VARIATION OF THE SURFACE GEOSTROPHIC FLOW IN THE EASTERN INTERTROPICAL PACIFIC OCEAN

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ABSTRACT

A sequence of seven maps is presented to show the distribution of geopotential anomaly at the sea surface in the eastern intertropical Pacific Ocean. Each map represents a 2-mo period during the EASTROPAC expedition from February 1967 to April 1968.

The most striking feature revealed by these maps is the variation of the North Equatorial Countercurrent in response to the annual variation of the atmospheric circulation. In February-April (both 1967 and 1968), when the atmospheric intertropical convergence zone (ITCZ) lay near its southernmost position at lat. 2°-6°N, the Countercurrent was discontinuous and was rapidly changing in intensity. In August-September, when the ITCZ lay near its northernmost position at lat. 11°-15°N, the Countercurrent was strong, broad, and extended east all the way to the coast of Costa Rica.

In southern summer a weak and narrow eastward current was indicated along about lat. 10°S between long. 112° and 90°W within the westward flow of the South Equatorial Current. This current is so weak that it is probably buried in the westward Ekman drift due to the southeast trades and can be observed only when the trade winds are unusually weak.

An eastward current, which can be interpreted as the Equatorial Undercurrent breaking the sea surface, was indicated within about 2° of the equator in April-May, when the southeast trades were relatively weak near the equator.

The distributions of relative geostrophic flow in February-March 1967 and February-April 1968 were remarkably similar over the entire study area.

The purpose of this paper is to present a sequence of seven maps (Figures 1-7) showing the distribution of geopotential anomaly at the sea surface of the eastern intertropical Pacific Ocean from February 1967 to April 1968 and to discuss the variations of the circulation revealed by these maps. Each map represents a 2-mo period during the EASTROPAC expedition, which was an international cooperative oceanographic investigation coordinated by the Bureau of Commercial Fisheries (now National Marine Fisheries Service).

Prior to EASTROPAC a considerable number of expeditions took place in the eastern intertropical Pacific Ocean; consequently, its principal oceanographic features were reasonably well known (e.g., Wooster and Cromwell, 1958; Bennett, 1963; Wyrtki, 1966, 1967; Tsuchiya, 1968; Stroup, 1969). However, the accumulated data were too sparse in time and space to give insight into monthly or seasonal variations in the distribution of oceanographic properties. The EASTROPAC expedition was designed to acquire data to bring to light these time variations.

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The expedition was divided into seven 2-mo cruise periods. During each period, a single-ship or multiship cruise was carried out. Multiship cruises took place in February-March, August-September 1967, and February-April 1968. These cruises covered the area between lat. 20°N and 20°S (15°S in August-September 1967) and from the coast of the American continents westward to long. 119°W (126°W in February-March 1967). Single-ship cruises took place in April-May, June-July, October-November 1967, and December 1967-January 1968 in time intervals between the multiship cruise periods. Each of these cruises covered the area between lat. 20°N and 3°S and between long. 98° and 119°W.

Details of the observational program, the list of participating vessels, and track charts have been published in the EASTROPAC atlas (Love, 1972a).

DATA

Almost all EASTROPAC stations with observations to 500 m or deeper were used in this study. These stations are listed in Table 1 and can be identified on the track charts included in the EASTROPAC atlas (Love, 1972a).

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TABLE 1.—List of stations used in Figures 1-7.

Ship and cruise	Stations	Dates	Number of stations used	Data type[1]	Figure number
Argo 11	2, 25-328	25 Jan.-2 Mar. 1967	152	a	Fig. 1
Jordan 12	2-284	12 Feb.-21 Mar. 1967	129	a	
Rockaway 13	1-265, 318-342	1 Feb.-20 Mar. 1967	129	b	
Alaminos 14	1-101, 110-159, 194-267, 301, 309, 332, 333, 340-342	31 Jan.-3 Apr. 1967	143	a, b	
			Total 553		
Jordan 20	5-264	13 Apr.-24 May 1967	129	a	Fig. 2
Jordan 30	8-264	17 June-27 July 1967	149	a, c	Fig. 3
Washington 45	7-206, 282-387	6 Aug.-15 Sept. 1967	177	a	Fig. 4
Undaunted 46	2-189	16 Aug.-22 Sept. 1967	141	a	
Rockaway 47	1-40, 49-113, 124-258, 268-382, 402-527	1 Aug.-23 Sept. 1967	212	b	
			Total 530		
Jordan 50	5-249	20 Oct.-26 Nov. 1967	126	a	Fig. 5
Jordan 60	2-289	21 Dec. 1967-28 Jan. 1968	166	a	Fig. 6
Washington 75	1-144, 187-258	18 Feb.-8 Apr. 1968	160	a	Fig. 7
Jordan 76	1-255	21 Feb.-30 Mar. 1968	131	a	
Rockaway 77	6-103, 113-278, 302-438, 475-571	30 Jan.-18 Apr. 1968	263	b	
			Total 554		

[1]a: STD digital data logger; b: STD analogue charts; c: Nansen-bottle casts.

Temperature and salinity data used for computing geopotential anomaly were collected with in situ salinity-temperature-depth recorders (STD) except for those from EASTROPAC cruise *David Starr Jordan* 30, on which a breakdown of the STD necessitated the use of Nansen bottles during the last half of the cruise. Most of the STD data were obtained from digital data loggers, but some were digitized from analogue charts (Table 1). The method of processing STD data is described in the EASTROPAC atlas (Love, 1972a).

From these temperature and salinity data, geopotential anomaly at the sea surface was computed with reference to 500 db. Because of relatively homogeneous water at depths greater than 500 m in the intertropical ocean, this reference is believed to be adequately deep for estimating the geostrophic current at the sea surface. The unit of geopotential anomaly is chosen to be joule per kilogram (abbreviated J/kg; equivalent to dynamic decimeter).

Computed geopotential anomaly was plotted on each map, and smooth isopleths were drawn at intervals of 1.0 or 0.5 J/kg. The base map is a Mercator projection and was adapted from U.S. Navy H. O. 526 and 823.

THE SURFACE GEOSTROPHIC FLOW

The surface geostrophic flow revealed by the maps of geopotential anomaly is described below. A comparison of these maps with other maps based on long-term averages of set and drift of ships is also made. The atlas of the monthly average surface currents in the eastern North Pacific published by the U.S. Navy Hydrographic Office (H. O. 570, 1947) and the atlas of the quarterly average surface currents in the South Pacific published by the Meteorological Office (M. O. 435, 1939) are pertinent to the comparison. There are also monthly drift charts by Cromwell and Bennett (1959) for the northern hemisphere and those by Puls (1895) and Wyrtki (1965) for both hemispheres. The charts by Cromwell and Bennett are simply a different presentation of the H. O. 570 charts for the area east of long. 120°W and south of lat. 30°N. Puls' charts show the current direction and relative intensity for the area between lat. 20°N and 10°S. Wyrtki's charts are based on averages over 1-degree squares, but it is not clear how he smoothed or interpolated the original 1-degree averages to obtain the current patterns shown on his charts.

Various sources of errors and disparities in the geostrophic calculation and set-and-drift observations should be kept in mind. Geopotential anomaly computed from oceanographic data may include short-period density fluctuations that are not necessarily associated with fluctuations of the actual current. The calculation of geostrophic flow neglects the direct frictional effect of wind stress.

