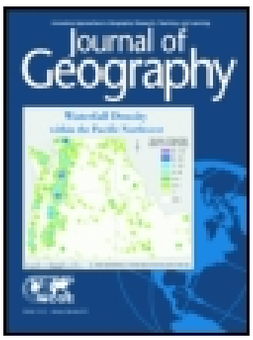

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land stood still during its long period of erosion, the detritus discharged in abundance from its valleys would have smothered any incipient fringing reefs that might for a time have grown on its rocky lava points, and that abrasion would thereupon have set in and the island would have been clift without embayments, like Reunion, instead of being embayed without cliffs, as is actually the case.

(To be continued)

THE GULF STREAM AND THE NORTH ATLANTIC DRIFT

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DESCRIPTION OF THE GULF STREAM

THE stream of warm salt water which issues from the Straits of Florida and takes a northerly course along the American coast constitutes the Gulf Stream proper. At its exit from the Gulf of Mexico it has a width of about 50 miles, and a depth of 2100 feet. Its surface temperature varies with the seasons; in June and July it reaches 83° F., and in September it may be as high as 86°. In February the temperature is reduced to about 76°.

The velocity of the current is greatest along an axis, where it may be as high as 5.4 miles an hour. Each hour it pours 90 billion tons of water into the Atlantic from the Gulf of Mexico.[1] With its deep blue color, high temperature and salinity, and decided northerly current it has been recognized, ever since its existence has been known, as the most striking feature of oceanic circulation on the globe.

As the Gulf Stream continues northward from the Straits of Florida its width varies from 50 to 100 miles.[2] Its depth, as far north as Charleston, is 2400 feet. Off Charleston it shallows to about 1800 feet in its passage over the submarine plateau encountered there.[3]

As far north as Cape Hatteras the western boundary of the Gulf Stream is the 600-foot curve of the outer margin of the continental shelf. Between 37° and 38° N. the course of the current swings away from the coast to the eastward. During its passage along the southeastern coast of the United States the waters of the

1. Pillsbury, J. E., *Nat. Geog. Mag.* 23:1912:768.
2. Reclus, E., *The Ocean*, p. 71.
3. Agassiz, A., *Ann. Report Smithsonian Inst.*, 1891, p. 206.

Gulf Stream are prevented from swinging to the eastward and being dissipated in the open Atlantic by the warm water of that portion of the Equatorial Current which moves northward outside of the West Indies. It is because of its reinforcement by this large volume of warm water that the Gulf Stream is able to continue northward as a current and maintain its high temperature.

The rate of flow of the Gulf Stream differs considerably in various parts of the same section, and the velocity in any one part changes from time to time. The variations in rate of flow are greatest at the surface, and the greatest velocities occur at the surface also. Regular variations in velocity are the daily, monthly, and seasonal changes. Daily variations may amount to as much as 2.5 miles an hour. Less regular variations occur as a result of winds blowing over the surface of the water.

As the Gulf Stream continues northward its velocity decreases very markedly. Off St. Augustine it is seldom more than 4 miles an hour; and by the time it reaches the latitude of New York it is reduced to 2.5 miles. Off the Grand Banks it has a movement of not more than 1.5 or 2 miles an hour; and by the time it reaches 40° W. its current has become practically imperceptible.[1]

From Cape Hatteras the Gulf Stream proceeds northward and eastward meeting the Labrador Current off the coast of Newfoundland. The relative position of the two currents vary with their strength; the Gulf Stream is farther north from April to Sepember than during the remainder of the year, when it is pushed south by the Labrador Current from the north. The cooling of the warm moist air over the Gulf Stream by its mixture with the air from above the Labrador Current results in the heavy fogs which are a menace to navigation in this region.

