THE QUESTION OF THE HUMBOLDT CURRENT (*)

by

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I. *THE HUMBOLDT CURRENT AND ITS VARIATIONS.*

By *Humboldt Current* is understood a drift, real or supposed, of relatively cold surface water, green or somewhat olive in colour, or inclining to yellow, and which apparently follows the western coast of South America from S. to N., from about Mocha Island (38°30' S.) to Cape Blanco (4°27' S.) where the thermal and colour conditions which characterize the current abruptly disappear: northward of Cape Blanco the water is generally warm and blue, even near the coast.

The relatively cold temperature of the water off the coast of Chile and Peru has been well known ever since the early days of the Spanish conquest. Alexander VON HUMBOLDT, in observing this temperature during his voyage from Callao to Acapulco, at the close of 1802, made no new discovery. But he was the first who had the idea of ascribing an Antarctic origin to the South American coastal waters. He believed that they represented a surface current coming from high latitudes, and connected the coolness of the Ocean water with the dry desert like climate of moderate temperature which prevails on the coasts of Chile and Peru, where persistant fogs, especially the well-known "Peruvian Haze", show active condensation of the humidity of the air in contact with the cold surface of the coastal waters.

The *Humboldt Current*, later connected to the anticyclonic gyratory system of the South Pacific surface currents, took rank as a positive notion on oceanographic charts, such as those of the *Deutsche Seewarte*, when the maritime observations referred to in the *Pilot Charts* and recorded in the *Sailing Directions* of the various countries revealed that, on the coasts of Chile and Peru, from Lat. 38° S. to 4° S., there actually existed a drift of the waters from S. to N., in agreement with the general direction of the trade winds on this coast, and with a slight seasonal advance and retreat which made the supposed limits vary from 2° to 3° at its N. and S. ends. This was remarked long ago, in particular by the French *Sailing Directions* (N° 985): "In various latitudes, southerly currents have been observed following on strong northerly winds, yet but nothing very accurate as to the laws which govern these currents has yet been established."

(*) The exposition of facts dealt with in this article can be advantageously followed with the aid, either of the *Deutsche Seewarte*'s charts of the *Stiller Ozean*, or of the *Pilot Charts* issued by the London and Washington Hydrographic Offices.

But, in March and in the beginning of April 1925 (the autumn of the southern hemisphere), the variations of the end zones became much more marked, to an extent beyond the memory of man; curious climatic consequences resulted on the steppe and desert-like edges of Peru and Chile, from Cape Blanco as far as Valparaiso.

On the whole of this coast, the S.E. trade wind disappeared, and the rainy N.W. monsoon, or Panama monsoon, took its place. The coastal water set in a S.ly direction ; its temperature rose suddenly by 7° to 8° (*). Coastal fish and plankton became rarer and sea-birds emigrated. Violent storms occurred, torrential rains brought about abundant drainage of water over the arid coast, the ever dry *quebradas* became filled with water and vegetation spread temporarily over the arid ground. Houses and huts made of earth and of pise collapsed and whole villages were inundated. The sudden arrival of innumerable insects caused a fear of the development of epidemics. These peculiar occurrences ceased just as abruptly as they had begun as soon as the trade winds returned in the month of April (**).

It is evident that, in this case, a climatic variation occurred which was correlated to a variation in marine circulation. But it must not be hastily concluded, as was the tendency, that the second was the cause of the first. It will be seen that the contrary is more likely. It may perhaps even be more accurate to state that there were concomitant variations, the first cause of which still remains veiled in mystery.

This will appear more clearly if, as will be done here, the facts as now known relative to the so-called *Humboldt Current*, and the interpretations hitherto proposed, be submitted to close analysis.

II. *THE FACTS.*

With regard to the movement of surface water, KRUMMEL notes (*Handbuch der Ozeanographie* II, 714-715) that, near the coast, the currents are not only very irregular, but also very weak and of no importance whatever to navigation ; they are, likewise, very weak off shore. This is BUCHANAN'S opinion also, and he goes so far as totally to deny their existence in coastal waters (J. Y. BUCHANAN, *Accounts rendered of work done and things seen*, p. 105, note). Yet, navigators concur in admitting the reality of a general movement, from S. to N., which is more noticeable near land than in the open, of a mean rate, between Valparaiso and Cobija, of 9.6 miles in 24 hours (*Sailing Directions*, N° 985). For the southern autumn, the Washington *Pilot Charts* give diurnal velocities of current varying between nil and 35 miles off Pisco ; between nil and 10 miles off shore in Lat. 20° S. Long. 80° W. ; still further off shore, from 0 to 25 miles ; off Callao, from 10 to 30 miles ; and off Cape Blanco, from 10 to 20 miles. It may be taken for granted that on the whole the *Humboldt Current* represents a very irregular drift manifestly connected

(*) All the temperatures mentioned in this article are given in or converted to degrees centigrade.

