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# OCEANOGRAPHIC OBSERVATIONS DURING THE LINE ISLANDS EXPEDITION, February-March, 1967



By
Klaus Wyrtki



AUGUST 1967

Prepared for
OFFICE OF NAVAL RESEARCH
UNDER CONTRACT NO. Nonr-3748(06)



HAWAII INSTITUTE OF GEOPHYSICS
UNIVERSITY OF HAWAII



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Approved by Director

George P. Woollard

Date: 18 August 1967

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ABSTRACT

In support of meteorological observations during the Line Islands Expedition the U.S.C.& G.S. Ship SURVEYOR made oceanographic observations between the Hawaiian Islands and 3°S. A hydrographic section from Hawaii southward crossed the North Equatorial Current and the Countercurrent, the transports of which were 22.1 million $m^3$/sec and 27.7 million $m^3$/sec, respectively. Two sections across the Equatorial Undercurrent, parallel to each other at a distance of 90 miles, revealed a fine structure of the Undercurrent not previously observed.

Two paddle-wheel current meters anchored near the island of Palmyra showed predominantly semidiurnal tides and a superimposed flow to the north. Current measurements during 11 days at 6.5°N from the anchored ship indicated that the Countercurrent was not present during most of this period. Flow was mostly to the west and north.

## INTRODUCTION

The Line Islands Expedition was a meteorological experiment to study the inter-tropical convergence in the central Pacific Ocean. In order to supplement meteorological observations on the various islands, the United States Coast and Geodetic Survey Ship SURVEYOR was assigned to provide additional information at sea. The ship had the task of making radiosonde observations along a section from Hawaii to south of the equator. Later on, the ship was to occupy a fixed position about 200 miles east of Palmyra Island near the inter-tropical convergence for continuous radiosonde observations.

To supplement the meteorological observations and to make more extensive use of the ship, plans were made to include an oceanographic program to be conducted by scientists of the Department of Oceanography of the University of Hawaii. The program was supported by the Office of Naval Research under Contract Nonr 3748(06). The following work was planned and successfully executed during the two voyages the SURVEYOR made to the Line Islands. A map showing the area of operations and station positions is shown as Figure 1. The general oceanographic conditions in the vicinity of the Line Islands have been reviewed by Barkley (1962).

### Voyage I (13 February—3 March, 1967)

1. A hydrographic section was made across the North Equatorial Current and the Countercurrent from 19°N to 6°S, taking hydrographic stations at 60 mile intervals with a temperature-salinity-depth recorder to 1500 meter depths.

2. Groups of 6 hydrographic stations were taken around the islands of Palmyra, Washington, and Fanning in order to study differences in the hydrographic structure on the windward and leeward sides of these islands.

3. Two paddle-wheel current meters were anchored near the island of Palmyra to record tidal currents for about 20 days each.

4. Tide gauges were installed and operated on Palmyra and Fanning islands.

5. A hydrographic section was run along 156°W between 3°N and 3°S with a station distance of 15 nautical miles in order to study in detail the structure of the Equatorial Countercurrent with the DTS recorder to depths of 750 meters. A similar section was run on the return voyage only 90 nautical miles to the west at 157°30'W from 3°S to Christmas Island

at 2°N. This section should give information on fluctuations in the hydrographic structure of the Undercurrent with respect to longitude.

Voyage II (9 March—31 March, 1967)

1. The SURVEYOR was anchored on a seamount at 6°25'N and 157°50'W over approximately 1250 m depth for almost 11 days, in order to make meteorological observations windward of the Line Islands at a fixed position. During this period hourly measurements were taken of the currents between the surface and 300 m depth at 40 m intervals to study the structure of the Equatorial Countercurrent. Hourly bathythermograph lowerings were made simultaneously with the current measurements.

2. After completing the anchor station the paddle-wheel current meters planted near the island of Palmyra were successfully recovered, as were the tide gauges.

## INSTRUMENTATION

1. Hydrographic stations were made with a Bissett-Berman temperature-salinity-depth recorder. The data were recorded in analog form and also digitized with a newly developed system described by Graefe (1967). This system digitizes the frequency signals from the DTS recorder at 1.8-second intervals and translates them into numerical values of depth, temperature, and salinity. These values are fed into a teletypewriter where they are simultaneously printed in numerical form and stored on punched paper tape for computer processing later.

2. Paddle-wheel current meters (manufactured by Hydro-werkstatten, Kiel, Germany) were used to record currents for longer periods near Palmyra. These meters record current speed and direction by photographing a compass and a counter at 5-minute intervals for periods of up to 24 days. A description and photograph of this instrument is given by Dietrich (1963).

3. Current measurements from the anchored ship were made with Savonius current meters manufactured by Hydro Products. This instrument had a pressure sensor attached to determine the depth of the observations. Values of current speed and direction were read out on board the ship.

The hydrographic station data, digitized to temperature and salinity values at depth intervals of 2 m, have been submitted to the National Oceanographic Data Center, Washington, D. C.

## HYDROGRAPHIC SECTIONS

The distribution of temperature, salinity, and geostrophic velocity along a hydrographic section from Hawaii to 3°S is shown in Figure 2. This section has been composed from stations made between Hawaii and 6°N, from stations made in the vicinity of the Line Islands, and from the section along 156°W across the equator (see Fig. 1). The temperature distribution shows very clearly the different hydrographic situations that are associated with the various current systems crossed. The surface mixed layer is uniformly warm. A few patches of water above 26°C appear in the Countercurrent and in the South Equatorial Current south of the equator. In the North Equatorial Current between 19°N and approximately 9°N the thermocline becomes steeper with progress toward the south. The depth of the center of the thermocline decreases from approximately 200 m to 100 m across the North Equatorial Current. In the Countercurrent between 9°N and 5°N the thermocline is extremely steep and the isotherms between 24°C and 12°C are very closely spaced. The Equatorial Undercurrent is very pronounced by a spreading of the isotherms within the thermocline.

Surface salinity decreases from the Hawaiian Islands southward. Lowest salinities (<34.1 ‰) are found in the North Equatorial Current between 14° and 9°N. Near 9°N, at the boundary between the North Equatorial Current and the Countercurrent, a salinity front is situated. This front marks the boundary between the low salinity Tropical Surface Water and the water of higher salinity called the Equatorial Water by Wyrtki (1967). Salinities in the Equatorial Surface Water are about 34.8 ‰ in the southern portions of the Countercurrent and the northern parts of the South Equatorial Current. Another front in surface salinity is apparent at 0°30'N, just north of the equator. This front separates the Equatorial Surface Water of about 34.8 ‰ from the Subtropical Surface Water of the South Pacific Ocean. This Subtropical Surface Water is characteristic for the main part of the South Equatorial Current. It is quite evident that both salinity fronts do not coincide with current boundaries. The Countercurrent carries Tropical Surface Water in its northern portions and Equatorial Surface Water in its southern portions. Equatorial Surface Water is also carried in those parts of the South Equatorial Current situated north of the equator.

