# THE GULF STREAM (1)

Extract from an opening lecture read by GEORG WÜST at the University of Berlin 13 November 1929, and published by the "*Zeitschrift der Gesellschaft für Erdkunde*", Berlin 1930 (1 & 2).

## I. *THE GULF STREAM CONSIDERED AS A PHENOMENON OF THE OCEAN SURFACE.*

We are indebted to Benjamin FRANKLIN for the first scientific chart of the Gulf Stream. By a singular exaggeration he represents the current as a *river in the ocean*. The current, in the shape of a dark hatched band which is sharply defined at its edges as though held by fixed banks from the other parts of the ocean considered as statio, nary, moves from the Straits of Florida along the American coast to the northward- then gradually broadening out turns to the N. E. until it reaches the Banks of Newfoundland where it finally bends to the E.S.E. and spreads out into the open ocean. According to the figures given by FRANKLIN its drift, which at the origin amounts to four nautical miles an hour, decreases to two miles. If the navigators of those days did not derive the value from the chart which FRANKLIN had hoped, it still represents the beginning of a scientific investigation of the current. FRANKLIN himself started the measurement of temperature in the Gulf Stream.

The representation given by Alexander VON HUMBOLDT of the Gulf Stream in the first volume of his "*Reise in die Aquinoctialgegenden* (1815) is a masterpiece of oceanic literature considering the lucid manner in which he presents the essential data and his masterly and careful combination of the scattered observations into a geophysical whole. Unfortunately, in none of the collections of the works of HUMBOLDT which have appeared up to the present, is it possible to find the chart which he constructed and which, according to accounts of KOHL, appeared in several issues under the title *Carte de l'Océan Boréal.* This accounts for the fact that in the modern oceanographic literature little credit has been given to HUMBOLDT for the investigation of the problems of the Gulf Stream (2).

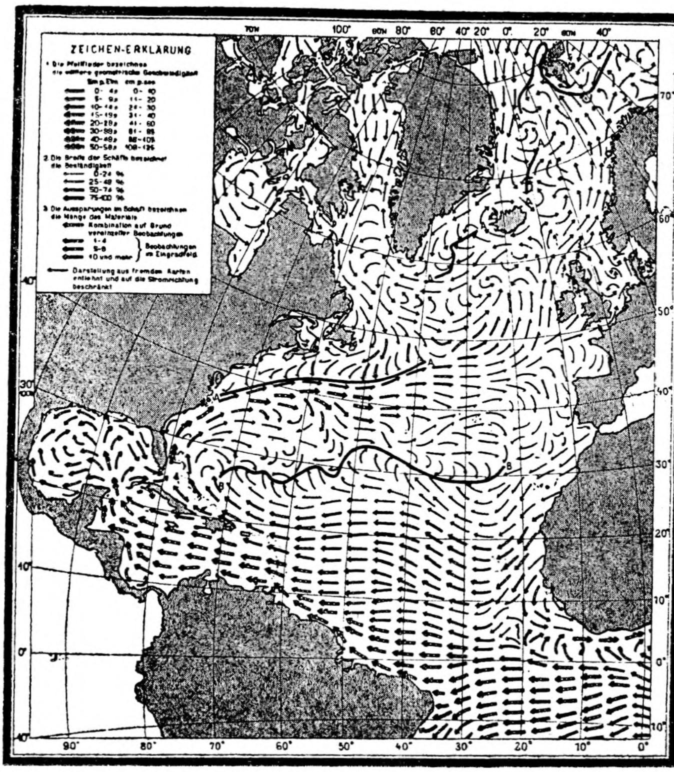
Further, HUMBOLDT pointed out for the first time the correlation between the equatorial currents and the Gulf Stream and expressed the opinion that the Gulf Stream is a part of the *circular movement* in which the waters of the North Atlantic are driven as though in a sort of continuous whirlpool. We find traces of his concepts in all of the works and in certain charts in the first part of the 19th century.