(**) *Annales de Géographie*, N° 193, 15th January, 1926, p. 96, quoted from the *Geogr. Zeitschrift*, 31st year, 1925, p. 1929.

with the variations of the trade wind; the mean value of 15 miles in 24 hours is not far from the truth; this is admitted by Charles DE KERHALLET in his *Considérations sur l'Océan Pacifique*, p. 47, which are still useful though they were published in 1853. Thus this current is weak, yet it was of interest in the days of sails and it had to be taken into account in dead reckoning; the French frigate *La Bonite* bound from Valparaiso to Payta experienced (1836) 3 miles minimum and 26 miles maximum drift. But it is evident that steamships need not take a current of such very small importance into account, notwithstanding its breadth, which KERHALLET, apart from the South Pacific anticyclonic movement, put at 120 miles on the Valparaiso parallel, and at 180 miles on that of Payta (*Considérations*, p. 47). As will be seen, this estimate is exaggerated as concerns the *Humboldt Current* proper, or that which it is agreed should be called by that name.

The thermal and colour conditions of the waters are of much more interest than the weak surface drift. It is discussion of these characteristics which may enlighten us on the real nature of the circulation of the sea westward of South America.

The information available on surface temperatures is derived chiefly from observations made by numerous merchant vessels; they are collected and shown, in the form of isotherms, on the synoptic charts for February, May, August and November, published in the *Deutsche Seewarte*'s Atlas of the *Stiller Ozean* (1895). Nevertheless, in a notice, the *Deutsche Seewarte* editors confess that, for the W. Coast of S. America, the information which they have is very incomplete; besides it is possible that, owing to the diversity of observers and of observational instruments, these indications are scarcely comparable and interpolations are risky. The observations, though old, of the French exploring vessels *La Bonite* (1836) and *La Vénus* (1837) have not become valueless on account of these. The researches at depths carried out by these vessels cannot be used now on account of the imperfection of their instruments at a time when oceanographic apparatus was in its infancy. But the surface observations, carefully carried out with good instruments, remain entirely valid. The observations made by BUCHANAN, the veteran of the *Challenger*, in his voyage in 1885 from Valparaiso to San Francisco, must be added thereto. As for the *Challenger*, in her voyage around the world she did not pass through the *Humboldt Current* area.

The frigate *La Bonite* studied the surface temperature as compared with the air temperature in June and July 1836, during her voyage from Valparaiso to Cobija and Callao, while lying in the harbours, and when going from Callao to Payta. The results of these observations show that, in general, the air and sea temperatures were relatively low taking the latitude into consideration. In the southern parts of the voyages and in the open sea, the sea was warmer than the air, but the reverse began to become pronounced to the northward of Cobija; it became more so at Callao, and from Callao to Payta, *where the sea gave lower temperatures than the air layers situated immediately above it.*

In Valparaiso harbour, the sea was the warmer 96 times and 44 times the colder; in Cobija harbour, 34 times warmer, 9 times colder; from Cobija to Callao, 103 times warmer, 56 times colder. *But at Callao there was a*

change: out of 261 observations, the sea was warmer only 21 times, and colder 240 times; similarly, between Callao and Payta, out of 88 observations, the sea was only 26 times at higher and 62 times at lower temperature.

The thermal means were taken by the observers of *La Bonite* as from + 16° to + 17.6° for the air at Callao; + 16.8° to + 18.4°, from Callao to Payta; for the sea, as from + 15° to + 16.1° at Callao, + 17.1° to 17.7° between Callao and Payta.

The observations of *La Bonite* thus limit the cold area to the *coastal waters between Cobija and Payta, i.e.* about from Lat. 22°30' S. to 4° S.

The isothermic curves of the *Deutsche Seewarte*'s Atlas show the same essential facts for all the terminal months. At no time of the year does the cold water zone become apparent southward of Copiapo. At all times it extends, becoming narrower, up to Cape Blanco, so that all along this coast, from the Equator to the tropic of Capricorn, the temperature of the water varies from only + 19°, at the height of the southern summer, to + 15°, and less, during the depths of the winter. In the same latitude, the waters of the western Pacific in the southern hemisphere never show a temperature lower than + 22°, even reaching + 28°. It is thus certain that the coastal waters to the Wd. of South America always have a temperature from 7° to 9° lower than the normal of the latitude.