A salinity maximum is found in the upper portions of the thermocline, associated approximately with the 22° isotherm. This maximum represents the Subtropical Water of the central North Pacific Ocean and stretches as a thin layer southward underneath the surface layer of lower salinity.

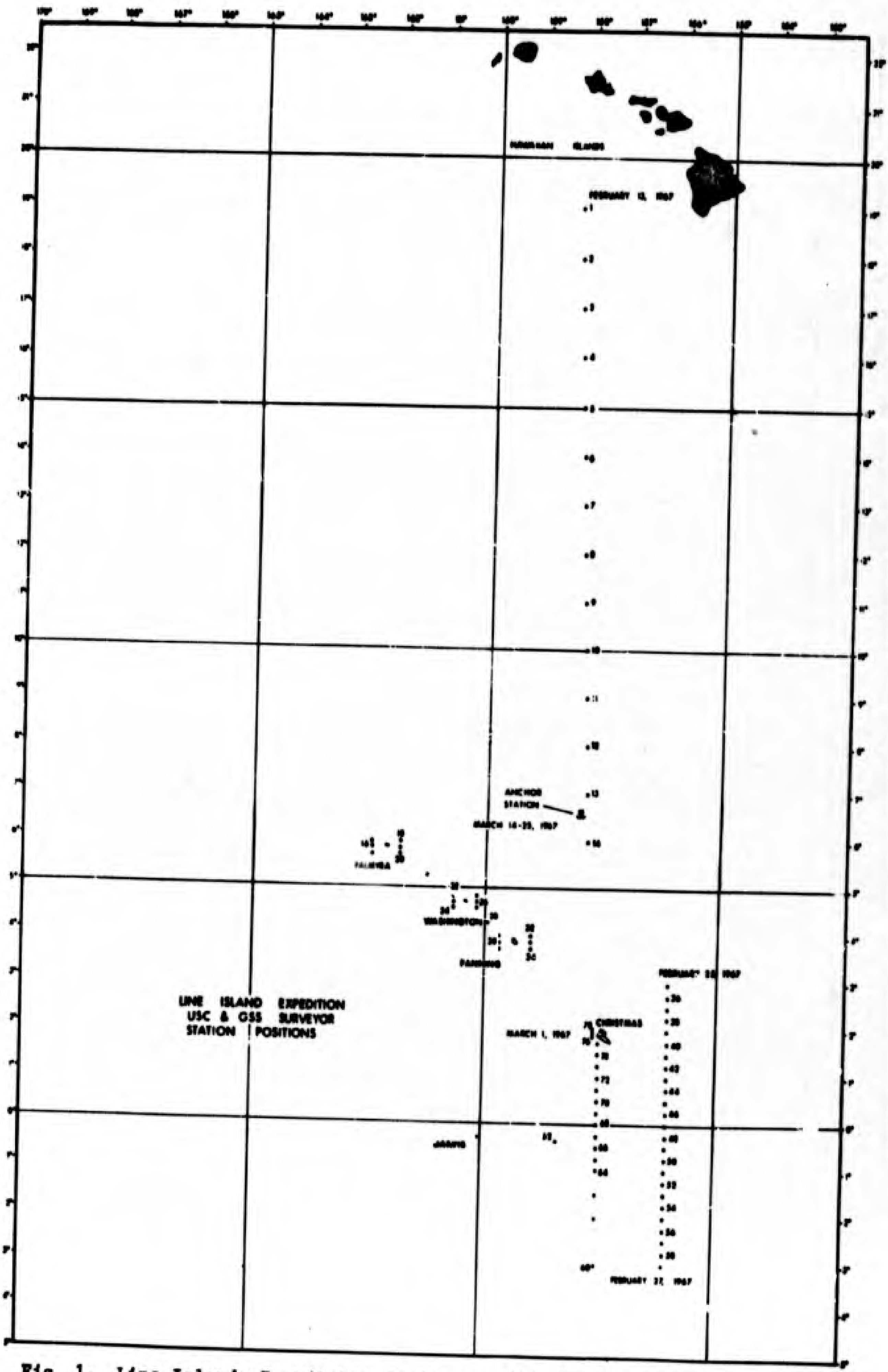


Fig. 1. Line Islands Expedition, station positions and numbers.