The North Atlantic Drift

The westerly winds continue the movement of the warm waters of the North Atlantic and force them up against the continent of Europe. Beyond the Newfoundland Banks the Gulf Stream water constitutes a part of this North Atlantic Drift, which is carried northward and eastward, reaching from the Azores to beyond the British Isles and Scandinavia into the Arctic Ocean where its influence is felt as far as Spitsbergen. As far north as the warm surface drift continues its temperature is maintained at from 41° to 43° F. although the Arctic water in the same region may have temperatures ranging from 36° to 32°.[2]

1. Agassiz, A., *Ann. Report Smithsonian Inst.*, 1891, p. 206.
1. Pettersson, O., *Geog. Journ.* 11:1898:614.

The movement of the surface waters of the North Atlantic is quite different from the river-like course of the Gulf Stream near its source. It involves practically all of the surface waters of the North Atlantic and continues the transfer northward and eastward of an enormous quantity of heat received originally from the sun by waters in the torrid zone.

The depth of warm water increases to from 4,000 to 8,000 feet off the shores of Europe as a result of the forcing of the drift against the continental slope. The drift is divided by the obstruction which the continent constitutes, and a part of it is diverted southward. Depending upon their destination rather than upon their individuality as distinct currents in their trans-Atlantic courses, the following divisions of the drift may be distinguished: (1) The northern division which extends toward Greenland and a part of which enters Davis Strait and penetrates as an undercurrent as far as Baffin Bay; (2) The North European branch which continues in the direction of the Gulf Stream itself, making its way to the British Isles, the North Sea and beyond into the Arctic; and (3) the waters which extend in a more easterly course to the Azores from which region they are directed southward and become part of the Equatorial drift.

During the summer months the area of warm surface water in the North Atlantic is greater than in the winter when it is partially covered by cold water from the Arctic region. Not only is there a seasonal variation in the distribution of warm and cold surface waters, but there are considerable differences occuring from year to year. Pettersson found that in 1896 and 1897 the flow of warm water toward Spitsbergen was unusually strong and that in July 1897 the warm surface water extended over the entire distance from Norway to northeastern Spitsbergen. By November, 1897, the area of warm water in the North Atlantic and the Norwegian Sea extended from 59° to 75°N, and covered, according to Pettersson's estimate, an area of between 80,000 and 160,000 square miles. As a direct response to this came an extremely mild winter in northern Europe in 1897.[1]

Causes of the Gulf Stream

Naturally the explanations of the causes of ocean currents in general and of the Gulf Stream in particular have been various. Of all those advanced, the ones which have been most widely accepted are those which assign the chief place in the production of all ocean currents to differences in the specific gravity of the waters in different parts of the ocean, and those which refer to the winds as the chief motive power of ocean currents.

1. In loco cit. p. 615.

Captain Maury, U. S. N., who wrote during the middle of the last century, was the chief exponent of the specific gravity theory. The differences in density depend either upon differences in temperature or salinity. Although Maury's view received the support of a number of other oceanographers at the time it was advanced, it was never generally accepted. As was pointed out by Wyville Thomson it could not be accepted as an adequate explantation, since cooling in higher latitudes and its resulting high density would be offset by the high salinity and consequent high density in equatorial regions. This explanation would account for a state of equilibrium existing between the two regions rather than for the existence of a current from one to the other.

The explanation generally accepted at the present time is that advanced and upheld by Franklin, Herschel, Thomson and other students of the subject. It assigns to prevailing winds the chief part in the production of ocean currents and regards the Gulf Stream as the reflux of the Equatorial currents produced by the impinging of these currents on the continental uplift of South America and the West Indies.

The Trade Winds, blowing toward the equator from the northeast in the northern hemisphere, and from the southeast in the southern, produce a westward drift of waters in the equatorial region of both the Atlantic and Pacific oceans. In the Atlantic this consists of a broad belt of water on either side of the equator moving from Africa toward the western hemisphere. Were it not for the obstruction which is met with in the form of land masses, this movement of waters would encircle the globe; but its westward course brings it to South America and the West Indies. The portion of the drift which is produced by the north-east trades and is north of the equator is deflected northward; that of the south-east trades which is somewhat stronger because of the greater force of those winds, is divided by the nose of the South American uplift into two portions, the larger of which constitutes the Guiana current. The latter moves northward along the South American coast to augment the reflux of the North Equatorial current. Thus all the water of the North Equatorial current and a large portion of the South Equatorial current is directed from the tropics into more northerly latitudes; and a great quantity of heat is thus transferred from regions where heat is in excess, to areas where its addition is highly beneficial.