On the other hand, set-and-drift observations are affected by strong winds, sea, swell, and tidal currents.

South Equatorial Current Region

The South Equatorial Current is well defined west of long. 90°W on the maps for February-March 1967, August-September 1967, and February-April 1968 (Figures 1, 4, and 7). South of lat. 10°S the direction of geostrophic flow is predominantly to the northwest, whereas the drift charts (Meteorological Office, 1939; Wyrtki, 1965) for the corresponding months indicate that the surface current flows almost due west in this region. This disagreement may be due to the effect of the Ekman drift. The trade winds in this area are from the southeast to east, so that if the Ekman drift is added to the geostrophic flow, the resultant surface current would be nearly to the west.

North of lat. 10°S the South Equatorial Current becomes more zonal and flows almost due west. In February-March 1967 (Figure 1) the westward flow of the South Equatorial Current extends across the equator to about lat. 5°N, and the current near the equator west of the Galápagos Islands is also westward. In April-May 1967 (Figure 2) the westward flow of the South Equatorial Current is interrupted by an eastward current within about 2° of the equator. Puls' (1895) charts of the surface current for March and April clearly show an eastward current at the equator between long. 110°W and the Galápagos Islands. Such an eastward current can be interpreted as the Equatorial Undercurrent breaking the sea surface during local weakening of the easterly trades (Cromwell, Montgomery, and Stroup, 1954; Montgomery, 1962; Montgomery and Stroup, 1962:59-60). Jones (1969) has presented evidence of a surfacing of the Undercurrent on the basis of direct current measurements made at long. 98°W in April 1968 (EASTROPAC cruise *Thomas Washington* 75). The distribution of geopotential anomaly from this cruise, however, does not suggest a surfacing of the Undercurrent (Figure 7).

On the other maps (Figures 3-7) flow is westward from the equator to about lat. 5°N, and in some longitudes an eastward current is revealed just south of the equator, because geopotential anomaly does not show a minimum at the equator but a few degrees of latitude south of the equator. The same distribution of geopotential anomaly can be seen on Bennett's (1963, Figure 6) map based on EASTROPIC data. This distribution is associated with a thermocline ridge that tends to occur at lat. 1°-3°S (instead of the equator) in the eastern Pacific. This southward displacement of the ridge from the equator is clearly evident on many of EASTROPAC vertical sections of temperature or thermosteric anomaly and maps of the topography of the 300-cl/t isanosteric surface, which lies close to the center of the thermocline (Love, 1971, 1972b, 1973, in press). According to Cromwell's (1953) simple model of the wind-driven meridional circulation, the direction of the wind near the equator determines the position of the maximum divergence of the Ekman transport in the surface layer. He points out that the meridional component of the southeast trades shifts the maximum divergence, which would correspond to a ridge of the thermocline, to the south of the equator.

The eastward geostrophic flow between the equator and the ridge was first discussed by Austin (1960) and later commented upon by Stroup (1969:35). It is not certain, however, that the actual surface current is eastward south of the equator. Estimates of the magnitudes of terms in the equation of motion suggest that the southward pressure gradient is in approximate balance with the northward component of wind stress. The M. O. 435 drift chart for the May-July quarter shows very weak easterly components just south of the equator at long. 100°-110°W between strong westward currents to the north and south. The drift charts for the other quarters show no evidence of an eastward current south of the equator.

The southern-summer maps (Figures 1 and 7) exhibit a weak eastward current along about lat. 10°S from long. 112°W to about 90°W. Examination of vertical sections of temperature and maps of surface temperature in the EASTROPAC atlas (Love, 1972a, in press) indicates that this current is associated with a slight southward shoaling of a shallow summer thermocline and with a meridional temperature gradient developed during summer between a pool of warm surface water south of the equator and cold surface water farther south that appears to be coming from the Chile Current (Wooster, 1970). This suggests that the eastward geostrophic current along lat. 10°S is found only in southern summer. (It is interesting to note that the North Equatorial Countercurrent, which flows east at roughly the same latitude in the northern hemisphere, is most strongly developed during the same season, i.e., northern