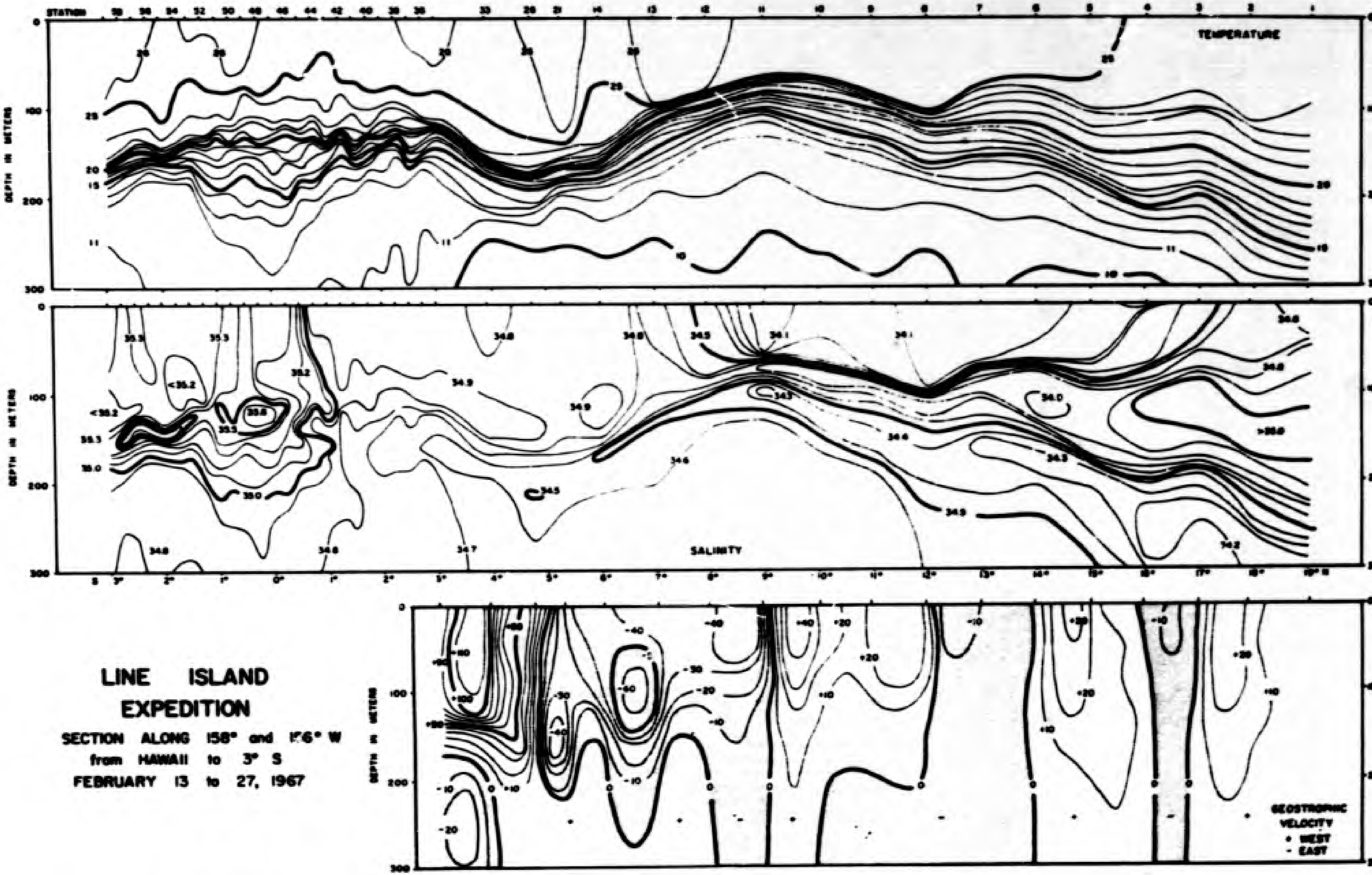


Fig. 2. Hydrographic section southward from Hawaii.

It can be followed as a salinity minimum to about 8°N where it terminates on contact with the Equatorial Surface Water. Salinities in the salinity maximum decrease from about 35 ‰ near the Hawaiian Islands to 34.8 ‰ in the southern parts of the North Equatorial Current.

Near the lower boundary of the thermocline and associated with temperatures between 12°C and 13°C, a salinity minimum is found. This salinity minimum represents the North Pacific Intermediate Water (Reid, 1965). Salinities in this minimum rise from 34.2 ‰ at 18°N to 34.4 ‰ at the southern boundary of the North Equatorial Current, but the minimum can be followed much farther to the south. It is evident with salinities near 34.5 ‰ below the Countercurrent and can be traced right to the core of the Undercurrent at 0°30' N where salinities in the salinity minimum have, however, increased to about 34.9 ‰.

Geostrophic velocities and geostrophic transports have been calculated from the hydrographic station data with reference to 500 db. The North Equatorial Current is broken up into three parts. The northernmost part has surface velocities of about 25 cm/sec; the branch near 15°N has speeds up to 32 cm/sec; and near the southern boundary, speeds exceed 42 cm/sec to the west. Between these three branches weaker flow is found to the east with speeds near 12 cm/sec. These observations agree well with similar sections made in 1964 and 1965 during the Trade-Wind Investigations of the Bureau of Commercial Fisheries (G. Seckel, personal communication) which also show that the North Equatorial Current is usually split into several branches and that the most southerly branch is the strongest. From the distribution of geostrophic velocities, it is also obvious that the North Equatorial Current extends only to about 250 m with appreciable velocities. The total geostrophic transport relative to 500 db in the North Equatorial Current between 19°N and 9°N is 26.8 million $m^3$/sec to the west. The two counter flows transport a total of 4.7 million $m^3$/sec to the east, giving a net transport of 22.1 million $m^3$/sec in the North Equatorial Current.

The velocity distribution in the Equatorial Countercurrent shows quite clearly a subsurface velocity maximum which has maximum speeds in excess of 60 cm/sec to the east. Below approximately 200 m depth the flow is to the west, showing that the Countercurrent is limited to a shallow surface-layer. This high-speed layer coincides approximately with the lower boundary of the thermocline. Geostrophic transports in the Countercurrent relative to 500 db are 27.7 million $m^3$/sec to the east. Counting the flow to the west below the Countercurrent, the net transport is 25.8 million $m^3$/sec between the surface and 500 m depth. Using the method developed by Wyrtki and Kendall (1967) for estimating the transports of the Equatorial Countercurrent from the thermal structure, the thermoclinic transport of the Countercurrent would be 33.9 million $m^3$/sec. Based on these geostrophic computations the Countercurrent was very well developed during the period of these observations, although it was not stronger than normal.

South of 5°N geostrophic flow is again to the west, representing the northern portions of the South Equatorial Current. Geostrophic speeds are very high, in excess of 110 cm/sec. The geostrophic transport in the small interval between 5° and 3°N is 27 million $m^3$/sec to the west, showing that the South Equatorial Current was very well developed during this period and extended as far as 5°N. Based on a very detailed section in August 1952, Montgomery and Stroup (1962) calculated a transport of 32 million $m^3$/sec for the South Equatorial Current between the equator and 6°N.

The section across the equator at 156°W is repeated in more detail in Figure 3 and shows the typical spreading of the isotherms at the equator, but the downward trend of the deeper isotherms is more pronounced than the upward trend of the isotherms near the surface. The surface temperature at the equator is only less than one degree lower than on either side, but this appears to be normal for February, as can be seen from maps of sea surface temperature (U. S. Navy Hydrographic Office, 1944). The temperature field is almost symmetrical to the equator. The salinity distribution indicates descending movements below the Undercurrent by the depression of the 35.1 ‰ isohaline, and upwelling above the Undercurrent, where the 35.4 ‰ isohaline extends right from the core of the Undercurrent to the surface at 0°30'S. The upwelling is apparently displaced to the south of the equator. The core of the Undercurrent is marked by a cell of high salinity (>35.6 ‰). This cell is not directly connected with the water of similar salinity found between 1°30'S and 2°45'S.

The section at 157°30'W (Fig. 4) shows a very similar situation in general, but also a few significant differences. The symmetry of the temperature structure in the first section is by no means repeated. The spreading of the isotherms is only weakly developed and the whole system of the Undercurrent seems to be displaced slightly to the south of the equator. The changes are much less drastic in the salinity distribution. The upwelling appears to be stronger and a water body with a salinity of more than 35.5 ‰ rises to the surface from the core at 0°45'S. These differences between two sections only 90 miles apart demonstrate the magnitude of possible space and time variations in the structure of the Undercurrent.

The distribution of temperature and salinity allows the drawing of certain conclusions about the cross circulation within the Undercurrent. Charney (1960) has advanced a scheme of such a meridional circulation based on theoretical considerations. This scheme, largely supported by observations, is symmetrical to the equator and includes a divergence at the surface at the equator, with water ascending from the core of the Undercurrent and flowing away from the equator in the surface layer. Within the thermocline there is flow toward the equator from both sides. The water converging toward the equator mostly ascends, but also descends. All these features are basically supported by observations. Questionable still is whether the water descending near the equator is also flowing away from the equator.

North of the equator a salinity minimum is situated within the thermocline, with salinities of less than 34.7 ‰ near 180 m depth shown in both sections. This salinity minimum represents the last traces of the North Pacific Intermediate Water (Reid, 1965). The temperature-salinity curves of four stations between 1°30'N and 0°15'N (Fig. 5A) demonstrate the advance of this water toward the equator and the rapid dispersion of the tongue of low salinity by mixing near the core of the Undercurrent. At station 41 the salinity minimum is broad and situated at temperatures between 11° and 20°C. As it spreads equatorward it becomes progressively narrower, and the core of the minimum is at a temperature of about 19°C. At station 46 the minimum is no longer noticeable. The same situation is found in the second section between stations 66 and 73 (Fig. 5C). There the salinity minimum penetrates almost to the equator. Everywhere between the equator and 1°30'N two salinity maxima can be found situated above and below the salinity minimum. The upper salinity maximum, situated on the bottom of the mixed layer, is indicative for the flow of water away from the equator in the surface layer. Salinities of more than 34.9 ‰ extend to the north of 3°N. The lower salinity maximum indicates a flow away from the equator of water of 14° to 18°C at depths between 150 and 180 m.