A portion of the volume of the equatorial waters is deflected into the Caribbean Sea and thence through Yucatan Channel into the Gulf of Mexico. The remainder flows northward outside of

the West Indies and joins the Gulf Stream proper north of the Bahamas. Since the passages through which the waters leave the Caribbean and the Gulf of Mexico are much narrower than those through which they enter, there results a banking-up, so that the surface level is raised above that of the open Atlantic. This retardation of the waters in tropical regions results in their temperature being increased, that of the Gulf of Mexico reaching as high as 86° in September. The elevation of the surface results in the development of hydrostatic pressure which adds to the momentum with which the waters are sent out into the Atlantic through Florida Straits. The force with which the waters are directed from the Gulf is sufficient to carry the Gulf Stream as far as 40°W. long. in the region south and east of the Grand Banks, where its existence as a separate and distinct current may be said to terminate.

Although it exhibits variations which are due to other causes, such as differences in density, depending upon temperature and salinity, the Gulf Stream exists primarily as a result of the movements of surface waters produced by the trade winds blowing over the Atlantic Ocean. The course of the Gulf Stream is determined by the outline of the coasts against which it is directed and along which it flows and to such other influences as the rotation of the earth and the prevailing westerlies.

The circulation of the waters of the North Atlantic continues the movement by which warm water from the equatorial region is carried into northerly latitudes. The prime factor in this movement is the westerly winds. Because of these winds the water is drifted eastward and northward; and eventually the heat which it contributes to the air above its surface is carried to the land.

Professor H. N. Dickson under whose direction extensive investigations concerning the circulation of the waters of the North Atlantic have been carried on, says in regard to this circulation, "It is the result of a large number of factors each of which is subject to a wide variation. The mean result shows that oceanic circulation is directly controlled by the winds, the form, position and intensity of the whole of the Atlantic anti-cyclone and the cyclonic area to the north of it being taken into account. The movements of water set up directly by these systems is modified by, firstly and chiefly, the configuration of the land, and secondly by the effects of melting ice."[1]

Effects of the Gulf Stream on Climate

In the popular mind the Gulf Stream is always associated with the climate of northwestern Europe which is so surprisingly

1. Dickson, H. N., *Phil. Trans. Roy. Soc.*, 1901: 196:108-109.

mild considering the latitude of the region. Whether we call the movement of waters, which carries this heat northward and from which heat is transferred to the land by the wind, the Gulf Stream, or the North Atlantic Drift, its effect on north European climate is exceedingly marked and, to the highest degree, benificent. The drift which extends across the Atlantic consists in part of water brought from tropical regions by the Gulf Stream and its heat thus helps to moderate the climate of Europe, although its original momentum does not carry it to European shores.

Croll has estimated that the heat which is carried north by the Gulf Stream alone is over a fifth of all that received by the North Atlantic and that it is equal to all of the heat received from the sun by a belt 32 miles wide on either side of the equator.[1] This heat transfer keeps the temperature of tropical lands lower, and of more northerly regions higher, than would otherwise be possible and is therefore beneficial in low as well as high latitudes. The heat which is carried northward would have little effect on land temperatures were it not for the winds by which it is transferred landward. Winds alone, however, could not transfer this heat from tropical regions to higher latitudes since there are no winds which continue at the surface from equatorial to polar regions. The heat is carried from the tropics by wind-produced currents, and later, when the heat is transferred from the water to the air above it, the wind carries this heat to the land.

As the warm waters from the Equatorial drift move northward their surface layers are cooled and their density is thus increased. As a result their place is taken by lighter, warmer waters from beneath. In this manner the entire mass of warm water gives off heat to the air above it. The Gulf Stream, as has already been pointed out, is able to maintain its temperature at a comparatively high point as it proceeds northward only because it is reinforced by the warm water of the portion of the Equatorial current which passes to the east of the West Indies. The Gulf Stream itself, instead of being "well equipped on starting on its long journey with an inexhaustible supply of salt and heat, actually does not start with as much as might be picked up anywhere in the Atlantic between Bermuda and the West Indies or our Southern States; moreover, it carries the best part of its supplies on its surface, where, by diffusion and dilution, they are liable to be soon dissipated."[2]

1. Croll, Jas., *Climate and Time*, p. 27 and 35.
2. Lindenkohl, A., *U. S. Coast & Geod. Sur. Rept.* 1895. App. 6, p. 366.