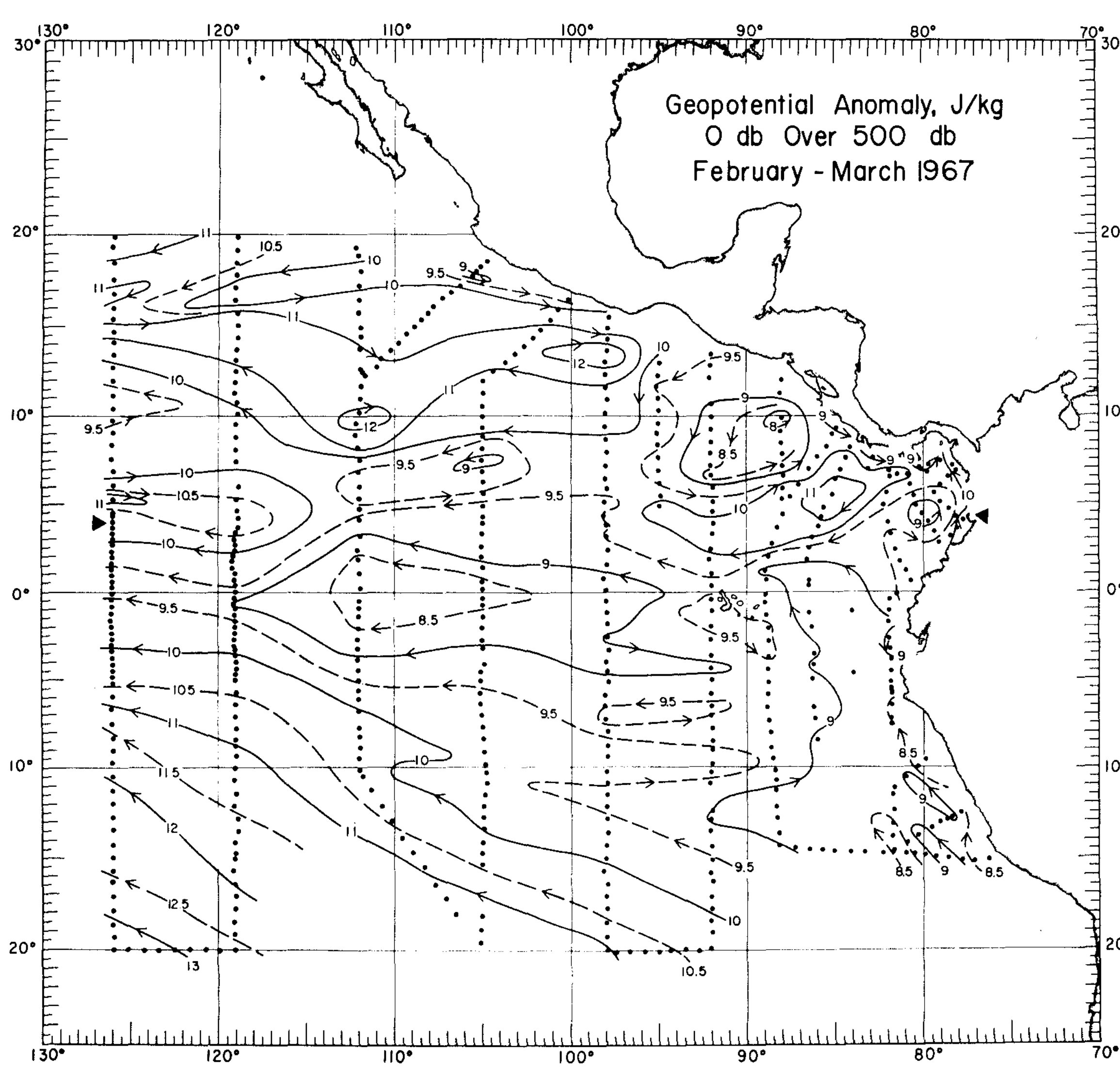

FIGURE 1.—Geopotential anomaly, in joules per kilogram (dynamic decimeters), at the sea surface relative to 500 db in February-March 1967. EASTROPAC cruises *Argo* 11, *David Starr Jordan* 12, *Rockaway* 13, and *Alaminos* 14. The position of the intertropical convergence zone at the eastern and western ends of the map is indicated by triangles.

summer.) However, the coverage of the southern-winter map (Figure 4) is limited to lat. 10°S, and this suggestion cannot be confirmed by winter data. None of the drift charts examined shows an eastward current near this latitude in the eastern South Pacific, but their data are too sparse to draw a definite conclusion. Because of its low speed, the countercurrent, indicated by the distribution of geopotential anomaly (Figures 1 and 7), may well be buried in the westward Ekman drift due to the prevailing southeasterly trades and may be observed only when the trade winds are unusually weak.

Peru Current

In the region south of the equator and between long. 90°W and the coast of South America, the distribution of geopotential anomaly is irregular, and its spatial variation is not large (Figures 1, 4, and 7). This distribution suggests a dominance of weak and broad flow with small-scale irregularities such as eddies and countercurrents (Wooster and Reid, 1963; Wyrtki, 1963). Partly because of this fact and partly because of a rather inadequate orientation of ship tracks in this area, contouring is difficult; there are many other ways

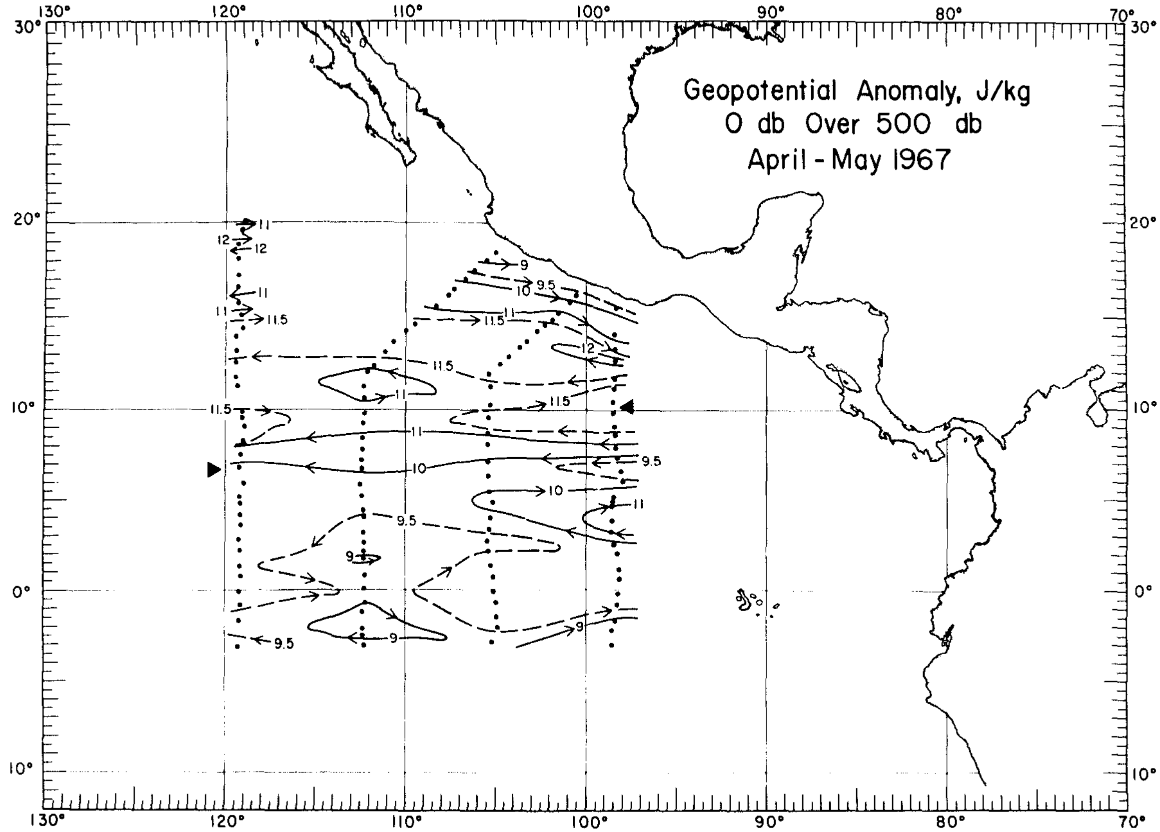

FIGURE 2.—Geopotential anomaly, in joules per kilogram (dynamic decimeters), at the sea surface relative to 500 db in April-May 1967. EASTROPAC cruise, *David Starr Jordan* 20. The position of the intertropical convergence zone at the eastern and western ends of the map is indicated by triangles.

to draw isopleths. Consequently, the deduced geostrophic-flow pattern is not everywhere reliable. Nevertheless, the general trend of flow indicated by the present maps is parallel to the coast and toward the equator. There is not much change in general flow patterns during the EASTROPAC period.

Eastern Boundary Currents in the Northern Hemisphere

In this region flow also tends to follow the coastline. On the map for February-March 1967 (Figure 1), there is an indication of a northward current, the Colombia Current (Wooster, 1959; Stevenson, 1970), flowing close to the coast of Colombia toward the Gulf of Panama. On the maps for August-September 1967 and February-April 1968 (Figures 4 and 7) the distribution of stations is inadequate for defining the Colombia Current.

Off Costa Rica the direction of flow varies, depending on the development of an anticyclonic eddy farther offshore. The strong southeastward flow indicated by the map for February-March 1967 (Figure 1) is associated with the northern edge of an anticyclonic eddy centered at lat. 5°N, long. 85°W. A similar anticyclonic eddy is observed in February-April 1968 (Figure 7), but is centered at lat. 5°N, long. 88°W, farther west than in 1967; and the flow near the coast of Costa Rica is northwestward. As Puls (1895:24 and 27), Cromwell (1958), and Wyrtki (1965) have noted, their drift charts also show a well-developed anticyclonic eddy in this area from February to March. This anticyclonic eddy seems to be a normal feature in these months. In August-September (Figure 4), when no such anticyclonic eddy develops, the area off the coast of Costa Rica is dominated by the northwestward return flow of the North Equatorial Countercurrent.

A cyclonic circulation is well developed around the Costa Rica thermal dome centered near lat.

