Low Sea-surface Salinity off Northeastern South America in Summer 1964[1]

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ABSTRACT

Between 24 July and 10 September 1964, low sea-surface salinity was present off South America between 5°N and 10°N in the form of two partly merged tongues extending more than 600 n. mi. east of 50°W. Near 9°N, 50°W, a marked eastward flow was found and identified as the Equatorial Counter Current; it apparently brought in much of the freshened water encountered east of 50°W. This Current consisted primarily of two bands of flow toward the east-southeast; the bands coincided so nearly with the tongues that they suggest that this Current largely controlled the distribution of fresh water. Climatological information for the period from August until November indicates a strong tongue east of 50°W between 5°N and 12°N during these months and, in the same period, a well-developed Counter Current at the surface, at least as far west as 50°W.

A low salinity is normal over large areas of the sea surface for considerable distances off the Guianas and northern Brazil except during the northern winter (Böhnecke 1936). Ryther et al. (1967), Metcalf (1968), and Hulburt and Corwin (1969) have discussed two detailed reconnaissances of large fresh patches centered northwest of the Amazon River mouth. In the period from 24 July to 10 September 1964, during the EQUACHEQUE Operation of Texas A & M University's ship R/V ALAMINOS, the salinities at the sea surface shown in Fig. 1 were observed in a region mainly to the east of the Amazon mouth.[2] Dates at various points along the cruise track are given in Fig. 2.

During the cruise, low sea-surface salinity was always associated with rather high temperature; the lowest temperature found with salinity below 33‰ was 27.9°C. The extent of the warm sea-surface region was slightly greater

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2. A preliminary unpublished report on the low salinities observed during this cruise was made by the author in 1965 in Equatorial currents of the western Atlantic, Progress Report, Texas A & M Univ., Dept. of Oceanogr. and Meteorol., Ref. 65-17T: 6-19.

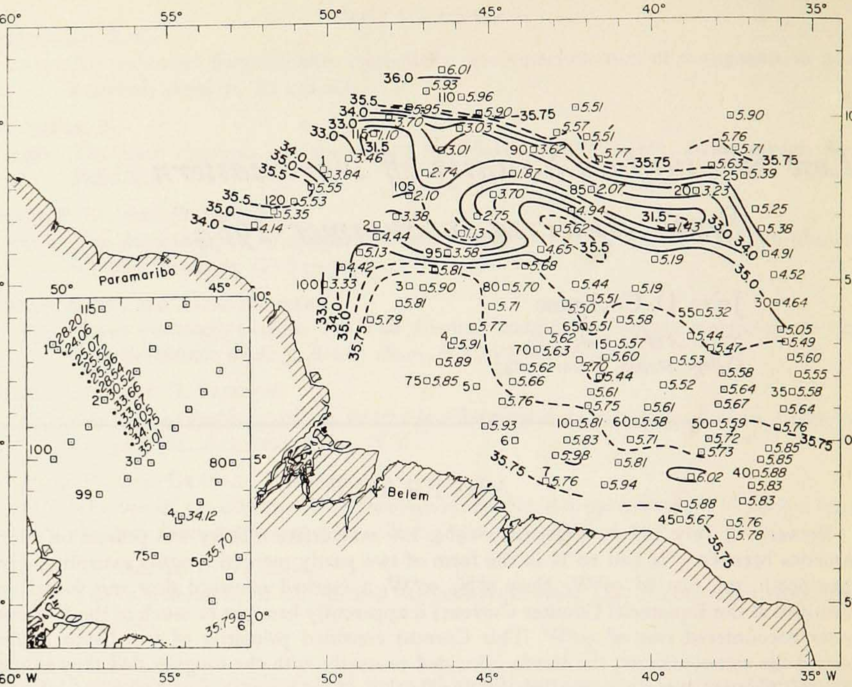

Figure 1. Sea-surface salinity (per mill), determined from bucket samples taken on the R/V ALAMINOS cruise between 24 July and 11 September 1964, is given with italicized numbers. Inset shows values encountered in the first leg. The first digit in the salinity values (the numeral 3) has been omitted, except in the inset. Station numbers are not italicized. Interpretive isohalines are entered.

than of the fresh water, but high salinity was usually coupled with relatively low temperature. The fresh water, which consisted of a layer that seldom exceeded 20 m, was confined by a sharp halocline that was usually accompanied by a weak thermocline above and separate from the main thermocline.