The convection currents which are set up in the water as a result of the surface cooling result in the temperature of the water being fairly uniform throughout its depth. The Challenger Expedition found that the daily range of temperature of the surface waters of the North Atlantic was only 8°F. while that of the air above it was four times as great.[1] The effect which the transfer of heat from the water to the air above it has is manifested very strikingly in the remarkable degree to which the trans-Atlantic isotherms parallel the Gulf Stream and its extension in the North Atlantic drift. The isotherms show variations according to the temperature and position of the Gulf Stream, the 70° isotherm for February extending as far north as 40° while that of August reaches 50°N.[2]

The loss of heat which the northward moving waters undergo off the American coast has no important effect upon the climate of Eastern United States, since the prevailing winds blow off-shore and carry the liberated heat seaward. Heat is given off more rapidly as the warm surface waters spread outward, but as far north as 36° the temperature of the Gulf Stream may be 74°F. while the sea beyond is only 62.5°. In latitude 40° to 41° its temperature may be as high as 72.5° with that of the water beyond it only 63.5°.[3] The difference in temperature between the waters of Europe and those in the same latitude off the American coast is striking. The mean sea temperature off the Hebrides is over 47° above that off the American coast in the same latitude and in the course of the Labrador Current.[4] The influence of the warm water is sufficient to prevent ice from forming in the Norwegian fiords except in those parts where the inner portion is cut off from the circulation of oceanic water by a submarine sill; and its influence is extensive enough to reach into the Arctic Ocean where it keeps parts as far north as 80° free from ice during the greater part of the year, while those of Greenland in the same latitude are never completely free from ice. On the southwest coast of Iceland, against which the warm waters are directed, are the two only ports of the island which are always open so that fishers may venture forth during all parts of the year.[5]

A comparison of land temperatures shows that those of latitude 52°N. in the western part of the British Isles average as high as those in the eastern United States 14° farther south or

1. Murray, Jno., *Geog. Jour.* 12:1898:128.
2. Murray and Hjort, *Depths of the Ocean.* p. 705.
3. Thomson, Wyville, *The Depths of the Sea.* p. 386.
4. Ibid. p. 362.
5. Irminger, C., *Proc. Roy. Geog. Soc.* 5:1861:234.

nearly 1000 miles nearer the equator. The average annual temperature of Dublin is exactly the same as that of Boston, although the latter is 11° nearer the equator than the former.[1]

To the heat which is brought northward by the currents and drifts of the North Atlantic is due the comparatively high temperatures of the British Isles which would otherwise possess a climate much like that of southern Greenland. It is estimated that the January temperature of London is 24°, of Edinburgh 30° and of the Shetland Islands 36° higher than can be accounted for by latitude alone.[2]

Investigations carried on in the Faeroe Islands show a great variation in air temperatures resulting from the direction of the wind. When the wind comes from the southwesterly quarter and brings the warmth of the surface waters with it the temperature may be as much as 43.7°F. higher in the winter and 34.7° higher in the summer than when the wind blows from the north, bringing with it the effect of the Arctic East Iceland drift.[3] The influence of the warm water is sufficient to keep the lakes of the Shetland and Faeroe Islands from being closed by ice during the winter in spite of their high latitudes.

The work of Pettersson, Nansen, and others, on Norwegian coast climates and their relation to the temperature of the sea shows clearly the influence of the temperature of the ocean water upon the land to the leeward. They found that when the water off shore was comparatively warm in February the flowering of certain plants began at an early date and that the snow disappeared and farmers were able to begin farm work sooner than when the water showed a comparatively low temperature. Investigations on the rate of growth of pine trees showed that their growth registered the influence of the water temperature of the year preceding the one for which the growth measurement was taken in each case. The high temperature of the ocean waters of May, 1905, had its manifestation the following year in an unusually great increase in the height of pine trees. Likewise the abnormally low temperature of the surface waters in 1902 was followed by a very slight development of the pines in the growing season of 1903. The retardation is due to the fact that the growth of the pine for any one year is affected by the conditions under which the bud is produced during the preceding year.[4] The results obtained by these studies make it seem probable that further investigation will make it possible to predict general

1. Thomson, Wyville, *Depths of the Sea.* p. 363.
2. Buchan, A., *Jour. School Geog.* 2:1898:362.
3. Irminger, C., *Proc. Roy. Geog. Soc.* 5:1861:234.
4. Murray and Hjort, *The Depths of the Ocean.* p. 300-302.

weather conditions for this region several months in advance with a fair degree of accuracy.