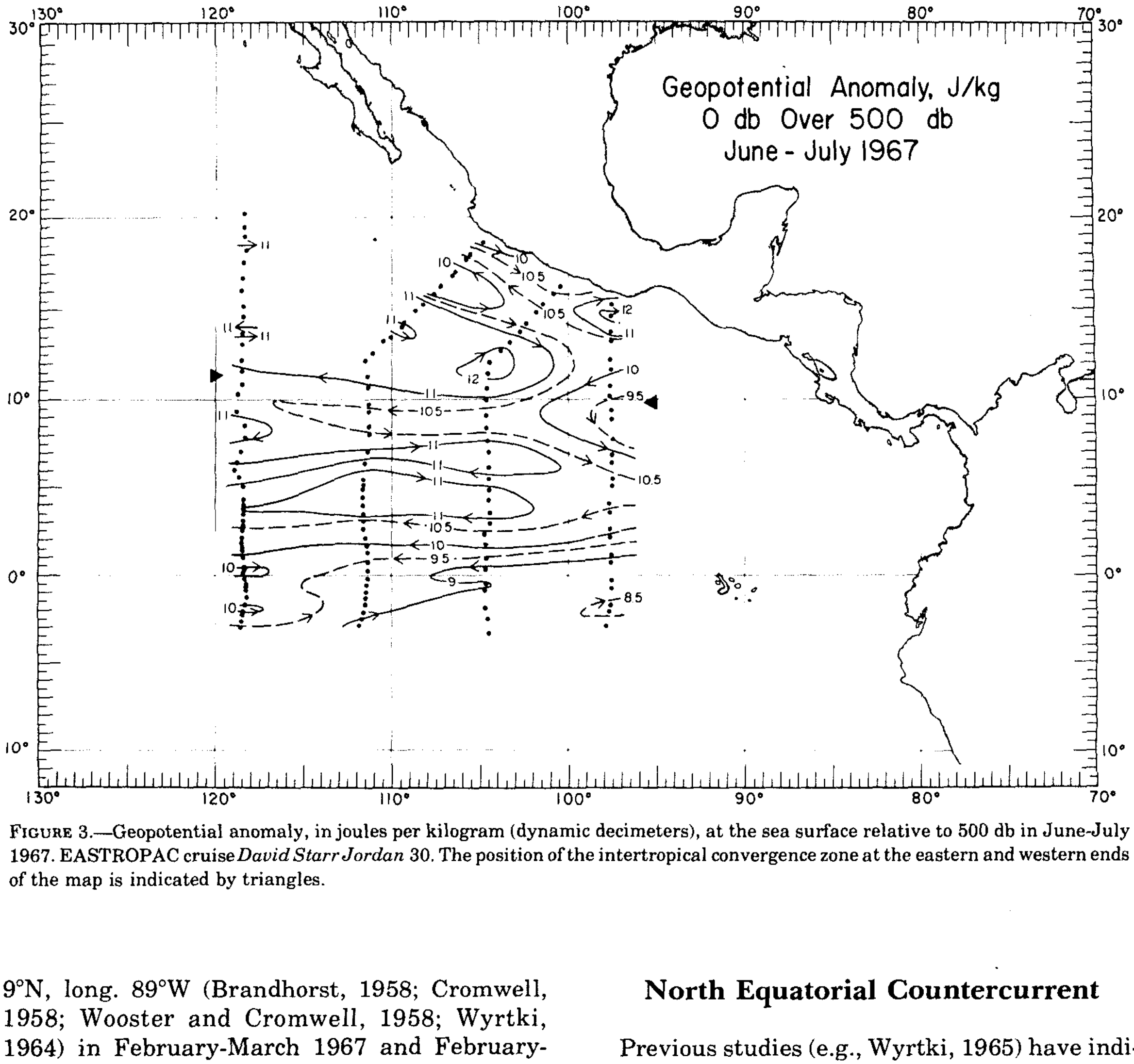

FIGURE 3.—Geopotential anomaly, in joules per kilogram (dynamic decimeters), at the sea surface relative to 500 db in June-July 1967. EASTROPAC cruise *David Starr Jordan* 30. The position of the intertropical convergence zone at the eastern and western ends of the map is indicated by triangles.

9°N, long. 89°W (Brandhorst, 1958; Cromwell, 1958; Wooster and Cromwell, 1958; Wyrtki, 1964) in February-March 1967 and February-April 1968 (Figures 1 and 7), but is less well defined in August-September 1967 (Figure 4).

Between Costa Rica and Cape Corrientes (lat. 20°N), nearshore flow is generally northwestward in August-September (Figure 4), when the North Equatorial Countercurrent is strongly developed. In the other months (Figures 1-3 and 5-7) flow is southeastward from Cape Corrientes at least as far south as the Gulf of Tehuantepec (lat. 16°N). This sense of flow is in agreement with that found on the H. O. 570 drift charts except for June-July, when the nearshore current is northwestward on the drift charts. Puls' (1895) charts, however, indicate easterly components of flow near the coast between Cape Corrientes and the Gulf of Tehuantepec in all months of the year.

North Equatorial Countercurrent

Previous studies (e.g., Wyrtki, 1965) have indicated that the North Equatorial Countercurrent is subject to a large variation in response to that of the atmospheric circulation, particularly the annual meridional migration of the intertropical convergence zone (ITCZ). During EASTROPAC the North Equatorial Countercurrent exhibited a high level of variability in position and intensity. The Countercurrent was weak and discontinuous in February-April 1967 and 1968, when the ITCZ lay near its southernmost position at lat. 2°-6°N. It was strong, broad, and extended all the way to the coast of Costa Rica in August-September 1967, when the ITCZ lay near its northernmost position at lat. 11°-15°N. (The position of the ITCZ during EASTROPAC can be inferred from surface-wind charts in the EASTROPAC atlas.