South of the equator the salinity distribution does not reflect the cross circulation that clearly, because a salinity maximum is situated within the thermocline. This salinity maximum represents the Subtropical Subsurface Water of the South Pacific Ocean (Wyrtki, 1967), which flows west and equatorward in the lower portions of the South Equatorial Current. Salinities in the core layer of the salinity maximum increase to the west. When this water reaches about 2°S, it is drawn north into the core of the Undercurrent and then flows east at high speed. Consequently, water at the equator will have a slightly higher salinity than that of water immediately south of it. This situation described by Knauss (1966) is quite apparent from the TS diagram in Figure 5B. The salinity in the salinity maximum at station 49 at 0°30'S

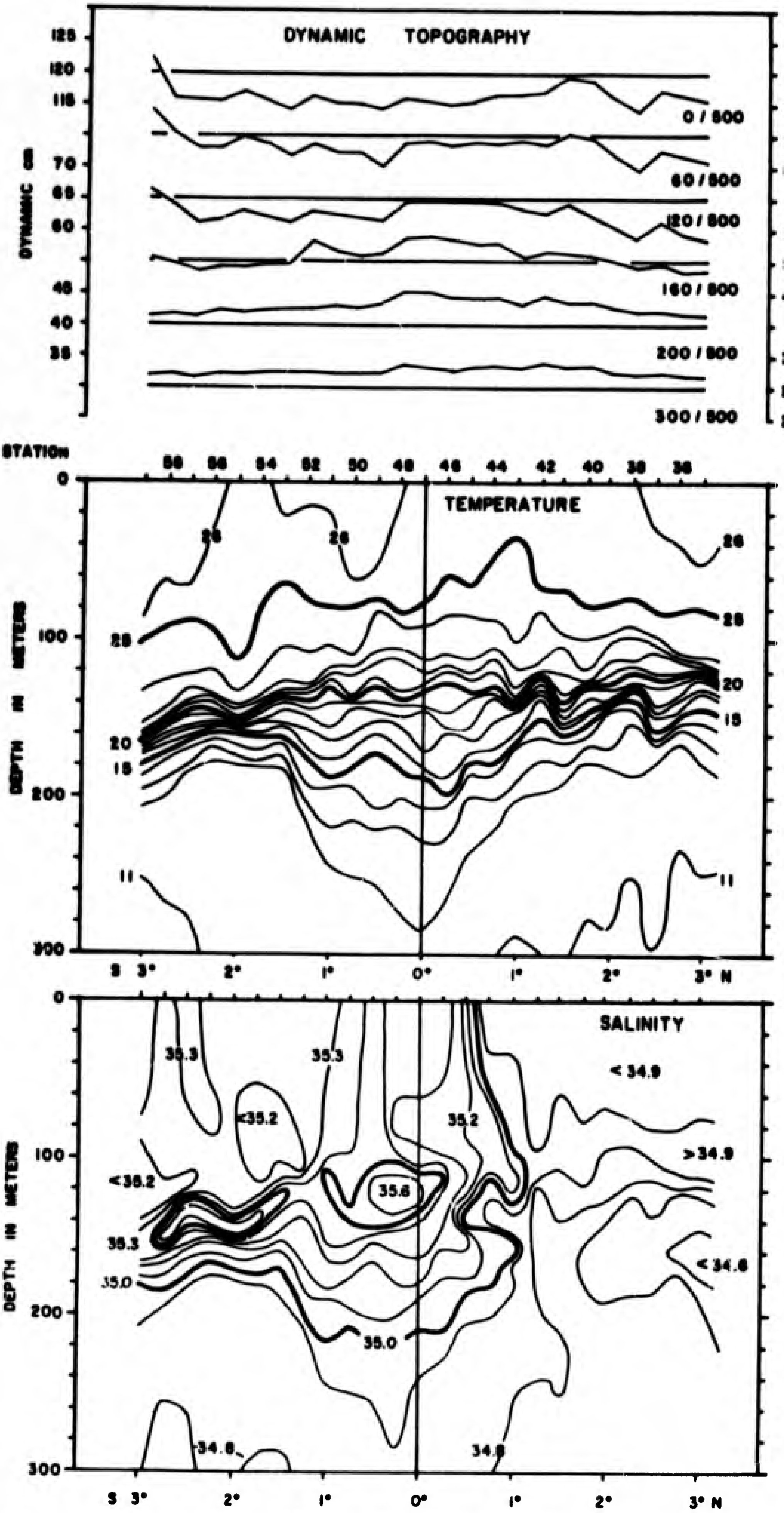


Fig. 3. Hydrographic section across the equator at 156°W.