Other Influences of the Gulf Stream

Since temperature is one of the factors which determine the distribution of life in the ocean water, it is evident that the influence of the Gulf Stream must be an important factor in oceanic ecology. In its waters are many forms of animals which would be unable to exist in such northerly latitudes outside of its course. The Nantucket whalers long ago recognized its influence on the distribution of whales none of which were found to inhabit this warm stream although they were found on either side of it. As its temperature is lowered in higher latitudes the tropical fauna disappear and those of intermediate latitudes take their place. In the inner basins of those Norwegian fiords, which are separated from the oceanic circulation by a submarine sill, occur purely Arctic animals, while in the seaward portion of these same fiords are found animals characteristic of more southerly regions. East of North Cape, where the fiords are all open arms of the sea, the two types of animal life are found together with the purely Arctic type preponderating and increasing eastward, until, where the Gulf Stream influence is finally dissipated entirely, it forms the only life. During the winter the area of the warm surface waters of the Atlantic is decreased by the invasion of Arctic waters which partially cover them; and as a result, there is a considerable migration of fishes from the north to the warmer waters. The winter herring fisheries of the Scandinavian coast are possible because of this migration.[1]

Any great or sudden change in the relative position of the warm and cold waters of the ocean may result in great destruction of life among oceanic animals. In 1882 as a result of heavy northerly winds, the area of warm water was decreased and the tile fish of the region affected were destroyed in enormous numbers. It was estimated that all the fish were killed in an area of from 5,000 to 7,000 square miles, and that the number of dead fish must have been at least one billion.

Influence on Navigation

From the beginning of trans-Atlantic voyages the Gulf Stream has influenced the course taken by vessels sailing between Europe and North America. Columbus was the first to

1. Pettersson, O., *Geog. Jour.* 11:1898:614-615.

make use of its current, and by means of it he was able to avoid the calms north of the trade wind belt. From that time on it was recognized as an important factor to be reckoned with in North Atlantic navigation, but it was not until the time of Benjamin Franklin that even the most elementary scientific study of the Gulf Stream was undertaken. Franklin's attention had been called to the fact that the New England trading vessels made better time in trans-Atlantic service than did the Royal Mail packets. From the captains of whaling vessels he found that it was because the American vessels made use of the Gulf Stream in going to Europe and took a course which would avoid its adverse current on the return voyage. From information received from the captains of Nantucket whalers Franklin published a map of the current about the year 1770. His suggestion regarding the use of the thermometer to determine the limits of the Gulf Stream was particularly useful, since the primitive instruments in use at that time did not allow a mariner to get his location with any degree of safety. By means of the thermometer vessels sailing off the southeastern coast of the United States could be kept within its current and hence be safe from the dangers of shallow water nearer shore. With the introduction of more exact nautical instruments the usefulness of the Gulf Stream in this respect came to an end, but it still had to be reckoned with on account of the force of the current itself.

Summary

(1) The Gulf Stream is a part of the reflux of the equatorial currents caused when the trade wind drifts impinge on the continental slope of South America and the West Indies.

(2) The Gulf Stream proceeds northward from the Gulf of Mexico to latitude 37°-38° and then swings eastward to longitude 41° to 40°W. south of the Grand Banks.

(3) From this position its waters form part of the North Atlantic drift, which moves under the influence of the westerlies.

(4) The Gulf Stream is one of the agents by which a great quantity of heat is transferred from the equatorial regions to higher latitudes.

(5) Since it contributes warm water to the North Atlantic drift the Gulf Stream is indirectly one of the causes of the mild climate of Northwestern Europe.

(6) In addition to its effect on land temperatures, the Gulf Stream exerts an influence on navigation and on the distribution of oceanic organisms.