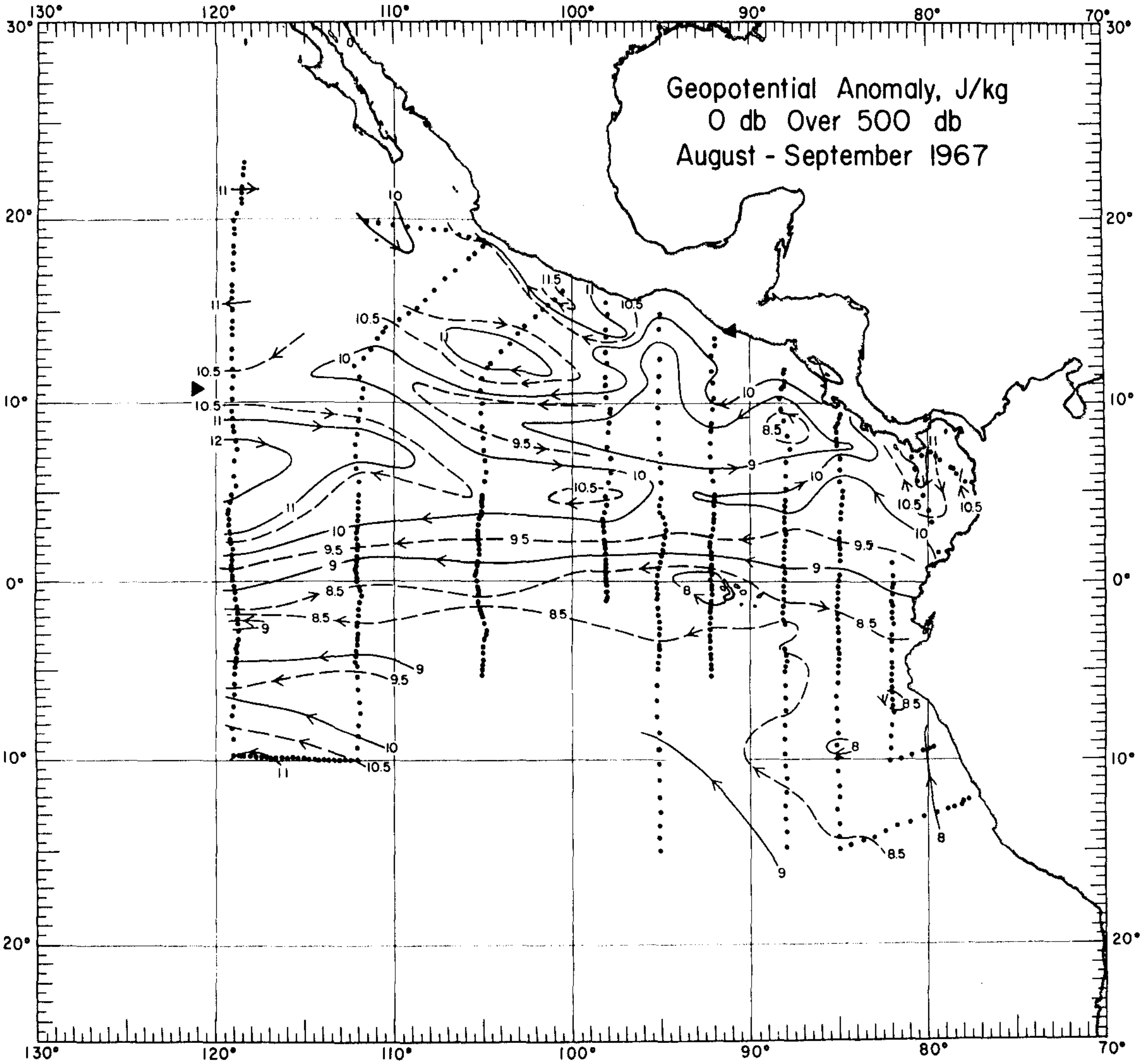

FIGURE 4.—Geopotential anomaly, in joules per kilogram (dynamic decimeters), at the sea surface relative to 500 db in August-September 1967. EASTROPAC cruises *Thomas Washington* 45, *Undaunted* 46, and *Rockaway* 47. The position of the intertropical convergence zone at the eastern and western ends of the map is indicated by triangles.

The position at the easternmost and westernmost meridional sections is indicated by triangles on each map in Figures 1-7.)

In February-March 1967 (Figure 1) the North Equatorial Countercurrent is present between lat. 5° and 8°N[2] at long. 126° and 119°W, but it is practically missing at long. 112°W and only weakly developed at long. 105°W. At long. 98°W the Countercurrent is entirely absent. From long. 95° to 85°W a strong eastward current, which can be identified as the North Equatorial Countercurrent, is found along lat. 5°-6°N between the cyclonic and anticyclonic eddies mentioned earlier. In April-May (Figure 2) no countercurrent is found at long. 119°, 112°, and 105°W, but a strong countercurrent is indicated between lat. 4° and 7°N at long. 98°W. In April-May the ITCZ starts returning to the north and is located north of lat. 6°N.

The development of the North Equatorial Countercurrent in February-April 1968 (Figure

[2] Near the northern edge of the North Equatorial Countercurrent, flow is usually weak, and the current boundary is not always well defined by the distribution of geopotential anomaly. The northern boundary cited here is that of the band of strong current. Weak eastward flow may extend farther north.

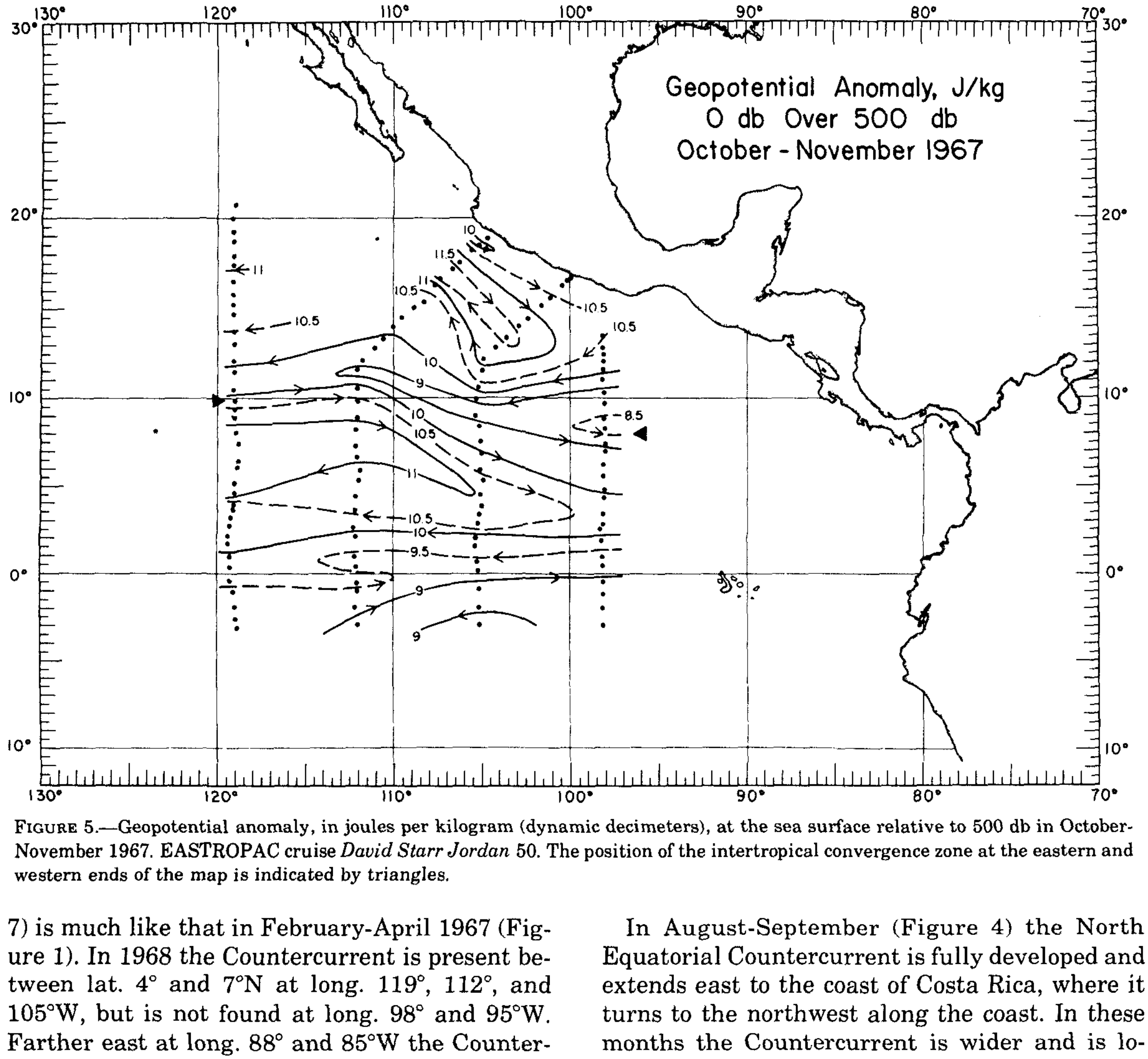

FIGURE 5.—Geopotential anomaly, in joules per kilogram (dynamic decimeters), at the sea surface relative to 500 db in October-November 1967. EASTROPAC cruise *David Starr Jordan* 50. The position of the intertropical convergence zone at the eastern and western ends of the map is indicated by triangles.