The lowest sea-surface salinity within the region of observation apparently occurred in the area between the first and second lines from the west (Fig. 1). The values encountered just after the ALAMINOS entered the region of observation were quite low (Fig. 1, insert), and in early September they were still low; a minimum apparently existed in the region between Sts. 105 and 115. From the region of lowest salinity observed during the ALAMINOS' cruise, two tongues extended eastward; a short southern tongue passed St. 94, and a longer northern tongue, the dominant feature of the distribution, extended to the eastern edge of the region observed. Possibly freshened water was present immediately adjacent to the coast where sampling did not extend; the coastal regions may have been connected with those regions where the lowest salinities were observed, for example, by a path between the first and second lines from

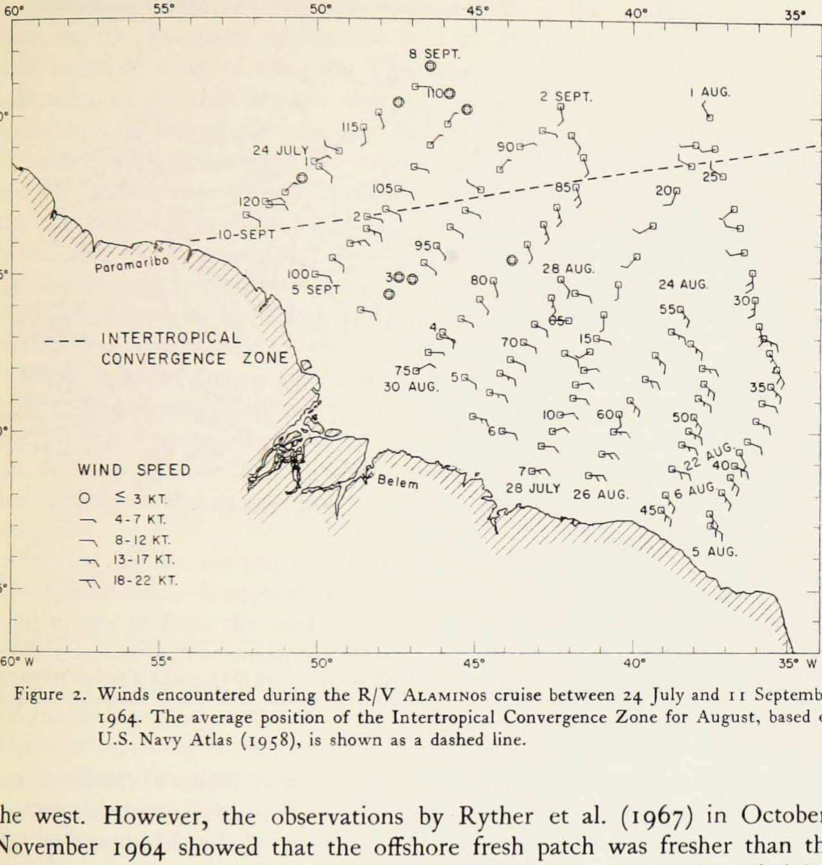

Figure 2. Winds encountered during the R/V Alaminos cruise between 24 July and 11 September 1964. The average position of the Intertropical Convergence Zone for August, based on U.S. Navy Atlas (1958), is shown as a dashed line.

the west. However, the observations by Ryther et al. (1967) in October-November 1964 showed that the offshore fresh patch was fresher than the patches at the coast and that it was separated from them by a region of higher salinity. Such connection as there was lay west of 50°W. Böhnecke's charts also indicate such situations.