(1) *The most important contributions to the history of the exploration of the Gulf Stream are :* J. G. KOHL : Geschichte des Golfstroms und seiner Erforschung von den Altesten Zeiten bis auf den grossen Amerikanischen Bürgerkrieg. Eine Monographie zur Geschichte der Ozeans und der geographischen Entdeckung.. *Breme* 1868 ; J. E. PILLSBURY : The Gulf Stream. A description of the methods employed in the investigation and the results of the research. Report of the Superintendent of the U. S. Coast and Geodetic Survey, 1890, Appendix N° 10, *Washington* 1891 ; Martha KRUG : Die Kartographie der Meeresströmungen in ihren Beziehungen zur Entwicklung der Meereskunde. Ein Beitrag zur Geschichte und Methodik der Seekarten, dargestellt am Beispiel des Golfstroms. Deutsche Geographische Blätter Bd XXIV, Heft 3 & 4, 1901 ; Otto KRÜMMEL : Handbuch der Ozeanographie Bd 11, *in particular p.* 475 *et seq., Stuttgart,* 1911 ; Ludwig MECKING : Der Golfstrom in seiner historischen, nautischen, klimatischen, Bedeutung. Meereskunde, *vol.* 51, *Berlin* 1911.

*A synoptic representation of the different problems concerning the Gulf Stream has been given recently by* H. A. MARMER *in an interesting article :* "The Gulf Stream and its problems" (The Geographical Review, New York, 1929, *page* 457 *et seq.*).

(2) Heinrich BERGHAUS : Allgemeine Länder und Volkskunde, *Vol. I, Preface, p. VII., Stuttgart,* 1837.

The careful plotting of *the drift of the vessels in the current,* undertaken for the first time by RENNEL (1832), showed that even outside of the limits of the currents known at that time, the surface was more or less in a state of movement, that the set




*Movements of the surface water in February, according to* H. H. F. MEYER, 1923. *The limits of the currents in heavy lines indicate the two most important lines of convergence of the current :* A-A, *Polar front and* B-B, *sub-tropical convergence.*

of the current is very irregular and that in the Gulf Stream itself there are marked differences in the set and drift of the current depending on the season and the locality. This was a death sentence to FRANKLIN'S concept of a marine river. However, the valuable data gathered on the drift of the current, which were considerably augmented after 1853 as a result of an international agreement, were in general applied to nautical charts statistically only and were used with great caution in the scientific study of the current phenomena (1). This is shown in the generalized scientific current charts even in modern times which give schematic representations of the currents. Their authors were generally imbued with the ideas of HUMBOLDT — a conception in which a circular movement is assumed, and in so far as the Gulf Stream is concerned they could not rid themselves of the concept of the river-like character of the current. Thus the current charts in the geographical manuals and atlases, up to a very recent date, showed practically without exception two symmetrical circles of currents in the two hemispheres, North and South, and represented the Gulf Stream by a band of beautifully curved current lines branching out in part from the equatorial currents and completely surrounding the central area, which was considered to be without current (2).

(1) *For further details, see :* Alfred MERZ : Meereskunde, Wirtschaft und Staat. Sammlung Meereskunde Heft 157 (*Vol. XIV*) p. 2-6, *Berlin,* 1922.

(2) *Cf.* Gerhard SCHOTT : Geographie des Atlantischen Ozeans, *Plate XIV, Hamburg,* 1912. *In the second edition of this work* (*Hamburg,* 1929) SCHOTT *gives a modern chart of the currents on the surface of the ocean* (*Plate XV.*) *and shows clearly the influence of the new concept of currents* (MERZ, 1922) *and the method of indicating the currents* (MEYER, 1923).

The exact analysis of the current fields by Alfred MERZ, who based his evaluations of current drift on the theoretical investigations of BJERKNES and SANDSTRÖM, finally eliminated these schematic concepts and in place of these has led to a complicated representation of the currents in the chart of his pupil, MEYER. Instead of the extensive areas without current symetrically disposed on each side of the equator, we see on the chart of MEYER (1) two regions of convergence filled with currents, adjoining the two subtropical convergence lines where the masses of water move towards the bottom. The westerly currents in the equatorial zones cover the greater part of the ocean (See Fig.). The meridional branch currents are much less pronounced than the zonal currents. *As a phenomenon of surface flow the Gulf Stream does not deserve in any manner the exceptional position which has been accorded to it on the previous charts since the time of* FRANKLIN. It is simply a distinct part of the general surface circulation and as such it takes position far behind the equatorial currents, which with their tremendous breadth and appreciable drift, together with a remarkable constancy, traverse the ocean from east to west as surface currents due to the wind. It is only in the Straits of Florida that the Gulf Stream is comparable with it in strength and constancy.