7) is much like that in February-April 1967 (Figure 1). In 1968 the Countercurrent is present between lat. 4° and 7°N at long. 119°, 112°, and 105°W, but is not found at long. 98° and 95°W. Farther east at long. 88° and 85°W the Countercurrent is strongly developed along lat. 5°-8°N between cyclonic and anticyclonic eddies similar to those observed in 1967.

By June-July 1967 (Figure 3) the North Equatorial Countercurrent is well established between lat. 6° and 10°N on all four meridional sections. In Figure 3 a weak eastward current, separated from the Countercurrent by a narrow band of westward flow, can be seen about 200 km south of the southern boundary of the Countercurrent. This secondary countercurrent represents a surfacing of a narrow but stable subsurface eastward current, which has its maximum speed at a depth of 50-200 m just south of the North Equatorial Countercurrent (Tsuchiya, 1972).

In August-September (Figure 4) the North Equatorial Countercurrent is fully developed and extends east to the coast of Costa Rica, where it turns to the northwest along the coast. In these months the Countercurrent is wider and is located farther north than in the February-April periods of 1967 and 1968. In August-September it lies between lat. 7° and 11°N at long. 119° and 112°W and between lat. 5° and 10°N east of long. 105°W (Figure 4). About the same condition continues through November (Figure 5), although the ITCZ starts shifting south in October. In December-January (Figure 6) the Countercurrent starts moving south, following the ITCZ's southward shift, which began 2 mo earlier.

The variation of the North Equatorial Countercurrent revealed by the present maps of geopotential anomaly generally agrees with the results of set-and-drift observations discussed by Puls (1895), Cromwell and Bennett (1959), and Wyrtki (1965).

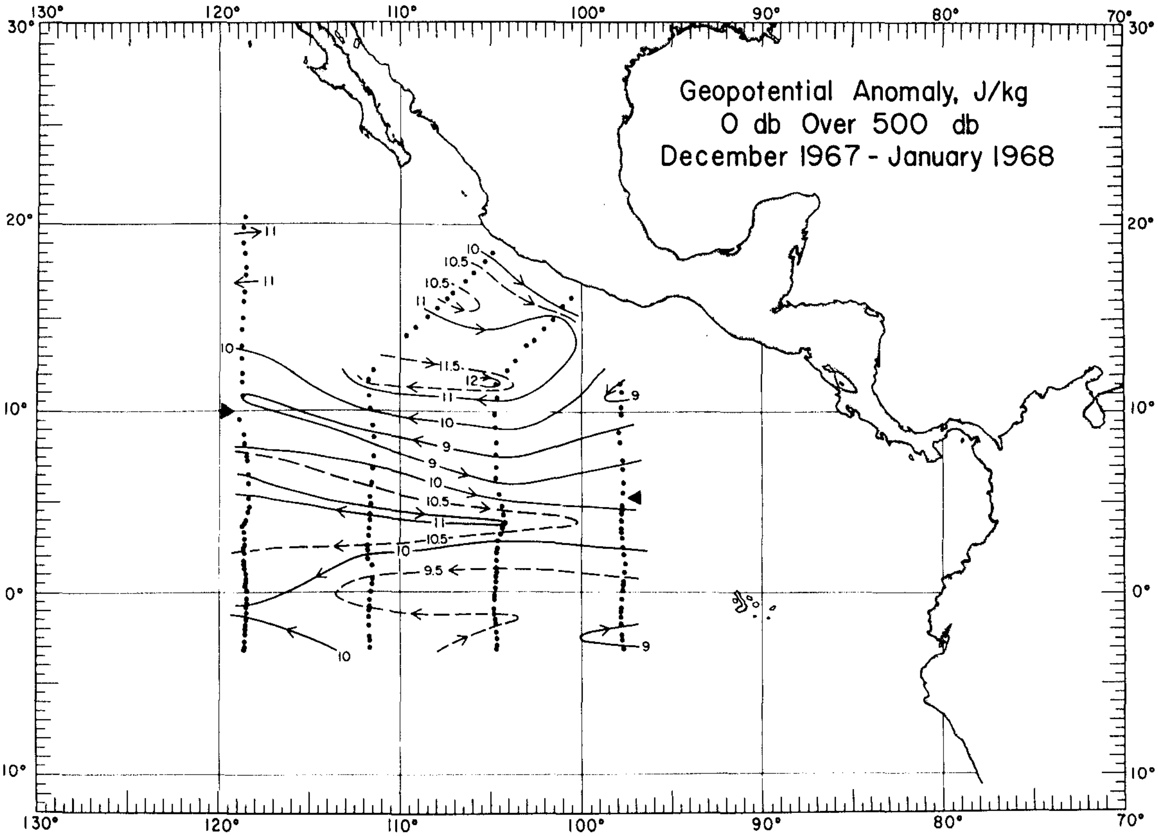

FIGURE 6.—Geopotential anomaly, in joules per kilogram (dynamic decimeters), at the sea surface relative to 500 db in December 1967-January 1968. EASTROPAC cruise *David Starr Jordan* 60. The position of the intertropical convergence zone at the eastern and western ends of the map is indicated by triangles.

North Equatorial Current Region

North of the North Equatorial Countercurrent, the North Equatorial Current is found on all seven maps (Figures 1-7). On the maps for February-March 1967 and February-April 1968 (Figures 1 and 7) the westward flow of the North Equatorial Current starts off the Gulf of Tehuantepec with a major contribution of water coming from the northwest along the Mexican coast. Water coming from the southeast appears to return to the east forming a cyclonic eddy around the Costa Rica thermal dome.

In February-March 1967 (Figure 1) the North Equatorial Current is interrupted by a continuous eastward flow indicated along lat. 15°N from long. 126°W to the coast of Mexico, where it turns to the south to feed the North Equatorial Current. This eastward flow is broadly developed at long. 112°W and extends from lat. 10° to 18°N. There is a suggestion that a similar eastward flow is present in April-May 1967 and February-April 1968 (Figures 2 and 7). Reid's (1961) map of the surface geostrophic flow also indicates an eastward current at about the same latitude from long. 130° to 95°W, but his data in this area are principally from northern fall and winter. The surface drift charts (Puls, 1895; U.S. Navy Hydrographic Office, 1947) do not show such an eastward flow west of long. 110°W, possibly because of the westward Ekman drift and leeway of ships due to the strong northeasterly trades.