A thin sea-surface lens of fresh water may be expected to move in response to both wind and underlying current. During the Equacheque Operation, the southeastern part of the region was dominated by southeast trade winds and the northwestern part by the doldrums—the zone of light winds between the northeast and southeast trade-wind regimes. Fig. 2 shows the winds observed at the ship; Fig. 2 also shows the climatic average position at the center of the doldrums, or the Intertropical Convergence Zone (ITCZ), as inferred from the U.S. Navy Marine Climatic Atlas (1958). On the basis of wind and rain observations, it appears that the ITCZ during Equacheque was somewhat north of its mean position.

Fig. 3 presents the geostrophic flow found in the cruise region by means of the acceleration potential (Montgomery 1937) at the 400-cl t^{-1} surface,

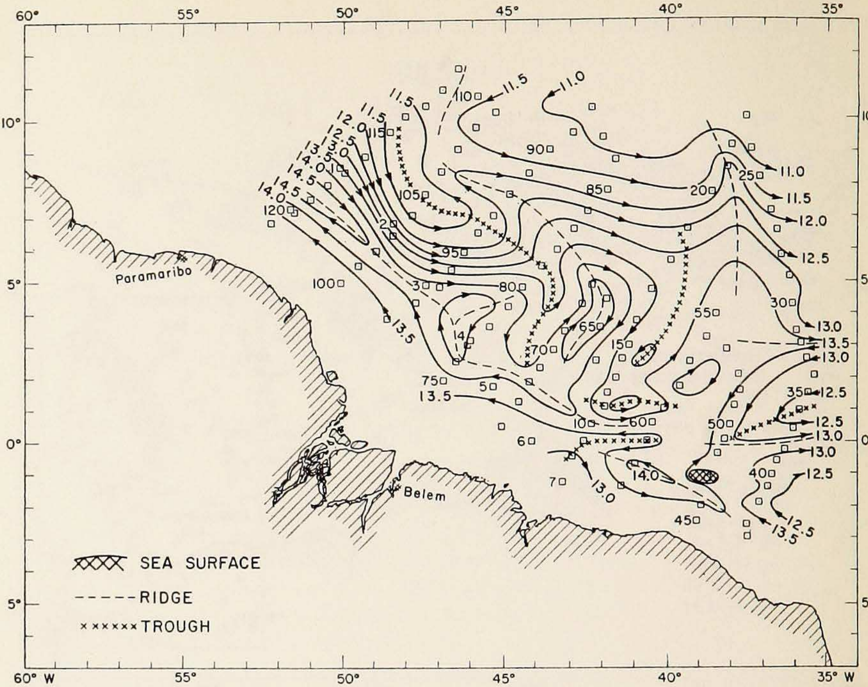

Figure 3. Acceleration potential in dynamic decimeters (kj t^{-1}) at the 400-cl t^{-1} surface relative to 1000 db. Arrows show the direction of geostrophic flow. The first six stations (see Fig. 1) were not used.

which lies in the upper thermocline. For the restricted region of the EQUACHEQUE Operation, the acceleration potential was computed from thermosteric rather than specific-volume anomaly, as suggested by Montgomery and Wooster (1954). In the computation, 1000 db was taken as the reference pressure.

The aspect of the flow pattern that corresponded most closely to the low-salinity tongue was the eastward flow. This consisted of connected bands that crossed the region of observation; these bands have been collectively identified as a segment of the Equatorial Counter Current system. A strong band entered the EQUACHEQUE region near 9°N, 50°W, near St. 1 (Fig. 3), and extended southeastward to 44°W. There the flow doubled back northwestward to the vicinity of 47°W, where a southeastward course was resumed to form a second band in the southeastward direction, offset to the north of the first. The northern band, which extended to the eastern end of the region observed, was joined near the northern end of the jog at 47°W by a weak flow from the northeast. At the beginning of the northwestward jog, part of the southern band continued to the southeast or south, but, after a rather short distance, it was lost in the complexities of that region.

