turning decidedly off to the E.S.E. whirls itself visibly and repeatedly into convergence with the south equatorial current, whereby the whole current system remains stationary.

It is worth noting the fact which is corroborated by numerous water movements that from this south branch the counter current water is carried to the equator in the vicinity of the 140° meridian. So that in this longitude we get the amazing extension of the eastern counter current from latitudes 9° to 0° North. The slight bending out of the E.N.E. and East bent branch of the counter current west of the Palau Island is probably not always to be met with; there at least, especially in May; westward water movements are also reported.

The separation line between the two branches of the North hemisphere counter current, which have been plainly recognised at first at the beginning of its course, runs finally straight to S.E. and ends in a neutral area in Longitudes 142° East. Hereby the northern portions of the counter current, in all probability under the pressure of the south equatorial current are forced to make a sharp turn, north eastward, northward and even north westward.

In the East, between Longitudes 140° and 145° East, available data are becoming rapidly very scanty. To this day it is still impossible to state with certainty, (from reports received up to date) whether, the considerable extension noted in a meridional direction, somewhere between Longitudes 142° and 152° E. is actually to be met there every year; although the generally more moderate speeds would warrant this statement. In any case, at this time of the year, the whole group of the Caroline Islands is in the counter current area.

SUMMARY.

1. *The North equatorial current* of the Western Pacific Ocean is considerably stronger during the north hemisphere winter, than during the summer. Its junction with the counter current takes place in Latitudes 6° to 7° North, in the winter, it flows quite regularly from West to East, this convergence line offers wavelike bends between Latitudes 7° and 10° North. The divergence line between its northern and southern branches, on account of the main land, is practically always in the same area in Latitude 11° North. The Mindanao current which is an offspring of its southern branch and which is strongly delineated in all months, splits up again into two portions, one of which bends to the right towards the Celebes Sea and the other more important one to the left towards the counter current.

2. *The south equatorial current* appears in the area under review in the northern hemisphere winter only in the south East; it bends somewhere in Longitude 140° East (?) wheeling in a left direction towards the region between New Guinea and New Pomeranie. At this time of the year, it may be considered as taking no part in the formation of the counter current. On the other hand, during the north hemisphere summer, it becomes an almost impetuous current reaching as far as Halmahera; it then supplies the water coming from the Moluccas sea as the main contribution to the counter current.

3. *The counter current* is quite predominantly fed by the north hemisphere water of the Mindanao current, in the north hemisphere winter; most probably, at this time of the year, this water appears in winding movements in the south hemisphere, on the coasts of New Guinea: In its eastern half, and during the winter, it becomes narrower and narrower between Latitudes 7° and 5° North. In the north hemisphere summer, especially in August and September, it reaches the highest point of its development, and assumes great force and steadiness somewhere in Longitude 130° East. Like its northern edge, its southern edge offers a very irregular course in the summer. There is, in particular, a striking indentation as far as the equator, which tallies with a split occurring within the counter current in E.S.E. and E.N.E. directions.

GENERAL.

1°) The fundamental and noteworthy result of the above investigation, seems to be that the exclusive working up of separate movements — not therefore of mean values whichsoever — taken from the most varied years, has led comparatively easily everywhere to significant and dynamically intelligible representations of currents.

This striking fact brings home the consideration and at bottom is only explicable by this conception that here in this part of the world, surface currents and consequently also seasonal changes in surface currents always make their yearly reapparance in practically the same form. Seafarers, as is well knonw, only rarely observe such a year in and year out regularity: even the Gulf Stream varies greatly from year to year.

2. *Origin of the counter current.* The reason for the participation of the north equatorial current or to speak more accurately for the sharp left turn of the Mindanao current in Latitudes 6° to 7° North and Longitude 130° East, is not directly perceptible. The whole of the Mindanao current could have turned to the right and made for the Celebes Sea. Moreover, during the north hemisphere winter, in the critical area of the counter current, north east winds (N.E. Monsoon) are still prevailing, frequently with considerable force; during the north hemisphere summer, the S.W. monsoon of the Western Pacific Ocean is mostly wea, unsteady and incapable of affecting the actually prevailing drift speeds of the counter current. The wind conditions as such, as we have more than once pointed out above, cannot supply a fundamental explanation for the counter current proper, especially for its great speed.