The new chart furnishes us with the following detailed information with regard to the origin and course of the Gulf Stream :— In the vicinity of Cape San Roque, which has a projecting salient to the N. E., the south equatorial current divides, and appreciable masses of water from the southern hemisphere are conveyed to the northern hemisphere through the medium of the Guinea Current which tends to the N. W. These join with the partially submerged northern equatorial current to form the West Indian Current, which traverses the Caribbean Sea in its entire width and flows with considerable constancy towards the west. The contraction in the Straits of Yucatan then causes this flow of water, which has been primarily set in motion by the wind, to pour into the Gulf of Mexico as through a funnel at a rate of from about 30 to 40 nautical miles per day. This Yucatan Current continues straight across the Gulf of Mexico as far as the mouth of the Mississippi, where it then divides into two weaker branches flowing along the coast. At the entrance to the Gulf the stream also sends out two branches, one flowing into the Straits of Florida to the right and the other to the left towards the Campêche Banks; but these have neither the strength nor the regularity of the main current. While the movement of the water through the Gulf of Mexico as far as the shore-line is largely influenced by the trade wind current, which sets from W. to N. W., the stream flowing out of the Gulf through the Straits of Florida is a gradient or pressure current flowing counter to the prevailing winds from the north. The velocity of this current is greatly increased by the narrowing of the cross sectional area in the Straits of Bimini where current velocities reach magnitudes of 60 and, in the main stream, even 80 nautical miles in 24 hours. The West Indian current passing outside the island group and setting to the N. W., becomes sharply bent in Lat. 27° N. shortly before it joins the Florida stream, due to the influence of the convergence zone in the Sea of Sargasso. Contrary to the previous representations of KRÜMMEL and SCHOTT, who showed the West Indian current with ten times the width of the Florida current, the former has scarcely the width of the latter, whose rate of flow and constancy is also much greater. (2)

To the northward of Cape Hatteras the Gulf Stream draws further and further away from the continent under the influence of the off-shore winds, the diverting force of the earth's rotation and the cooler streams along the coast which have a smaller saline content. Its left flank is sharply divided from the coastal waters while the right flank on the other hand is very indeterminate. At this place numerous small streams branch from the current, curving more and more into the Sargasso Sea and having a velocity of only 5 miles with little regularity. After Longitude 55° W. the left flank of the Gulf Stream comes in contact with the colder Labrador current, poor in salt, the water masses of which form numerous eddies (3) and sinking into the depths pass underneath the

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(1) Hans H. F. MEYER: Die Oberflächenströmungen des Atlantischen Ozeans im Februar. *Published by the Institute f. Meereskunde; New Series A; Heft* 11; *Berlin* 1923.

(2) *On this subject see the special chart of* Georg WÜST: Florida and Antilles Currents. A hydrodynamic investigation, *published by Meereskunde. New series A. Heft* 12 (*p.* 38, *Fig.* 6), *Berlin* 1924.

(3) *An interesting account of these eddies has been given by* E. H. SMITH *on the back of the* "Pilot Chart of the North Atlantic Ocean" *March* 1925, *Washington. This is also found in the* Geographie des Atlatnischen Ozeans, 1926, of SCHOTT, p. 190, *fig.* 60).

lighter Gulf Stream. To the southward of the Bank of Newfoundland, the Gulf Stream takes a remarkably sharp and well-defined bend to the southward which, though not shown on the current chart of MEYER, is clearly apparent as a wedge of cold water between Longitudes 48° and 50° W. on the temperature charts of HELLAND-HANSEN and NANSEN (1).