On the map for August-September (Figure 4) the North Equatorial Current starts off the coast of Costa Rica. East of long. 100°W it is fed almost entirely by the return flow of the North Equatorial Countercurrent, which is fully developed in these months.

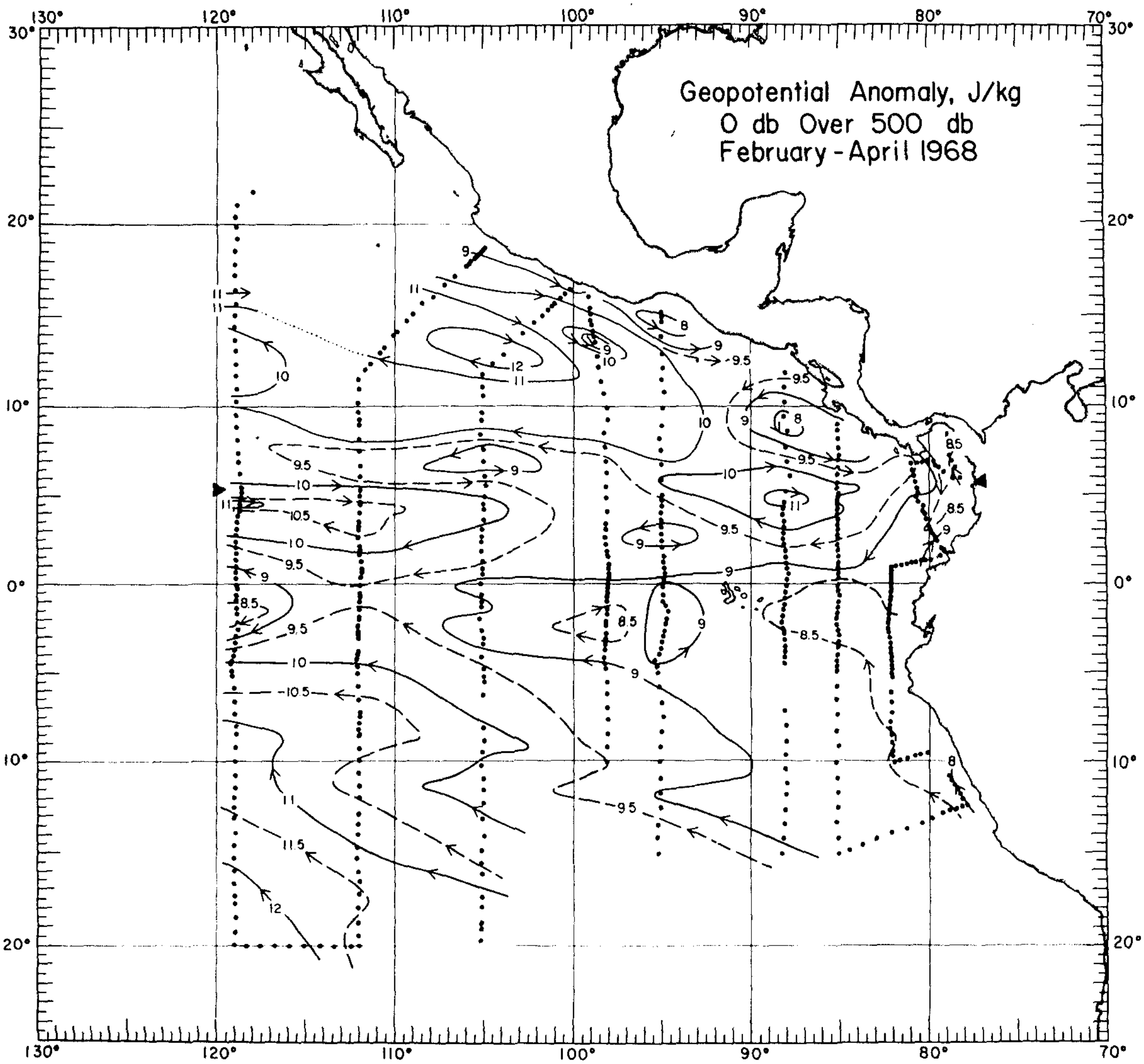

FIGURE 7.—Geopotential anomaly, in joules per kilogram (dynamic decimeters), at the sea surface relative to 500 db in February-April 1968. EASTROPAC cruises *Thomas Washington* 75, *David Starr Jordan* 76, and *Rockaway* 77. The position of the intertropical convergence zone at the eastern and western ends of the map is indicated by triangles.

DISCUSSION

As was noted earlier, geopotential anomaly computed from oceanographic data contains short-period nongeostrophic fluctuations of the mass field, but there is no way of removing them from the data. Consequently, not all of the features indicated by the present maps may be real. Despite this problem, EASTROPAC data are unique in their time and space coverage and in the close spacing of stations on tightly coordinated ship tracks and, thus, reveal some interesting features that have not been observed previously.

A zonal discontinuity of the North Equatorial Countercurrent in the months when the ITCZ lies near its southernmost position is suggested by the monthly average drift charts (U.S. Navy Hydrographic Office, 1947; Wyrtki, 1965); however, the present maps (Figures 1, 2, and 7) are the first to show it on the basis of quasi-synoptic oceanographic data from the entire eastern intertropical North Pacific. (It is highly unlikely that the breakup of the Countercurrent as shown on these maps is an artifact of short-period fluctuations of the mass field.) In these months the Countercurrent shows a drastic change in intensity; its rapid disappearance and reappearance on this sequence of maps (Figures 1-3, 6, and 7) are remarkable. The maps demonstrate that the Countercurrent can either disintegrate or reestablish itself on a time scale less than 2 mo.

A comparison of the present maps (Figures 1-7) with meteorological charts in the EASTROPAC atlas (Love, 1971, 1972a, 1972b, 1973, in press. See also the position of the ITCZ indicated at the eastern and western ends of each map.) reveals a rather good correlation between the positions of the North Equatorial Countercurrent and the ITCZ. The northern boundary of the Countercurrent (minimum of geopotential anomaly) coincides approximately with the ITCZ except in February-March and August-September. In February-March the southern boundary of the Countercurrent, if it is present, more nearly coincides with the ITCZ; in August-September the ITCZ is located far to the north of the northern boundary. This finding is in agreement with what can be seen on Wyrtki's (1965) long-term average charts.

There is a high degree of similarity in geostrophic-flow patterns between February-March 1967 (Figure 1) and February-April 1968 (Figure 7). The major features are much the same for the two maps; even the development of the cyclonic and anticyclonic eddies off Costa Rica, the discontinuity of the North Equatorial Countercurrent near long. 98°W, and the eastward flow along about lat. 10°S are similar. In view of the large variations observed between the two cruise periods, this similarity is perhaps surprising. The only notable difference is the latitude of the minimum of geopotential anomaly near the equator (discussed in the preceding section) west of the Galápagos Islands; the minimum is located at the equator in 1967 (Figure 1), while it is located a few degrees south of the equator in 1968 (Figure 7). The southward shift of the minimum in Figure 7 is probably due to the more southerly trade winds near the equator in 1968 than in 1967 (Cromwell, 1953).