Along the two great convergence lines, as well as in the region of the southern edge of the North equatorial current and northern edge of the south equatorial current, there are compensating movements on a smaller scale to replace the bodies of water running westward; a whole succession of movements point to whirlings of this kind. Now, the question arises as to whether the appearance of the counter current, on the whole is sufficiently accounted for as a large scale compensating phenomenon. Judging from the two charts (tables 26 and 27) which show in all details a natural in itself as well as exceptional phenomenon, I am not any longer of the opinion, that the principle of the compensating current holds sufficiently good, although it should not be discarded altogether and, moreover the direct action of monsoon like winds, for instance in the eastern Pacific Ocean before the west coasts of Central America, should be taken into consideration.

In this respect, the following consideration seems to me quite conclusive. During the northern hemisphere winter, the counter current is, on the whole "weak and narrow". But, at the same period of the year, the north equatorial current is particularly strong and steady, the south equatorial current exists throughout to a considerable degree from the East to as far as Longitude 140° East; it falls out only at the last 10 degrees from Longitude 140° to 130° East. In such circumstances the prevailing weakening of the counter current over and acress the whole of the Pacific Ocean is not accounted for by the notion of compensation.

A new explanation for the genesis of the equatorial counter current has now been given by H.U. SVERDRUP and after him, in details, by A. DEFANT (8). They also start from the existence of the north and south equatorial currents, but place in the foreground the fact that both great west currents run non symmetrically to the equator; for even the south equatorial current has its course north of the Line.

It follows, while the earth's rotation acts on bodies of water symmetrically to the equator, in stationary conditions and for hydrodynamic reasons, that an eastward counter current of the upper layers, must necessarily be formed, if, besides, stability in a physical sense (9), must be maintained. We need not here go into the substance of this theory, which

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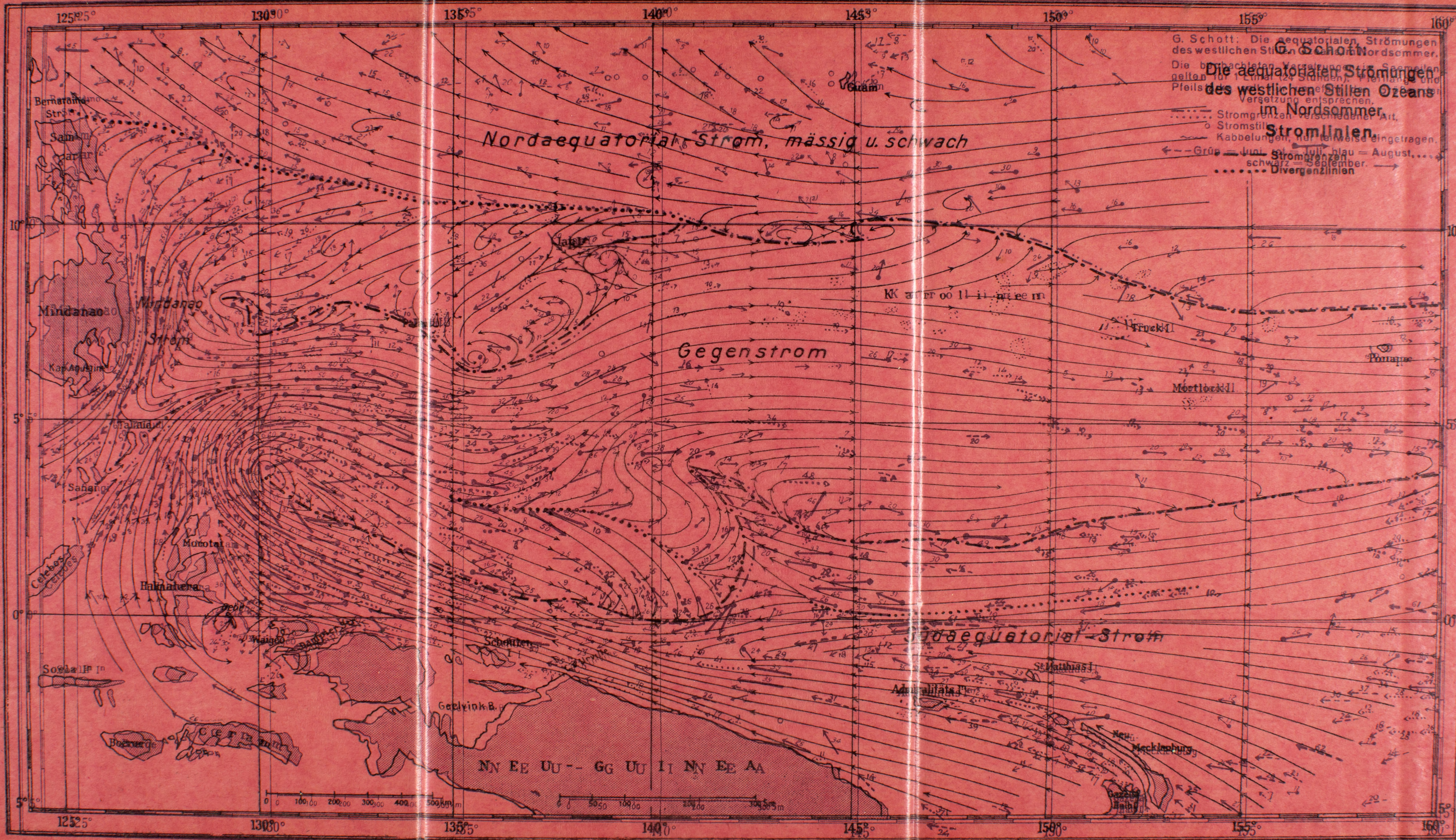
(8) The equatorial counter current: Sitz-Ber. d. Preuss. Akad. d. Wissensch. XXVIII, Berlin 1935. Some more literature on the subject is to be found here. The mean forces given by A. DEFANT, on page 452, for the western part of the Pacific counter current are however considerably toc great.