This apparently unmotivated change in the course of the Gulf Stream, according to recent determinations of EKMAN and HELLAND-HANSEN (2), depends on the morphological conditions and appears to confirm a law, recently formulated by EKMAN, regarding the effects of the topography of the bottom on deep ocean currents. Aside from this wedge-shaped bend, the general flow of the Gulf Stream is from Cape Hatteras to the Irish Coast in an easterly to northeasterly direction, during which time the velocity drops from 15 miles a day to about 5 miles, and the constancy from 75 % to 30 %. *If the Gulf Stream were primarily a wind drift current, then with the prevailing westerly winds and under the influence of the earth's rotation we should expect a south-easterly direction of flow. Since the actual set of the current is, however, from East to N. E. we are forced to conclude that even in this part of its course it is primarily a gradient current* (3). The principal branches of the Gulf Stream in the eastern half of the ocean turn towards the N. E., with somewhat reduced set, and make their presence felt through the channel between the Shetland and Faroe Islands and along the Norwegian coast as far as the Arctic Ocean. The branches running to the East and Southeast, after the division at about Long. 20° W., which pass along the French and Spanish coasts are weak and irregular, and therefore we can scarcely regard the stronger Canary Current as a continuation of the Gulf Stream, as assumed recently by THORADE. (4)

## II. *THE VERTICAL STRUCTURE OF THE GULF STREAM.*

Thanks to the initiative of the U. S. Coast and Geodetic Survey during the years 1845-1860 and particularly during the period 1867-1889, observations (5) on a large scale were made in the American Mediterranean and in the Gulf Stream region to obtain physical data at great depths. The temperature measurements and the soundings made by SIGSBEE and BARTLETT at various depths can be counted by the hundreds. They succeeded in the tremendous task of anchoring the schooner yacht *Blake*, 45 metres long, in depths of several hundred metres and even a thousand metres; and for hours, days and weeks they recorded the current flow at various depths from the fixed point in the ocean obtained in this manner. In general the current was measured at depths of 238 metres. This performance has only recently been equalled by the research vessel *Meteor* in the South Atlantic.

In 1914 the Coast and Geodetic Survey resumed the exploration of the Gulf Stream and using the hydrographic vessel *Bache* they caused four hydrographic sections to be made in the Florida Current and the West Indian Current, which gave us the first reliable observations on the stratification of the saline content of these two currents (6) To the southward of the Bank of Newfoundland, the Norwegian expedition *Michael Sars* with Bj. HELLAND-HANSEN as oceanographer, had made a modern survey of the transverse

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(1) Björn HELLAND-HANSEN *and* Fridtjof NANSEN : Temperatur Schwankungen des Nordatlantischen Ozeans und in der Atmosphäre. *(Videnskapsselskapets Skrifter I Mat. nat. Kl. 1916, N° 9) Fig. 5, page 16, Christiania, 1917.*

(2) V. Walfrid EKMAN : Uber Horizontalzirkulation bei winderzeugten Meeresströmungen. *Arkiv f. Mat. Astr. och Fysik, Vol.* 17, *N°* 26, *Stockholm* 1923.

(3) *The correctness of this concept has been shown in a striking manner by* MEYER *through a comparison of the pure wind current with the actual current.*

(4) H. THORADE : Neuere Anschauungen über Oberflachenströmungen (*Rückseite der* "Monatskarte des Südatlantischen Ozeans", *Deutsche Seewarte, Hamburg,* 1928).

(5) *These observations were utilised in* : A AGASSIZ : Three cruises of the U. S. Coast and Geodetic Survey steamer *Blake* in the Gulf if Mexico, in the Caribbean Sea, and along the Atlantic Coast of the United States from 1876 to 1880. *Two volumes, Boston,* 1888.

(6) Henry B. BIGELOW : Explorations of the U. S. Coast and Geodetic Survey steamer *Bache* in the western Atlantic, *Jan.-March* 1914, under the direction of the United States Bureau of Fisheries. Oceanography. Report of the Commissioner of Fisheries 1915. Appendix V. *Washington* 1917. *This series of measurements by the hydrographic steamer* Bache *were also published in the* Papers from the Department of Marine Biology of the Carnegie Institution of Washington, *Vol. IX*, 1918.

profile of the Gulf Stream. (1) We owe to the Danish expedition of the *Dana* the numerous recent measurements made in a series of transverse sections across the Gulf Stream. This expedition, which worked in 1921-1922 under the direction of Jahan SCHMIDT finally undertook the systematic exploration of the western part of the Sea of Sargasso and the American Mediterranean.