BUCHANAN'S observations, at the time of his voyage in 1885, substantiate these data, but limit them strictly to the coastal area. *Some few miles offshore,* says BUCHANAN, the waters draw nearer to the thermal normal of the latitude. He ascertained this by sailing along the coast from Coquimbo to Arica, and continuing off shore (only 10 to 12 miles from the coast) from Arica to Callao. On this trip he recorded + 13.89° just off Coquimbo, + 19.45° at Arica, and + 22.78° at sea, northward of Arica, then a fall to + 16.12° along the coast after Callao, and to + 17.51° at Payta, whilst in the course of one night, after having rounded Cape Blanco, the temperature rose to + 23.89°.

The colour of the water gave indications which were perhaps still more suggestive. Earlier navigators had noted the greenish, green-olive, or yellowish colour of the coastal waters of Chile and especially those of Peru. The observers of *La Bonite* and *La Vénus* noticed the same phenomenon, but had not discovered its cause. We now know that it is due mainly to the abundance of diatoms, the cold water plankton, the presence of which on this coast is accompanied by great plentifulness, as yet little exploited, of fish, crustaceans and molluscs. Green water, chalky-green water, olive-green water, such are BUCHANAN'S successive notes. At a short distance off-shore (15 to 20 miles), the water has an oceanic colour, dark marine blue. But BUCHANAN also notes that at some points off the coast, the *water is blue* (*i.e.* it has no diatoms) *with relatively low temperature*; at Huasco (Lat. 28°27' S.), where the surface temperature was + 14.7°, and at Corizal (Lat. 28°15' S.), where the temperature was + 15.1°. This observation of *blue cold water patches* is of great importance, as will be seen (*).

(*) J. Y. BUCHANAN, *Accounts rendered,* etc..., pp. 130-131.

In all latitudes, between 35° S. and 4° S., the thermal index and the colour index become less and disappear fairly quickly in proportion to the distance to seaward. Where it exists, the greenish or yellowish colour disappears first and rather abruptly, and it is limited to a narrow band. The temperature falls by degrees and, at an average distance of from 80 to 100 miles from the coast, the sea water recovers its normal temperature for the latitude. HOLLMANN observed + 18.3° at Callao; + 20.6°, 30 miles; + 23.8°, 80 miles; and lastly + 27°, 130 miles off-shore (O. KRÜMMEL, *Handbuch der Ozeanographie*, II, 714-715). But up to about Long. 100° W., the slight and irregular surface drift sets always, but with seasonal variations in the general direction of the trade winds, from S.E. to N.W., and with an anticyclonic gyratory tendency about the South Pacific high pressure center. Such is the aspect of the movement in the whole of the area called by J. THOULET the *Easter Island Sea* (*Ann. de l'Institut Océanographique*, Vol. V., Part II, 1928). This movement is generally considered as connected with that of the *Humboldt Current*, and all charts, *e.g.* those of the *Deutsche Seewarte*, group into one drift all the waters of the Pacific westward of South America as far as the meridian of Easter Island. With a surer instinct, though ill-informed, Charles DE KERHALLET made a distinction between the South America coastal current and the off-shore current, which he called the *Mentor Current*, from the name of the Prussian sloop which recorded it in 1833 (*Considérations sur l'Océan Pacifique*, pp. 43-45). The coastal current, or *Humboldt Current*, says KERHALLET, is cold. The *Mentor Current* observed between Easter Island and Juan Fernandez is warm. Indeed, Ingénieur Hydrographe DE TESSAN of *La Vénus* gives + 22.2° to the westward, + 20.5° in the centre, and + 19.3° to the eastward as the temperatures of this current in Lat. 33° S. The width of the *Mentor Current*, according to KERHALLET, is from 360 to 780 miles. The drift to the northward reaches 18 to 21 miles per diem in Lat. 26° S. The Saint Felix and Saint Ambrose Islands are nearly in the middle of the current.

KERHALLET's *Mentor Current* is but a fraction, the eastern fraction of the great South Pacific anticyclonic gyratory movement. Southward, the *Mentor Current* connects with the W. to E. southern current which bifurcates in about Long. 81° W. and Lat. 40° S., throwing off to the N. the *Mentor Current*, and to the E. a relatively warm current which passes round South America after having reached the coastal zone to the neighbourhood of the Chiloe and Chonos Archipelagos. Near the Equator, in the latitude of the Galapagos, the anticyclonic movement of the waters amalgamates with both the movement of the coastal waters and the equatorial currents at their origin: this is the extremely remarkable area of the equatorial eddies.

Such are the facts. Let us now see how they are interpreted.