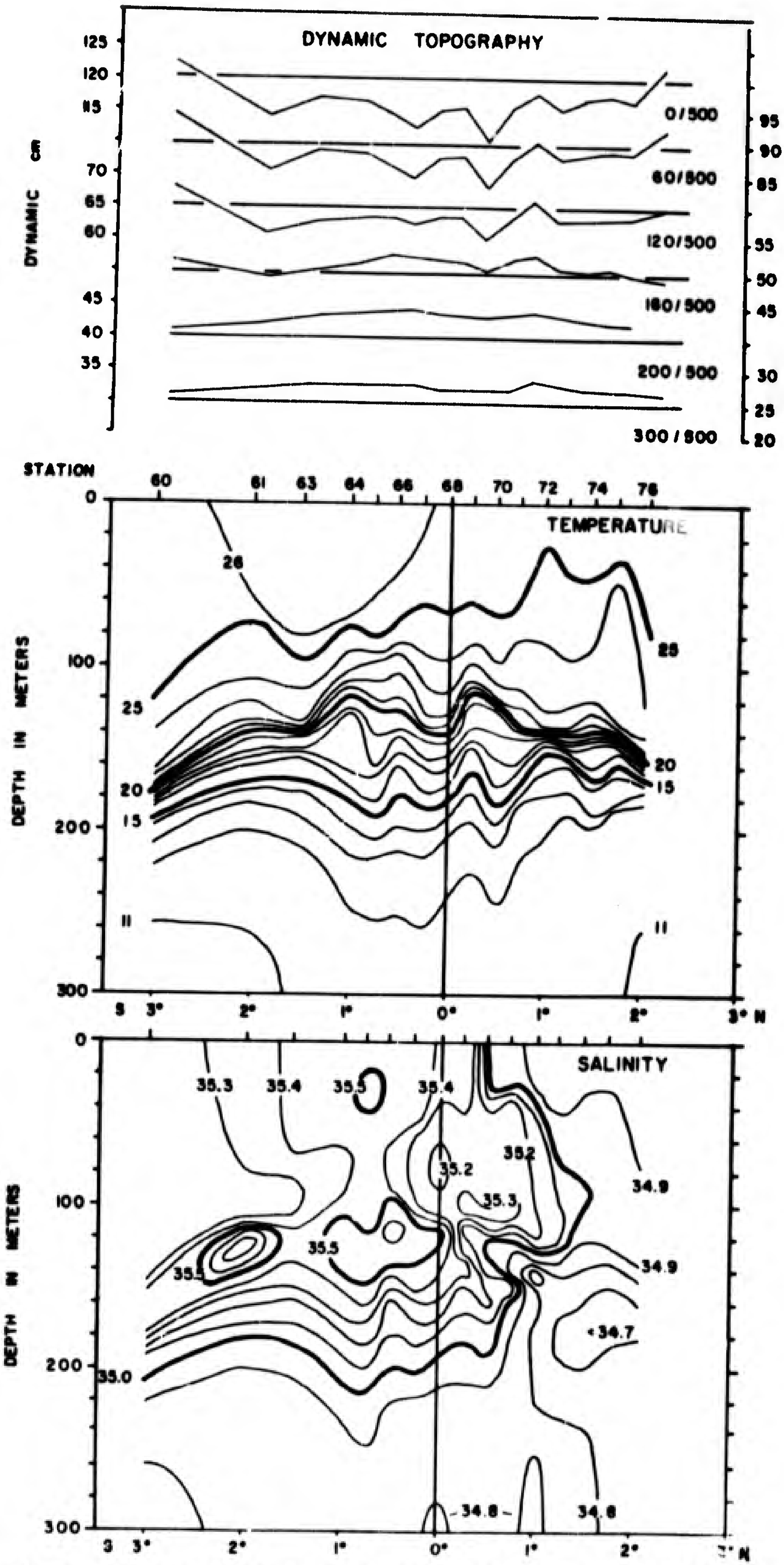


Fig. 4. Hydrographic section across the equator at 157°30'W.

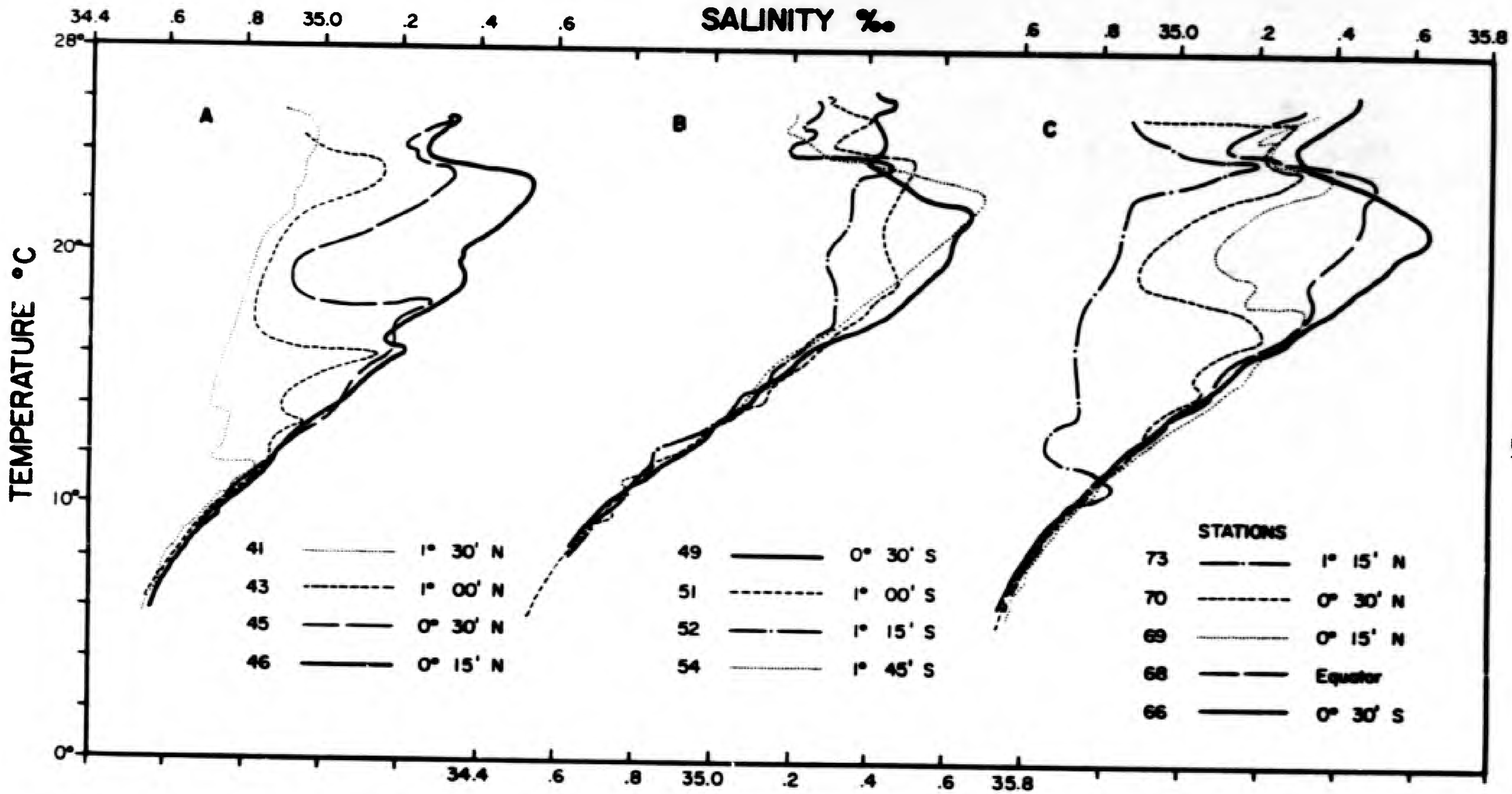


Fig. 5. Temperature-salinity diagrams of selected stations.

is almost as high as that at station 54, but inbetween, at stations 51 and 52, the salinity in the salinity maximum is about 0.2 to 0.4 ‰ lower. This indicates that the high salinity water in the core comes from farther west, where it is entrained into the core from the south.

The dynamic heights at the DTS stations have been computed directly from the temperature and salinity values at 2 m intervals without the need for interpolation; the dynamic topographies shown in Figures 3 and 4 are referred to 500 db. Because of these detailed measurements the apparent fluctuations in the dynamic heights from station to station must be considered as real, and are probably due to short time fluctuations of the structure or to internal waves.