## *TRANSVERSE SECTIONS WITH REGARD TO TEMPERATURE.*

Contrary to the ideas commonly held on the subject, the transverse sections which have been explored show that the Gulf Stream does not consist of a large body of highly warmed water extending to great depths. *In comparison with the masses of water in the open sea in these latitudes, in the Sargasso Sea, the layers of warm water in the Gulf Stream proper, are relatively shallow, as shown by the distribution of the* 10°, 15° *and* 20° *isotherms.* (2) On the left flank, towards the Continent, the water in the Gulf Stream, which is approximately enclosed by the line of the 10° isotherm, does not extend below depths of about 300 metres and in the Straits of Bimini does not even reach 200 metres depth. Outside of the island group, however, this temperature limit extends as far down as 800 metres. The isotherms in the Gulf Stream are very sharply inclined and the masses of the water are considerably more stratified than in the open sea. The further we move away from the left flank the more the conditions in the open sea are approached. This great inclination of the lines is due to the hydrodynamic conditions and caused by the deflecting force of the earth's rotation which, for its part, is directly proportional to the strength of current perpendicular to the section. *The more the cross sectional area diminishes the stronger the flow of current and the more the masses of cold water are banked up on the left flank.* At the point where the Gulf Stream passes out of the Florida Straits, the current stream widens, not only to the northward but also to the East towards the Sea of Sargasso and comes in contact with the waters of the West Indian Current of similar composition. At this point (about Latitude 30° N.) the Gulf Stream, fed from two sources, shows its greatest vertical depth of about 1.000 metres and the very considerable width of 200 km. Its left flank is still well-defined but has moved about 100 km. from the coast, while the right flank merges into the waters of almost equal temperature in the Sea of Sargasso and is very ill-defined. After curving to the eastward the Gulf Stream widens considerably, but loses in vertical depth as a result of the admixture of the layers of colder water beneath. To the southward of the Bank of Newfoundland, the Labrador Current strikes its flank and brings about a further splitting up of the stream. About 350 km. to the southward of the Bank of Newfoundland, the *Michael Sars Expedition* observed a wedge of cold water, which is due to the above-mentioned sharply-defined turn to the southward of the Gulf Stream at this point. To the southward of this loop the isotherms drop to include a second and equally important mass of water contained in the Gulf Stream.

## *TRANSVERSE SECTIONS WITH REGARD TO SALINITY.*

The transverse sections with regard to salinity are in full accord with the temperature profiles. The isohalines show the same degree of inclination as the isotherms, as well as their very inclined position in the Bimini Pass. *In comparison with the water in the Sargasso Sea the Gulf Stream appears as a relatively shallow body of water of moderate salinity.* There is, however, one marked difference in comparison with the stratification of the temperature. The nucleus masses of the Gulf Stream, having the highest salinity values of more than 36.5 ‰ do not lie on the surface as one would suppose, but in an intermediate layer at depths of 100 to 200 metres and somewhat displaced to the right. This distribution, which is also found in the sections taken in the Gulf of Yucatan, shows that the nucleal masses are formed outside of the Florida Channel and the Gulf of Mexico and stations in the passes of the Caribbean have shown that these masses of water have been formed even outside the Caribbean and have later been covered over by layers of less concentrated water flowing into the stream from fresh-water sources. This intermediate layer of high salinity is a characteristic of the

(1) J. MURRAY and J. HJORT : The depths of the ocean, *London*, 1912.

(2) *It is only in those localities where the "ramifications" of the Gulf Stream enter the part of the North Atlantic influenced by the northern arctic waters that the Gulf Stream appears relatively warm and high in salinity.*