III. *THE INTERPRETATIONS.*

Alexander VON HUMBOLDT considered that the cold water which slowly flows northward along the coasts of Chile and Peru represents a flow *on the surface* of Antarctic water towards the equator. The fact that polar currents

of this kind exist in the same latitudes in other parts of the globe, such as off the S.W. coast of Africa, lent support to this theory. The total want of information which existed for a long time with regard to the thermal and haline conditions of the southern Pacific, especially to the westward of Cape Horn, from Long. 80° to 110° W., prevented the hypothesis of the flow from the southward from being verified, but also it yielded nothing to the contrary. The *Humboldt Current* was therefore regarded for a long time as a surface drift of Antarctic water.

However, the investigations made by the French vessels, backed by the experience of the observers, soon caused doubts to be entertained as to the reality of this surface movement.

The report drawn up by ARAGO (1842) on the scientific work of *La Vénus* contains interesting remarks with regard to the Chile Current, which were suggested by the observations and the deductions of Monsieur DE TESSAN: "The Chile Current must no longer be considered as just a surface river of cold water, it is produced by a considerable section of the polar seas moving majestically from S. to N. with a depth of 1780 m. at least (Voyage de *La Vénus*, III, 435)". "We are compelled to admit the existence of submarine currents which carry the lower waters of the glacial seas right up to the equator" (III, 419). Elsewhere in the report ARAGO recalls the fact that for a long time seamen have observed "the cooling influence which shoals usually exert on the temperature of the sea" (III, 422). An old discovery which suggested to BUCHANAN his famous theory of marine circulation, and which has been re-made, with much ado, if I may so express it, by the *Meteor* expedition.

Thus, the observers of *La Vénus* and ARAGO, their interpreter, had a sort of presentiment that the flow of cold water did not arise from a surface drift of Antarctic origin. But they did not go further, for they could not do so.

It became quite a different matter when the laws of the temperature and of the ice drift in the south of the Pacific began to be known over the vast area which extends westward of Cape Horn, from Long. 80° to 110°.

This area, where it should be possible to detect at the surface the flow of cold water towards the coast of South America, if it existed, has revealed itself on the contrary as an area of *positive thermal anomaly* as to the surface water: *this is warmer than the air.*

The chart of isoabnormals reproduced by O. KRÜMMEL (*Handbuch der Ozeanographie*, I, 405), is highly significant. Whilst to the southward of the Atlantic, the temperature of the water is lower by 2° to 3° than that of the air, to the southward of the Pacific, it is higher by 1° to 2°: this was noticed long ago by ships which, passing round Cape Horn from the Atlantic to the Pacific, have remarked on the relative warmness of the waters in the zone of terrible gales off Cape Horn, and the area of fogs of the South Pacific. The drift of icebergs is another and still more striking clue. Icebergs never appear in the vicinity of the west coast of South America, in spite of the high latitude. They remain, during the southern summer, to southward of the 55th degree, from Long. 70° to 80°, to southward of the 52nd degree, from the 80th meridian to the 110th meridian W., whilst between the 120th and the 130th meridians, they come as far as 46° S. latitude.

There exists therefore no surface current which carries Antarctic water towards the Equator, on the W. coast of South America, between the Lat. 55° and 38° S.

BUCHANAN, in 1885, taking the facts as then known, absolutely denied the existence of the *Humboldt Current*. He attributed the low temperatures observed off the coast of Chile and Peru to *an uprush of cold water* from the bottom: a phenomenon of vertical and not of horizontal circulation; water of deep-sea origin, and not of Antarctic origin, coming up to the surface in sheets or patches separated from one another, exactly as springs of fresh water may sometimes be seen at the surface of the sea near certain coasts. In order to explain these vertical rushes of constitutionally heavier, because colder, water, BUCHANAN appealed to his general theory of circulation in tropical and subtropical latitudes *viz.*: a gyratory movement of lukewarm water drawn, by degrees, on the surface towards the center of the tropical Oceans, then made heavier by evaporation and falling gently towards the bottom by vertical convection; the deep coastal waters returning to the surface, ascending simply in compensation of the first movement.

It seems fairly clear that, according to BUCHANAN, this movement causes *deep-sea* water, not water of *abyssal* origin to return to the surface: in other words, water coming from about the 2000 metre isobath, and not from the greater depths. BUCHANAN does not explain why, whilst the greater part of the water is green or yellowish, *i.e.*, loaded with diatoms, a part of it while cold remains blue, *i.e.*, nearly azoic. BUCHANAN'S explanation is thus obscure and incomplete. Nevertheless it gives a satisfactory interpretation of the phenomena in the aggregate. BUCHANAN'S only fault was to deny the surface drift due to the trade winds. This drift did not seriously disturb him and, anyhow, did not invalidate his essential idea.