When discussing the relations between the density structure and the velocity distribution in the Equatorial Undercurrent, Montgomery and Stroup (1962) have claimed that the current is in approximate geostrophic balance. Recently, Knauss (1966) presented data which demonstrate that such a balance is not necessarily always present. According to the temperature distribution on the first section (Fig. 3) the Undercurrent is situated between approximately 100 and 260 m depth. The corresponding dynamic topographies at depths of 300, 200, 160 and even 120 m show that there is a ridge at the equator. Dynamic heights at the equator are approximately three dynamic centimeters higher than at 2° latitude on either side. Such a difference is approximately sufficient to balance the Undercurrent geostrophically. In the upper layer the dynamic topographies appear much more irregular and a trough at the surface is not clearly indicated.

During the second section the thermal structure does not reflect the Undercurrent equally well. The dynamic topographies at 300, 200 and 160 m depths still show the high pressure at the equator which might balance the Undercurrent geostrophically. In layers above 120 m depths the dynamic topography clearly shows a trough at the equator with values on either side being 5 to 8 dynamic cm higher.

The confrontation of these two sections, only 90 nautical miles apart, demonstrates quite convincingly the large spatial differences in the structure of the Equatorial Undercurrent which are possible in zonal direction. Such differences must have pronounced effects on the dynamics of the current and indicate that zonal gradients are present, that the current is at least temporarily not in a simple geostrophic balance, and that the flow is non-stationary. It appears very likely that the Undercurrent meanders about its main position like other ocean currents. This meandering of the Undercurrent may be caused by Jarvis Island, situated at 0°23'S, 160°02'W.

## HYDROGRAPHY SITUATION NEAR THE ISLANDS

In order to investigate changes of the hydrographic situation on the windward and leeward sides of some of the Line Islands, clusters of six stations were placed around the islands of Palmyra, Washington, and Fanning (see Fig. 1). The temperature profiles between the surface and 300 m depth are shown in Figure 6. The measurements around Palmyra Island show that a mixed layer of approximately 80 m depth was found at all six stations, and that temperature in this mixed layer was virtually the same at all stations. Only at station 29 on the windward side of the island was found a very thin layer, less than 4 m thick, of slightly warmer water on top of the mixed layer. Below the mixed layer temperatures decreased rapidly, although the thermocline is split into several parts. At each station temperature gradients in excess of 0.5°C per meter were recorded.

Near Washington Island the depth of the mixed layer varied between 60 and 110 m, and the temperature within the mixed layer also varied, between the individual stations. There are, however, no definite contrasts between stations on the windward and leeward sides of this island. It can rather be observed that the structure changes from north to south in the same manner on the windward and on the leeward sides of the island.

The same situation is basically found around Fanning. All stations except station 29 showed a similar pattern. The mixed layer is approximately 130 m deep but is divided into two parts: An upper, warmer part reaching from the surface to depths between 50 and 100 m at the various stations, and a lower, cooler part reaching from there to the top of the thermocline at 130 m depth. At station 29, situated northwest of Fanning, the warmer top layer was missing and the mixed layer extended almost to 160 m depth.

The general conclusion from these clusters of DTS stations around mid-ocean islands is that there is no noticeable effect of the islands on the hydrographic structure in their vicinity over distances as big as 20 nautical miles. If there are any effects, then they should be of smaller dimensions.

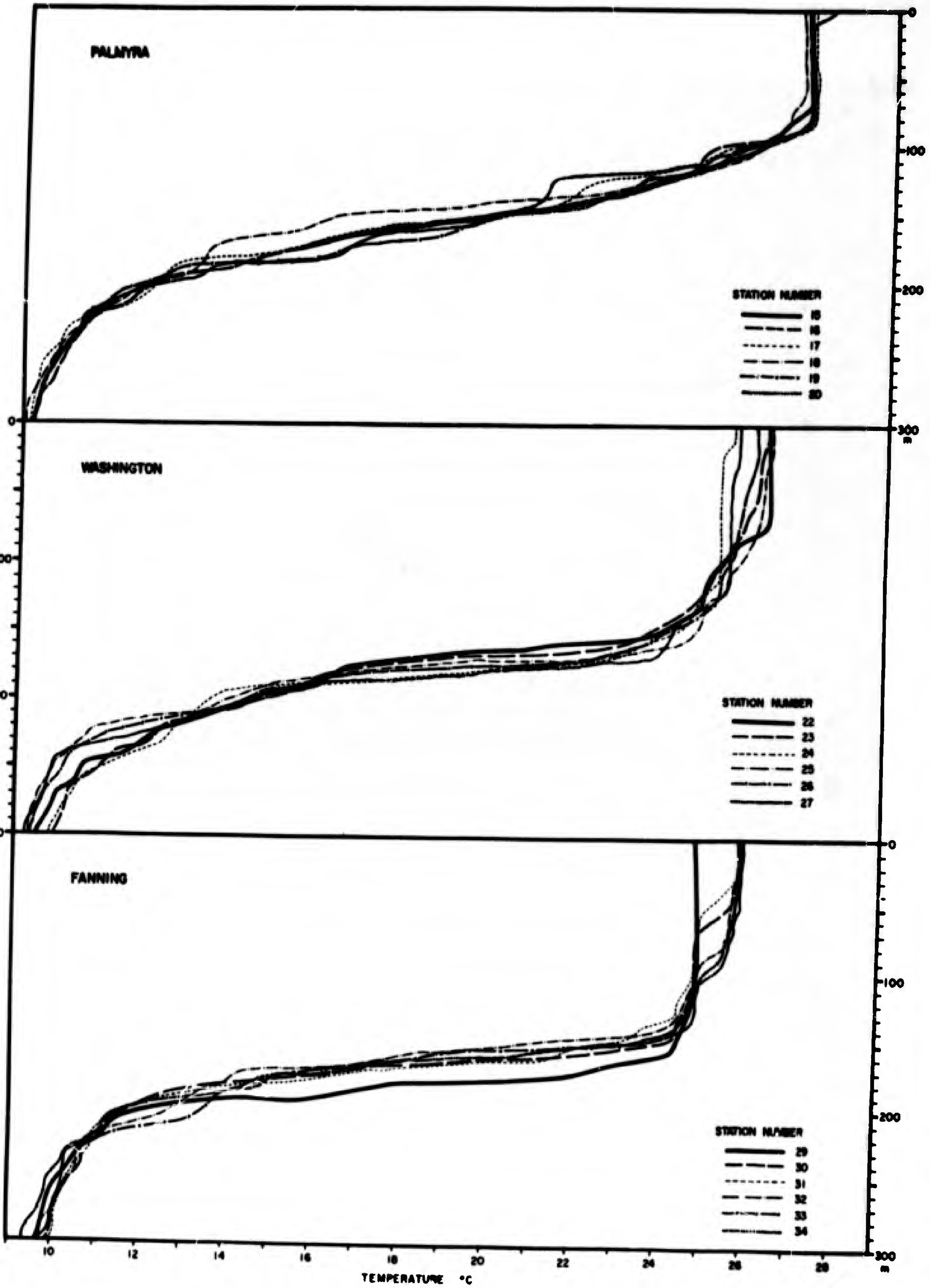


Fig. 6. Temperature-depth curves of hydrographic stations around the islands of Palmyra

## CURRENTS NEAR PALMYRA ISLAND

Two paddle-wheel current meters were anchored on the shelf of Palmyra Island (see Fig. 7). It was planned to anchor one on the western, the other on the eastern extremity of that shelf, but conditions at the eastern end of the shelf were such that the meter could not be anchored there and consequently it was also planted on the western side of the island at the position marked as #2 in Figure 7. Both paddle-wheel current meters were measuring at 10 m depths at places where the bottom was at 30 m depths. The recordings showed predominantly tidal currents, although a prevailing flow to the north was superimposed during most of the time. The distribution of the frequencies of current direction shows that at position #1 about 70% of the time flow was to northward with directions between 320° and 40°. Flow with southerly directions occurred during only about 20% of the time. There is very little onshore or offshore flow. The situation at position #2 is quite different — the scattering of directions is more pronounced although flow to the north and northwest is predominant.