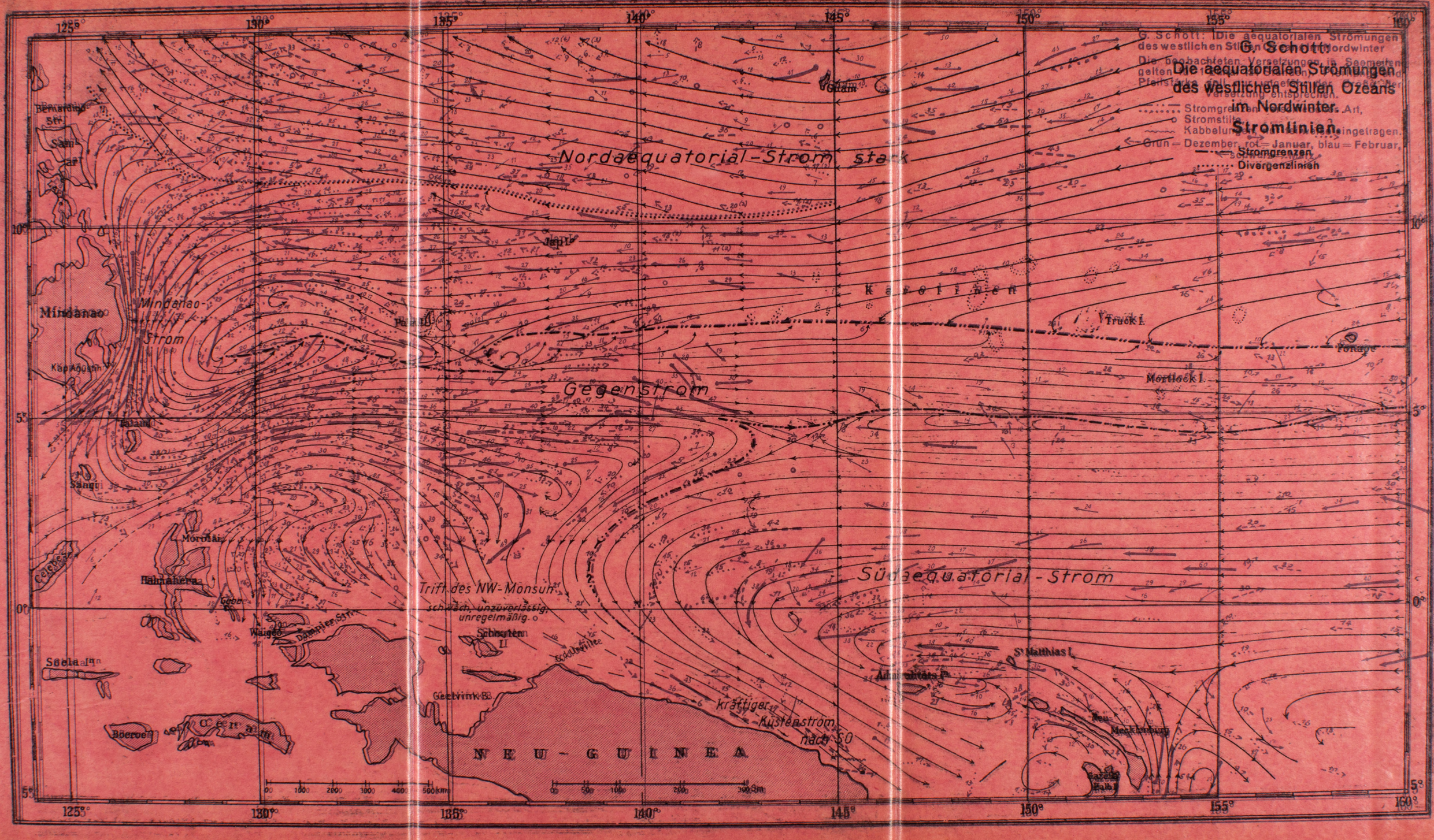
(9) The expression "Steadiness or stability" (Beständigkeit, Stabilität) used on several occasions in our text has here the other conventional sense of the percentage relation between the vectorial and the arithmetic speeds.