Independent evidence supports many aspects of the indicated geostrophic flow. As the ALAMINOS approached St. 1 in late July, GEK's and the ship's drift indicated a set to the east. The same indications were found in early September as the ship worked along the westernmost line. The core of the southern band was characterized in the first three western lines by a salinity maximum in the 200-to-250-cl t^{-1} range and by relatively low oxygen throughout the thermocline; the water characteristics at Sts. 116, 104, and 94 along the core were similar. The jog to the northwest that connected the two bands is indicated in the geostrophic flow at 100 cl t^{-1} and deeper. At 80 cl t^{-1} it lay above a weak low-salinity tongue that appears to represent the path taken by Antarctic Intermediate Water. The core of the northern band was characterized by a recognizable salinity maximum in the thermocline.

While it might be argued that the complexities of the flow pattern result from putting together data taken over a long period of time, it should be noted that the four western lines were occupied during the short period from 30 August to 10 September (Fig. 2) and that the eastward flow across the westernmost line was found in the same position at both the beginning and end of the operation.

In view of the eastward flow—the Equatorial Counter Current, at the westernmost line—it appears that much of the relatively fresh surface water was brought in from the west. Within the cruise region, the two tongues of fresh water (Fig. 1) correspond closely to the two bands of eastward flow (Fig. 3). The southern tongue evidently extended across the first, second, third, and fourth lines, but on the second line the two tongues seem to have merged. The northern tongue extended for more than 600 n. mi. across the cruise region, always in close proximity to the core of the northern band of the Counter Current. Since such detailed agreement can hardly be accidental, the distribution of low-salinity water seems to have been determined largely by the Counter Current.

While much of the relatively fresh water may have entered the cruise region from the west, the data considered thus far do not preclude contributions of low-salinity water from the south; such water, for example, might have come from the Amazon River mouth by a path within the region. The sea-surface salinity (Fig. 1) is not incompatible with such a path between the first and second lines from the west. However, the underlying geostrophic current indicated at 400 cl t^{-1} (Fig. 3) does not support such a route. Instead, the indicated flows were across the region: inshore there was a current to the northwest; somewhat farther off the coast there was a narrow anticyclonic shear zone; and finally, there was the eastward to southeastward flow of the Equatorial Counter Current.

Nevertheless, between the third and fourth lines from the west, the acceleration potential does indicate a northward flow around the western limb of an anticyclone, which appears to represent the recurving of the North Brazilian

Current described by Metcalf and Stalcup (1967). At the core of this flow, in the thermocline, there were high values of salinity and oxygen, which, as Metcalf and Stalcup have pointed out, typify water of southern hemispheric origin. However, such water was not found west of the third line. Thus, the northward flow did not (Fig. 3) occur far enough west to carry low-salinity water from the Amazon River mouth.

Wind drift rather than underlying currents might have transported fresh water from the Amazon River mouth toward the north between the two westernmost lines. However, the winds observed west of the third line (Fig. 2) were, for the most part, quite weak, as is seasonally normal for the region.

Another agency that might freshen the sea-surface layers is the local rainfall in the doldrums. The climatological mean position of the doldrums, as given by the Deutsches Hydrographische Institut (1967) or in the U.S. Navy Marine Climatic Atlas (1958), is close to that of the fresh tongue from July or August until November, as shown by Böhnecke (1936). Possibly the warm fresh tongue provides a favored location for convection in the atmospheric convergence zone. However, Ryther et al. (1967) have noted (i) that the silicate concentration in the fresh lenses studied by them was appreciably higher than that in typical surface water of the tropical Atlantic and (ii) that such a high concentration is characteristic of river outflow. Climatological data also argue against such rainfall as a major cause of the fresh-water tongue. According to Böhnecke's charts, the tongue does not follow the seasonal migration of the ITCZ. During the northern winter, no fresh tongue exists near the position of the ITCZ, despite the maximum rainfall frequency in the zone at that time, according to the U.S. Navy Atlas (1958). During the EQUACHEQUE Operation, rain was seldom observed at the ship within the ITCZ, although showers were not infrequently sighted. Apparently, rain in the ITCZ on the average freshens the sea surface only to a minor degree. The low wind and high humidity in the zone nevertheless minimize an evaporative increase in salinity and so tend to preserve the freshened regions.