The eastward current indicated along about lat. 10°S on the southern-summer maps (Figures 1 and 7) is of particular interest, because no previous data from the eastern Pacific have suggested it. This countercurrent is very weak (the average geostrophic speed from seven meridional sections is 7 cm/s) and was not noticed in earlier examination of vertical sections based on EASTROPAC data (Tsuchiya, 1972). It is a narrow and thin current (about 50 m thick) and is completely separate from a subsurface eastward current which has its maximum speed at a depth of 70-200 m and which flows along about lat. 6°S (Stroup, 1969; Tsuchiya, 1972).[3] More data are needed to determine the relation of this surface eastward countercurrent with the South Equatorial Countercurrent, which is well developed near lat. 10°S at the sea surface of the central and western Pacific (Reid, 1959, 1961; Merle, Rotschi, and Voituriez, 1969; Rotschi, 1970; Tsuchiya, 1970; Donguy and Rotschi, 1970). As was mentioned in the preceding section, the former countercurrent is defined only between long. 112°W and long. 90°W and is not found in the west of the EASTROPAC area.

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LITERATURE CITED

Austin, T. S.
1960. Oceanography of the east central equatorial Pacific as observed during expedition Eastropic. U.S. Fish Wildl. Serv., Fish. Bull. 60:257-282.

Bennett, E. B.
1963. An oceanographic atlas of the eastern tropical Pacific Ocean, based on data from EASTROPIC Expedition, October-December 1955. [In Engl. and Span.] Bull. Inter-Am. Trop. Tuna Comm. 8:31-165.

Brandhorst, W.
1958. Thermocline topography, zooplankton standing crop, and mechanisms of fertilization in the eastern tropical Pacific. J. Cons. 24:16-31.

[3] A detailed report on this subsurface eastward countercurrent is being prepared for publication elsewhere.

CROMWELL, T.
1953. Circulation in a meridional plane in the central equatorial Pacific. J. Mar. Res. 12:196-213.
1958. Thermocline topography, horizontal currents and "ridging" in the Eastern Tropical Pacific. [In Engl. and Span.] Bull. Inter-Am. Trop. Tuna Comm. 3:133-164.
CROMWELL, T., AND E. B. BENNETT.
1959. Surface drift charts for the Eastern Tropical Pacific Ocean. [In Engl. and Span.] Bull. Inter-Am. Trop. Tuna Comm. 3:215-237.
CROMWELL, T., R. B. MONTGOMERY, AND E. D. STROUP.
1954. Equatorial Undercurrent in Pacific Ocean revealed by new methods. Science (Wash., D.C.) 119:648-649.
DONGUY, J.-R., AND H. ROSCHI.
1970. Sur un courant Est dans le Pacifique central tropical Sud. C. R. Acad. Sci. Paris, B 271:869-872.
JONES, J. H.
1969. Surfacing of Pacific Equatorial Undercurrent: direct observation. Science (Wash., D.C.) 163:1449-1450.
LOVE, C. M. (editor).
1971. EASTROPAC atlas, Vol. 3. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ 330.
1972a. EASTROPAC atlas, Vol. 1. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ 330.
1972b. EASTROPAC atlas, Vol. 5. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ 330.
1973. EASTROPAC atlas, Vol. 7. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ. 330.
In press. EASTROPAC atlas, Vol. 9. U.S. Dep. Commer., Natl. Mar. Fish. Serv., Circ 330.
MERLE, J., H. ROTSCHI, AND B. VOITURIEZ.
1969. Zonal circulation in the tropical western South Pacific at 170°E. Bull. Jap. Soc. Fish. Oceanogr., Spec. No., p. 91-98.
METEOROLOGICAL OFFICE, AIR MINISTRY.
1939. South Pacific ocean currents. H. M. Stationery Off., Lond., M. O. 435, 3 tables, 11 fig., and 8 charts.
MONTGOMERY, R. B.
1962. Equatorial Undercurrent observations in review. J. Oceanogr. Soc. Jap. 20th Anniv. Vol., p. 487-498.
MONTGOMERY, R. B., AND E. D. STROUP.
1962. Equatorial waters and currents at 150°W in July-August 1952. Johns Hopkins Oceanogr. Stud. 1, 68 p.
PULS, C.
1895. Oberflächentemperaturen und Strömungsverhältnisse des Aequatorialgürtels des Stillen Ozeans. Arch. Dtsch. Seewarte 18(1), 38 p.
REID, J. L., JR.
1959. Evidence of a South Equatorial Countercurrent in the Pacific Ocean. Nature (Lond.) 184:209-210.
1961. On the geostrophic flow at the surface of the Pacific Ocean with respect to the 1,000-decibar surface. Tellus 13:489-502.
ROTSCHI, H.
1970. Variations of equatorial currents. *In* W. S. Wooster (editor), Scientific exploration of the South Pacific, p. 75-83. Natl. Acad. Sci. Wash., D.C.
STEVENSON, M.
1970. Circulation in the Panama Bight. J. Geophys. Res. 75:659-672.
STROUP, E. D.
1969. The thermostad of the 13-C Water in the equatorial Pacific Ocean. Ph.D. Thesis, Johns Hopkins Univ., Baltimore, 202 p.
TSUCHIYA, M.
1968. Upper waters of the intertropical Pacific Ocean. Johns Hopkins Oceanogr. Stud. 4, 50 p.
1970. Equatorial circulation in the South Pacific. *In* W. S. Wooster (editor), Scientific exploration of the South Pacific, p. 69-74. Natl. Acad. Sci., Wash., D.C.
1972. A subsurface north equatorial countercurrent in the eastern Pacific Ocean. J. Geophys. Res. 77:5981-5986.
U.S. NAVY HYDROGRAPHIC OFFICE.
1947. Atlas of surface currents, northeastern Pacific Ocean. H. O. Publ. 570, 12 p.
WOOSTER, W. S.
1959. Oceanographic observations in the Panama Bight, "Askoy" expedition, 1941. Bull. Am. Mus. Nat. Hist. 118:113-151.
1970. Eastern boundary currents in the South Pacific. *In* W. S. Wooster (editor), Scientfic exploration of the South Pacific, p. 60-68. Natl. Acad. Sci., Wash., D.C.
WOOSTER, W. S., AND T. CROMWELL.
1958. An oceanographic description of the eastern tropical Pacific. Bull. Scripps Inst. Oceanogr. 7:169-282.
WOOSTER, W. S., AND J. L. REID, JR.
1963. Eastern boundary currents. *In* M. N. Hill (editor), The sea: Ideas and observations on progress in the study of the sea, Vol. 2, p. 253-280. Interscience Publ., N.Y.
WYRTKI, K.
1963. The horizontal and vertical field of motion in the Peru Current. Bull. Scripps Inst. Oceanogr. 8:313-345.
1964. Upwelling in the Costa Rica Dome. U.S. Fish Wildl. Serv., Fish. Bull. 63:355-372.
1965. Surface currents in the Eastern Tropical Pacific Ocean. [In Engl. and Span.] Bull. Inter-Am. Trop. Tuna Comm. 9:269-304.
1966. Oceanography of the eastern equatorial Pacific Ocean. Oceanogr. Mar. Biol. Annu. Rev. 4:33-68.
1967. Circulation and water masses in the eastern equatorial Pacific Ocean. Int. J. Oceanol. Limnol. 1:117-147.