The 24-hour vector averages of the current show that the average daily flow is to the north most of the time, and can be as high as 30 cm/sec. This consistent flow to the north during the period of these current measurements agrees very well with the flow observed during the anchor station that was made later on. Its implications with regard to the ocean circulation near the southern boundary of the Countercurrent will be discussed in conjunction with the anchor station.

For the purpose of comparing the current measurements with sea-level observations at Palmyra, currents with a northerly component were called "positive" and those with a southerly component "negative"; they are plotted in Figures 8 through 11. Maximum current velocities are about 45 cm/sec. It is evident that tidal currents dominate the flow, but they appear with a quite different pattern during various periods. From March 3 through March 8 tidal currents were semidiurnal and very regular at both locations, although the tide heights exhibited a pronounced diurnal inequality. From February 21 to 23, tidal currents had a marked diurnal component; flow to the south was strong only at noon while at midnight it barely reversed direction. During other periods (February 26 to 28) tidal currents were very weak, although the tides were highest during that period. It can even happen that average flow is northward at one position and southward at the other (February 27). During the last few days of observations at location #2 flow was chiefly to the north but extremely irregular, and no tidal currents were observed.

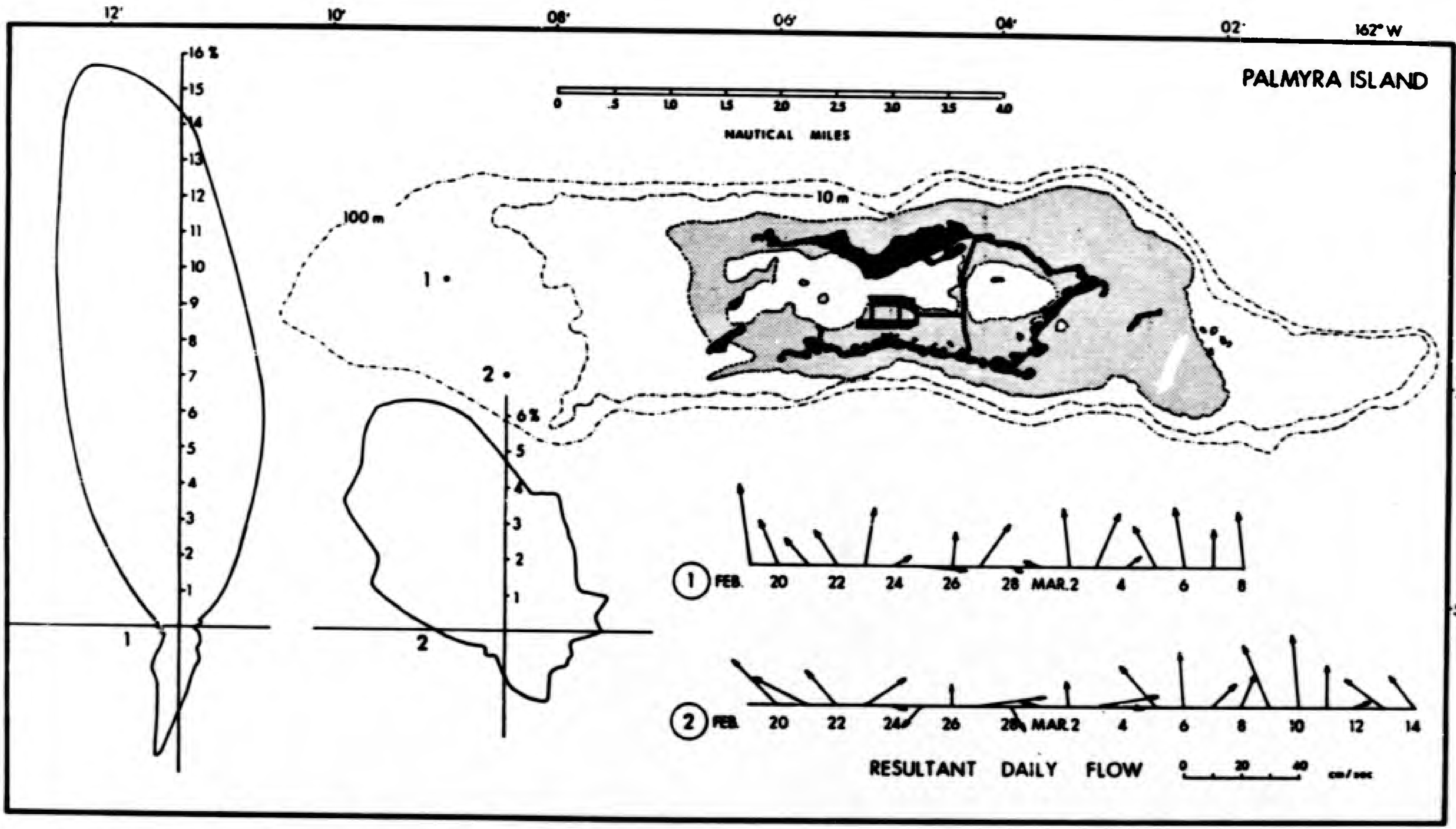


Fig. 7. Location of two paddle-wheel current meters near Palmyra Island. Scattering diagrams of current direction and average daily current vectors.