The EQUACHEQUE results suggest that the Equatorial Counter Current plays a leading part in the development of a fresh tongue (or tongues) east of 50°W. Ryther et al. (1967) and Hulburt and Corwin (1969) have noted the role of this Current in the situations they studied. Böhneckes's charts indicate the presence of a strong fresh tongue extending east of 50°W between 5°N and 12°N in May and from August until December. This tongue may result from seasonal tapping of the low-salinity water accumulation west of 50°W by the Counter Current. Such atlases as that of the Deutches Hydrographische Institut (1967) show that the current is well developed at the sea surface from August until November. According to Defant's (1961) account of Schumacher's results, the Counter Current is continuous across the Atlantic and is present at least as far west as 50°W from July until November.

Böhnecke's charts show (i) a decrease in salinity west of 50°W prior to the indicated appearance of the Counter Current at the surface near 50°W and (ii) an increase during the months in which the eastward tongue is strong. The presence of a marked but short tongue in May and its absence in June and July may result from inadequate sampling when the Current is only occasionally at the surface. From December until August the surface current in the west is absent near 50°W (Deutsches Hydrographische Institut 1967). Böhnecke's charts indicate that the tongue also weakens after October and is nearly absent from January until August, except in the anomalous May distribution.

It is noteworthy that the Counter Current appears, on surface current charts, near 50°W in August after the ITCZ reaches almost to its northern position in July, remains while the zone is on the average relatively stationary from August until November, and is absent at 50°W in December after the zone has begun moving southward in November.

Data from the EQUALANT II cruise of A.R.A. COMODORO LASERRE in August 1963 lend further support for a connection between the fresh tongue and the Counter Current. At St. 15 at 6°28.0′N, 37°25.0′W, an isolated and relatively low salinity value of 34.40‰ was observed. In that vicinity, the isotherms sloped upward to the north, indicating eastward flow; presumably this was the Counter Current. The station was located within the region of the northern fresh tongue of August 1964.

REFERENCES

BÖHNECKE, GÜNTHER
1936. Temperatur, Salzgehalt und Dichte an der Oberfläche des Atlantischen Ozeans. Wiss. Ergebn. dtsch. atlant. Exped. "Meteor" 5, Atlas.

DEFANT, ALBERT
1961. Physical Oceanography. Pergamon Press, New York. 729 pp.

DEUTSCHES HYDROGRAPHISCHE INSTITUT
1967. Monatskarten für den Nordatlantischen Ozean (Vierte Auflage).

HULBURT, E. M., and NATHANIEL CORWIN
1969. Influence of the Amazon River outflow on the ecology of the western tropical Atlantic. III. Planktonic flora between the Amazon River and the Windward Islands. J. mar. Res., *27* (1): 55–72.

Metcalf, W. G.
1968. Shallow currents along the northeastern coast of South America. J. mar. Res., *26* (3): 232–243.

Metcalf, W. G., and M. C. STALCUP
1967. Origin of the Atlantic Equatorial Undercurrent. J. geophys. Res., *72* (2): 4959–4975.

MONTGOMERY, R. B.

1937. A suggested method for representing gradient flow in isentropic surfaces. Bull. Amer. meteorol. Soc., *18* (4): 210–212.

MONTGOMERY, R. B., and W. S. WOOSTER

1954. Thermosteric anomaly and the analysis of serial oceanographic data. Deep-sea Res., *2* (1): 63–70.

RYTHER, J. H., D. W. MENZEL, and NATHANIEL CORWIN

1967. Influence of the Amazon River outflow on the ecology of the western tropical Atlantic. I. Hydrography and nutrient chemistry. J. mar. Res., 25 (1): 69–83.

U.S. NAVY

1958. Marine Atlas of the World. Vol. II, South Atlantic Ocean.