tropical zones and its origin is found on the surface areas in the northerly subtropics, a locality in which the salt content reaches its highest value. Here, in the convergence area, the masses of water of high salinity sink to lower levels and are carried towards the equator by the north tropical (1) sub-current and incorporated in the mighty north equatorial current which carries them with it in its flow towards the Gulf of Mexico and the Florida Straits. *Thus in the final analysis the nucleal masses of the Florida Current lying at depths of* 100 *to* 200 *metres, have their origin in the surface of the Sea of Sargasso and in this phenomenon we recognise the distant influence of the great vertical circulation in the Atlantic.* Even in the West Indian Current this intermediate layer of high salinity is present; this, however, stands in direct relation to the surface water of the Sea of Sargasso. Although the West Indian Current receives this mass of water of high salinity as a result of more or less direct infusion from the east, the Florida Current receives its salt stratification after a large detour through the American Mediterranean. But a second distance influence of the great Atlantic circulation is evident in the saline stratification of the waters of the Yucatan Straits and the entrance to the Florida Straits. If the isohaline for 34.9 ‰ is plotted in the profile section, then it is found that a deep layer of water, poor in salt (less than 39.4 ‰), lies between about 700 and 1000 metres' depth, while below this the salt content increases. *This layer owes its origin to the last branches of the intermediate sub-antarctic current,* whose cooler masses, poor in salt, sink to depths of 700 to 1000 metres between latitudes 45° and 50° S. at the borders of the Antarctic, and thence broaden out in layers as far as the northern hemisphere (2). Although outside of the island group in the Sea of Sargasso, the layer of water due to sub-antarctic current having a salinity below 34.9 ‰ can scarcely be followed further than 18° N., we find such values in the Florida Current as far North as 25° N. latitude. To the southward of the Bank of Newfoundland the Gulf Stream appears to divide into two parts owing to the previously mentioned wedge of colder water of low salinity. Owing to the admixture of this fresher water the salinity drops below 36.5 ‰ and the intermediate layer of high salinity is almost completely destroyed.

## *VERTICAL DISTRIBUTION OF THE VELOCITY.*

The distribution of velocities in the upper 200 metres is similar to the current profiles shown by the great continental water-courses. The physical conditions and the magnitudes, however, are entirely different. The rivers flow as a result of a drop in altitude over an inclined bed with a generally increasing width. *The bed of the Florida Straits rises in the direction of the flow and constantly narrows from the entrance of the Straits almost to the opening.* The axis of the river current follows closely the contours of its bed: *the axis of the Florida current also follows the shortest path in accordance with its origin as a gradient current.* Similar to the Bosphorus, the current spreads out after pouring through the narrow straits and even at a great distance outside continues to follow the direction imposed on it. Another difference is the following:— In rivers in which homogeneous masses of water are flowing, the current distribution depends to a large extent upon the eddies which are formed on the bottom and rise to the surface. In the Florida current, however, we are dealing with a pronounced stratification below the 200 metres depth which considerably diminishes the turbulence. *This is the explanation for the close relationship between the stratification and the distribution of velocities.*

It is characteristic of the power of the pressure built up in the Florida current that even in the open parts of the Straits velocities of more than 120 cm/sec. are found on the surface and velocities of over 80 cm/sec. at depths of 200 to 300 metres. The concen-

(1) *In this connection and with regard to the material which follows, see the recent work on the vertical circulation in the Atlantic by* Merz *and* Wüst (*in this same review* 1922-1923) *and the longitudinal sections by* Wüst 1928, Der Ursprung der Atlantischen Tiefenwasser, *in the special jubilee issue of the same review.*

(2) *The deeper layers of cooler water in the depths and bottom of the Florida Straits were previously considered as forming a prolongation of the Labrador Current. In recent times* Idrac *in* Sur Quelques Singularités du Gulf Stream - Comptes-rendus de l'Académie des Sciences, *T.* 188, p. 644, *Paris* 1929, *has again revived this conception We know now that the masses of water of the Labrador Current at the northern polar front sink to the depths and form, though to a small extent, the deeper waters of the North Atlantic. But a distinct sub-oceanic continuation of the Labrador current into the colder current underneath the Florida current and flowing counter to the Gulf-Stream, cannot be conceived.*

tration of the current lines in the Straits of Bimini leads to the very high current velocities of approximately 180 cm/sec., on the average, which are recorded here. In some cases the velocities rise to as much as 200 to 250 cm/sec. : values which are comparable with the great continental rivers at times of high water. Some idea may be formed of the tremendous velocity of the current in the Straits of Bimini when we consider that a ship drifting without power will be carried 200 km. in 24 hours. Although in most ocean currents, and particularly in the wind drifts such as the great equatorial currents for example, the velocities fall off abruptly in the depths and even at 100 metres very weak countercurrents may prevail. In the Gulf Stream, owing to its origin as a gradient current, the masses of water at depths of 400 and even 600 metres are carried along with relatively high velocities in the direction of the surface water. In this respect the Gulf Stream occupies a peculiar place among the ocean currents. At the narrowest point of the Florida Straits the masses of water are moving with a velocity of more than 1 m/sec. through a cross section 200 m. deep and 70 km. wide. The tremendous dimensions of this powerful current become apparent when we realise that the length of the Florida Strait is equal to the length of the Rhine from the Bodensee to its mouth and its width corresponds to the width of the Rhine banks including both Baden and Elsass.