G. Schott:
Die aequatorialen Strömungen
des westlichen Stillen Ozeans
im Nordsommer.
Stromlinien.
Stromgrenzen
Divergenzlinien
Nordaequatorial-Strom, mässig u. schwach
Gegenstrom
Südaequatorial-Strom
Mindanao
Strom
Guam
Pompaue
Mortlock I.
Celebes
Halmahera
Waigeo
Gcelvink B.
Neu Mecklenburg
125°
130°
135°
140°
145°
150°
155°
160°
10°
5°
0°


G. Schott: Die aequatorialen Strömungen des westlichen Stillen Ozeans im Nordsommer.
Die beobachteten Versetzungen in Seemeilen gelten für 1 Etmal (24 Stunden). Pfeillänge und Pfeilstärke soll nur ungefähr der Größe der Versetzung entsprechen.
Stromgrenzen verschiedener Art.
o Stromstille.
Kabbelungen, nur teilweise eingetragen.
Grün = Juni, rot = Juli, blau = August, schwarz = September.
125°
130°
135°
140°
145°
150°
155°
160°
10°
5°
0°
Mindanao
Kap Agustin
Talaud
Sangi
Celebes
Morotai
Halmahera
Waigeo
Soela In
Boeroe
Ceram
Palau I.
Jap I.
Guam
Karolinen
Truck I.
Ponape
Mortlock I.
Schouten I.
Geelvink B.
NEU-GUINEA
St. Matthias I.
Admiralitäts I.
Neu-Mecklenburg
Gazelle Halbi.
0 100 200 300 400 500 km
0 50 100 200 300 Sm

G. Schott: Die aequatorialen Strömungen des westlichen Stillen Ozeans im Nordwinter.

Stromlinien.




G. Schott: Die aequatorialen Strömungen des westlichen Stillen Ozeans im Nordwinter
Die beobachteten Versetzungen in Seemeilen gelten für 1 Etmal (24 Stunden). Pfeillänge und Pfeilstärke soll nur ungefähr der Größe der Versetzung entsprechen.
Stromgrenzen verschiedener Art,
Stromstille,
Kabbelungen, nur teilweise eingetragen.
Grün = Dezember, rot = Januar, blau = Februar, schwarz = März
125°
130°
135°
140°
145°
150°
155°
160°
10°
5°
0°
Bernardino Str.
Samar
Leyte
Mindanao
Kap Agustin
Talaud
Sangi
Celebes
Halmahera
Mortai
Jebe
Waigeo
Dampier Str.
Soela In
Boeroe
Ceram
Schouten I.
C. d'Urville
Geelvink B.
NEU-GUINEA
Japle
Palau I.
Guam I.
Karolinen
Truck I.
Ponape
Mortlock I.
St. Matthias I.
Admiralitäts I.
Neu Mecklenburg
Gazelle Halbi
0 100 200 300 400 500 km
0 50 100 200 300 Sm

is fairly well known. I think that the two new current line charts agree in principle with this conception. The north equatorial current, particularly, which runs far away north from the equator, must, according to this theory, be very effective in the formation of a counter current. Still, I also maintain, as I have already remarked, that this new stand point, is not sufficient to explain everywhere and in every case, some important facts, even if great spaces be taken into consideration. In the north hemisphere summer, a great portion of the counter current bends strongly in a E.S.E. direction to enter the south equatorial stream, which, in addition at this time of the year, runs little beyond north of the equator; this first -western end portion of the counter current should not be an independent and ordinary dynamically qualified movement, but a direct eddy current (Neerstrom) a compensating phenomenon on a large scale. Moreover, O.H. WENDLER (10) and A. SCHUMACHER (11) also account for the western portion of the Atlantic counter current, viz. the Guinea Current, by the necessity of compensation. Several causes can therefore be valid and prove effective.