J. THOULET, in his substantial treatise entitled *Le Courant de Humboldt et la mer de l'Ile de Pâques* (*Ann. de l'Institut Océanographique*, Vol. V, Part II, 1928), reverted to the idea of a flow of cold surface water towards the Equator along the coasts of Chile and Peru. But he does not make these waters come from Antarctic latitudes.

He accepts the current representation of surface currents which admits a large drift from W. to E. in the South Pacific, in about Lat. 45°; which drift, when approaching the American continent, divides into two currents, one ascending to the N. and becoming part of the gyration of the South Pacific, the other turning to the S.Ed. and rounding Cape Horn.

The first branch comprises both KERHALLET'S *Mentor current* and the *Humboldt Current*. J. THOULET recognises it as being composed of lukewarm water in the off shore gyratory movement. In order to explain the coastal cold water he calls in the glacier waters and the névés of the Chilean Andes, which drain off in great quantities towards the Pacific during the summer.

It is certain that a film of fresh and brackish waters of this origin fills up the fjords of southern Chile and even spreads itself over part of the coastal zone of the Pacific. The density of the surface layer is found to be remarkably small. The *Deutsche Seewarte's Atlas des Stillen Ozeans* shows it as

being below 1.0260 from Valvidia to the Straits of MAGELLAN to a fair distance off-shore (Chart 5).

But it is not very likely that the zone of extension of this glacier fresh water reaches the coasts of northern Chile and of Peru, where the most striking patches of cold water on the coast make their appearance.

As a matter of fact, glaciers and snow come to an end in the Chilean Andes in about Lat. 40° S.. To the Nd. of this parallel, the Andes are dry mountains, nearly bare of show streams or glacier water; from Lat. 33° there is no drainage whatsoever.

If the cold water which appears on the coast up to Cape Blanco were to proceed from the Andine snow and ice, it would have come, at the nearest, from the 40th parallel. From this parallel to Cape Blanco Lat. 4°27' S., it would have to travel over 2100 miles on the surface. At the rate of 15 miles in 24 hours, this drift would take 140 days. The water would therefore have plenty of time to warm up and to reach the normal thermal level of the latitude. It is known that nothing of the kind occurs; on the contrary, the low temperature of the water tends to become more accentuated, as compared with the higher air temperature, the further it goes North (observations of *La Bonite*).

BUCHANAN's general interpretation of the cold coastal waters, thus seems to be the most probable. It allows for the existence of the offshore gyratory movement and separates the off-shore and coastal waters, as Charles DE KERHALLET had already done more than half a century ago.

IV. *PRESENT STATE OF THE QUESTION.*

With all necessary reservations due to an insufficiently explored field, the following general views may be accepted relative to the zone of the *Humboldt Current* and the gyratory movement in the eastern part of the South Pacific.

At the surface, the coastal waters are pushed towards the N. by the S.E. trade winds. This movement is slight, *viz*: in the vicinity of 15 miles in 24 hours. It is irregular, as regards both intensity and set of current, as well as to the limits of the zone in which it makes itself felt. These irregularities are connected with the seasonal oscillations and daily changes of the trade winds.

The temperature of the coastal water is due, most likely, to the flow of cold water ascending along the slopes of the continental talus, according to BUCHANAN's idea. Where the waters are green and loaded with diatoms, they must come from less deep areas still rich in planktonic life. Where they are blue, they come from deeper areas and, may be, for these it would be necessary to accept lateral deep-sea movements the origin of which is in Antarctic latitudes, in accordance with the theory now adopted by German Oceanographers (*See* Memoirs of WÜST and DEFANT).

The relatively warm off-shore waters, *i.e.* KERHALLET'S *Mentor Current*, are subject to the influence of both the trade winds and the anticyclonic gyration of the South Pacific; the latter is deflected by the earth's rotation in an anticyclonic direction.

The off-shore and coastal waters, pushed by the trade winds, mingle in the vicinity of the Galapagos; there they equalize their temperatures and are transformed into an equatorial current.

Further investigation is necessary before these views can be taken as thoroughly reliable. No doubt it will be possible to utilize the numerous and important observations resulting from the work carried out in this part of the Pacific by the American scientific vessel *Carnegie,* for mention is made of 4 or 5000 oceanographic observations taken across the zone of the *Humboldt Current.* May be they will modify some of our ideas on this subject, but it is not very likely that they will transform them to such an extent as to render our present views entirely invalid.