### *THE CONVEYANCE OF WATER AND HEAT.*

The quantities of water and heat which are conveyed from the Gulf of Mexico to the North Altantic Ocean are enormous. We may calculate the average value of the conveyance of water at 85 km3/hour, or 24 million cubic metres per second (1). Some idea may be formed of this enormous quantity when we consider that the greatest of the terrestrial rivers, the Amazon, only conveys to the sea on the average about 1/10 million cubic metres of water per second, and the total discharge of all the rivers of the earth, including glacial streams, has been computed at about 1.2 million cubic metres per second (2). *These figures indicate that in unit time the Florida current transports on the average about 22 times the amount of water discharged to the sea by all the rivers of the earth combined.*

Even in comparison with the other ocean currents, it is shown to be a most powerful conveyer of water masses owing to the high velocities of the sub-surface water. Since the time of KRÜMMEL, who first undertook to estimate the relation between the masses of water and quantities of heat in the Florida and West Indian Currents, it has been generally held that about 3/4 of the water flowing in the Gulf Stream beyond 45° W. is due to the West Indian Current. For this reason KRÜMMEL proposed to abolish the name "Gulf Stream" for this continuation of the junction of the Florida and West Indian Currents and to substitute the name "North Atlantic Westwind Current" (3).

Our hydrographic sections now permit us to calculate the quantities of water and heat in both branches of the Gulf Stream and these computations show that the relations between the two root currents are exactly the reverse of those assumed by KRÜMMEL, on the basis of his statistical temperature profiles. If we include the movement factor in our calculations, *i.e.* if we take the current fields into consideration as well as the temperature fields, the result shows that *the Florida Current carries almost twice the quantity of water of the West Indian Current and further, with regard to the conveyance of heat, the Florida Current proves to be by far the principal current.* From this it follows that the greater part of the water masses and heat units carried by the North Atlantic Gulf Stream originates in the Gulf of Mexico. Although the greater part of the mass of water flowing into the Gulf of Mexico is due to the external force of the wind, the outflow from the Gulf of Mexico is primarily a gradient current. *There appears therefore to be double justification for retaining the name of "Gulf Stream" for the current composed of the junction of the Florida and West Indian Currents.*

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(1) *The integral calculation of the quantities of water and of heat is given in Note 1 at the foot of page 50 in the work cited.*

(2) *See on this subject* Richard FRITZSCHE : Niederschlag, Abfluss und Verdunstung auf den Landflächen der Erde, *Halle* 1906, *and* G. WÜST : Verdunstung und Niederschlag auf der Erde. *This review* 1922.

(3) O. KRÜMMEL : Handbuch der Ozeanographie. *Vol. II, page* 584, *et seq., Stuttgart* 1911.

Up to now we have tacitly assumed that in the Gulf Stream we have been dealing with constant currents — an assumption which is only valid as a first approximation. Since the classic investigations of PILLSBURY we know that the Gulf Stream displays appreciable periodic and heterogeneous changes in velocity, and a recent communication by IDRAC (1) makes it evident that appreciable non-periodic changes in the thermal stratification of the Florida Current arise from these pulsations in the flow. But these observations do not permit the variations in the heat conveyance to be determined with any degree of certainty. One of the most important problems of the future will be the careful survey of these hydrographic profiles at the various sections of the Gulf Stream to clarify the relations between these changes and the oceanic and atmospheric circulation (2).

(1) P. IDRAC : Sur Quelques Singularités du Gulf Stream. Comptes-rendus des Séances de l'Académie des Sciences. *T.* 188, p. 644, *Paris* 1929.

(2) *After the experience of the* Meteor *expedition, it would appear desirable that future "true" observations in the Gulf Stream of the depths and samples of water for each series should be determined by indirect measurement of the depth (By comparing the temperatures in reversibles thermometers both protected and unprotected from the pressure). Since the sounding wire often makes a considerable angle with the vertical due to the great drift of current in the Gulf Stream area, the resultant errors in the deep measurements of the temperature and salinity make a reduction necessary. Some of the discrepancies in the older and recent observation data are to be attributed to this cause.*