3. The current lines of the two charts show with great lifelikeness, the wheeling about and adjustment into one another of the various movements rarely observed to that extent. These pictures remind us in their restlessness of the great turbulent phenomena occuring on the surface of a swift running river either winding its way along its banks, or running in a bed broken up with shoals. Both factors can perhaps also be found at the west extremity of the equatorial Pacific Ocean, in the surface currents. Not only the separation of the current before the Philippine Islands takes place there, but also the contraction of the south equatorial on its left flank through the northern coast of New Guinea; lack of space in a horizontal direction imposes a mighty acceleration of speed during the summer of the north hemisphere.

4. Finally the submarine relief. The eddy twist in Latitude 3°5 North and Longitude 130° East, at the time of the particularly violent action of the south equatorial current in the north hemisphere summer is quite clearly located. Why is the well drawn figure so plainly developed here. The "Snellius" Expedition (12) has located in about Latitude 2°,5 North and Longitude 129°,40 East, a bottom elevation of approximately 2000 metres in a 4000 metres deep sea; this elevation may stretch out for another 60 nautical miles eastwards as it has not been more closely explored. Probably, the current coming from the south and driving northward with mighty force between the Morotai Island and the elevation, is induced by the bottom relief, to flow round this rise immediately to the North. V.W. EKMAN (13) has repeatedly stated, chiefly on theoretical grounds, and then above all with reference to the peculiar slight southward swinging of the Gulf Stream in the south of the Newfoundland Bank, that even very moderate differences in sea depths or geographical latitudes are conducive to a surprising sensitiveness of depth currents. He deals with the case (in the above mentioned place pp. 63-65) where an isolated shoal in the middle of the sea is in the way of a homogeneous depth current field and gives a schematic drawing of the resultant disturbance of the current lines. In the northern hemisphere, this disturbance is represented by an anticyclonic bend of the current field. Here, EKMAN goes on with the following proposition. For the time being, a really definite confirmation is not to be thought of. I have referred to the equatorial counter current, which seems to be an example in favour of the theory. *It might perhaps be possible by a careful statistic examination of the movement directions in the region of this current* (15), *in relation to depth variations to obtain a more accurate confirmation...* In reference to the influence of the bottom topography, it is in any case an advantage to possess a colonel chart... An

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(10) The upper surface movements of the Guinea current. Gerlands Beiträge 3, Geophysic. 44, 1935, pp. 193, 195.

(11) Current rips, especially in the Guinea current, Ann. d. Hydr. 1936, pp. 380, 382.

(12) P.M. van RIEL. — The "Snellius" expedition, volume II, Oceanographic results, part 2, Chapter 2, the bottom configuration... Appendix; The chart opposite page 60 brings out a representation of this elevation supplemented by later soundings. See also plate II, Utrecht 1934.

(13) On the horizontal circulation of sea currents produced by the wind. Arkiv. för Matematik. K. Svenska Vetensk. Akad. Vol. 17, N° 26, 60 ff. Stockholm 1923.

(14) "Depth currents" is used here in the sense of Ekman's well known division into three of elementary currents produced by the wind.

(15) that is the Pacific counter current, as shown in page 38 by EKMAN.

accurate examination of these relations is still quite unfeasible to this day, owing to the inadequate soundings made in the region under review, although the other part of the hypothesis, the statistic research work on current movements, may now be considered as adequate. But the fact of the shoal is verified, and the ensuing evasion in a anticyclonical sense to the north, through the northern current, which becomes thereby the eastern current is so obvious, that here at least we have a local proof which tallies with Ekman's views. Of course, a ridge shaped elevation stretching as far as Latitude 4° North, as assumed by Van RIEL (in the above mentioned place, Appendix, Fig. 30), would be quite unlikely and we would maintain, if this course of argument should prove correct, in the converse case, that the oceanographer may infer a certain configuration of the deep sea bottom from the sharp change of direction of a surface current.