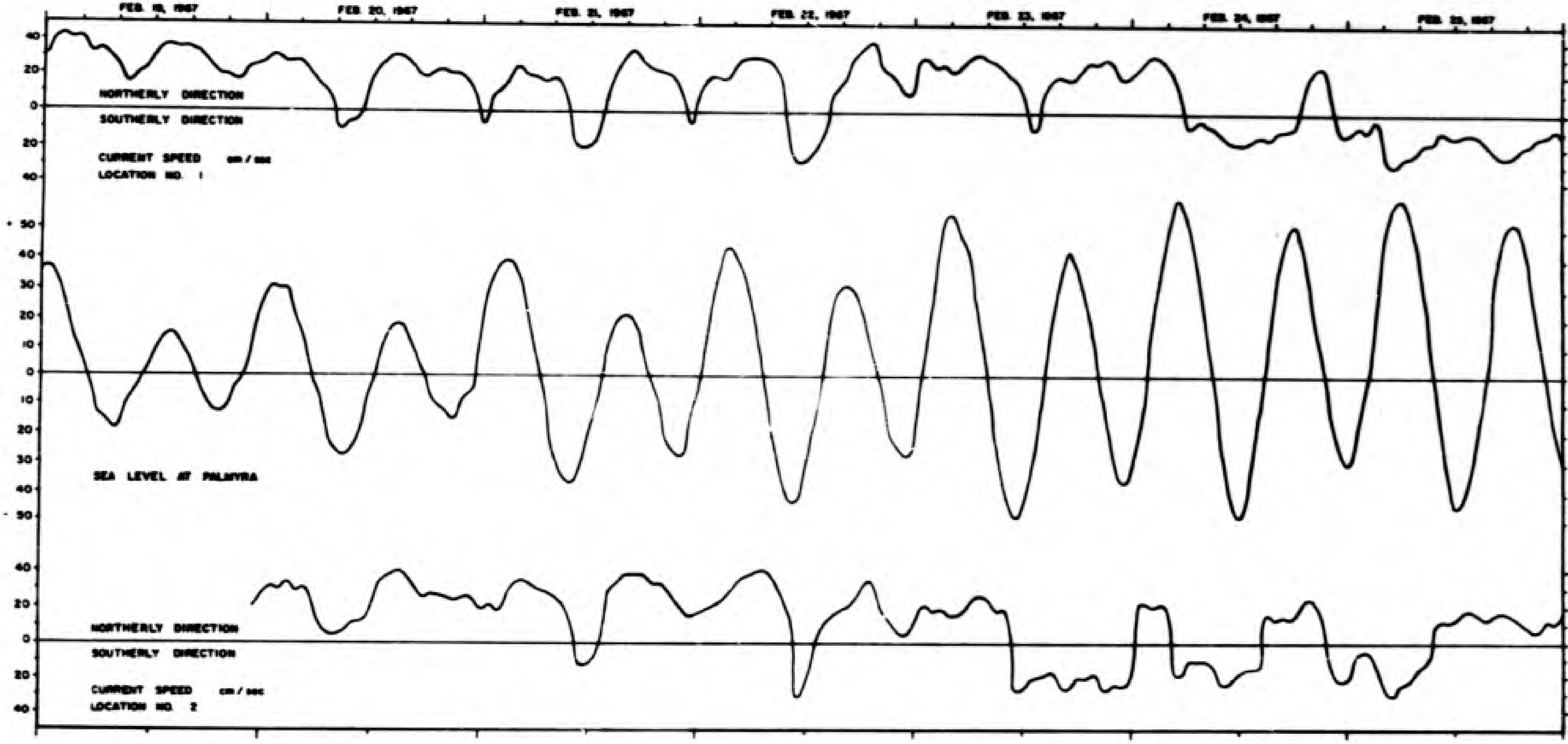


Fig. 8. Tidal currents and sea level at Palmyra Island, February 19 to February 25, 1967. Current speed is positive for flow with northerly components, and negative for flow with southerly components. Sea level is in cm relative to average sea level. For positions of current meters, see Figure 7.

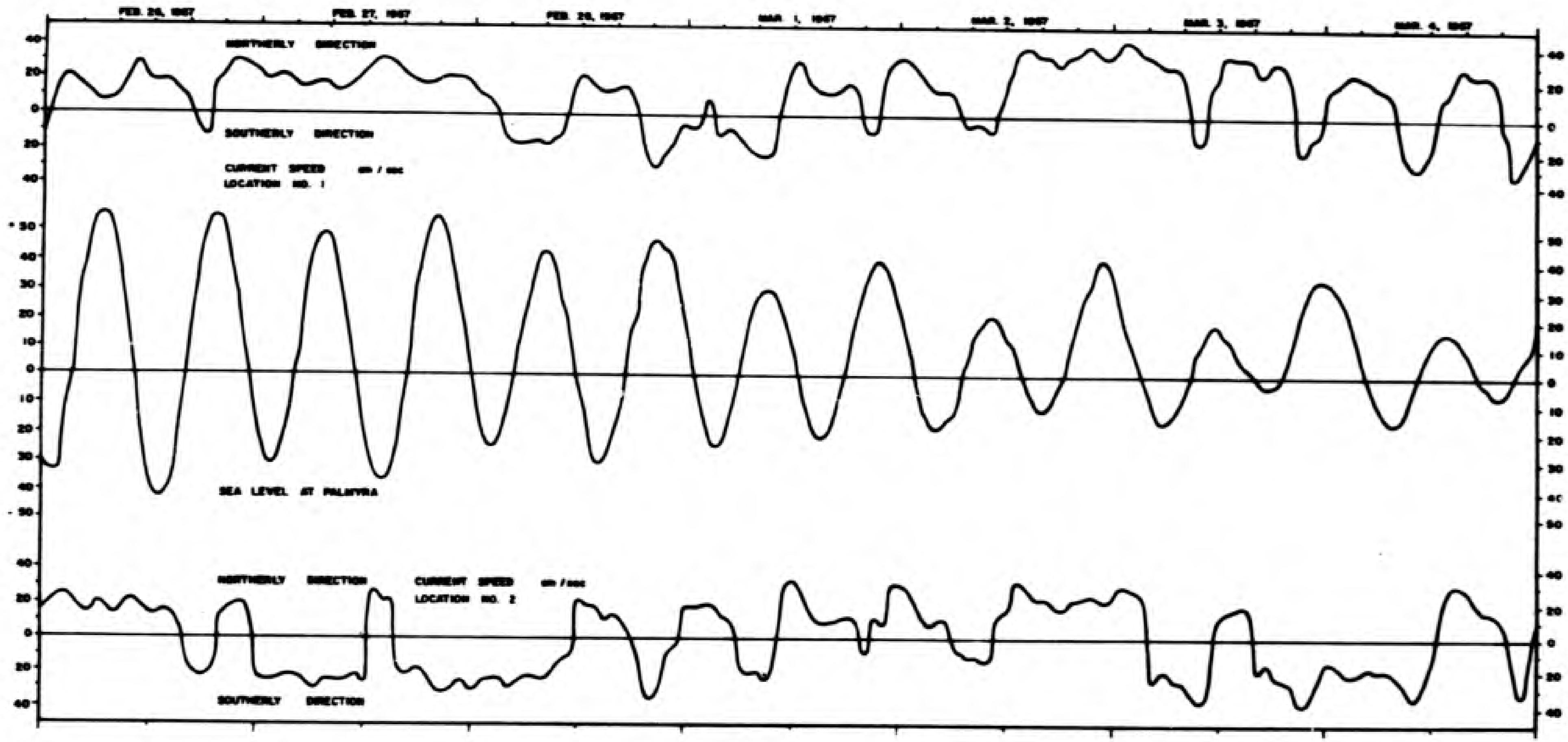


Fig. 9. Tidal currents and sea level at Palmyra Island, February 26 to March 4, 1967. Current speed is positive for flow with northerly components, and negative for flow with southerly components. Sea level is in cm relative to average sea level. For positions of current meters, see Figure 7.

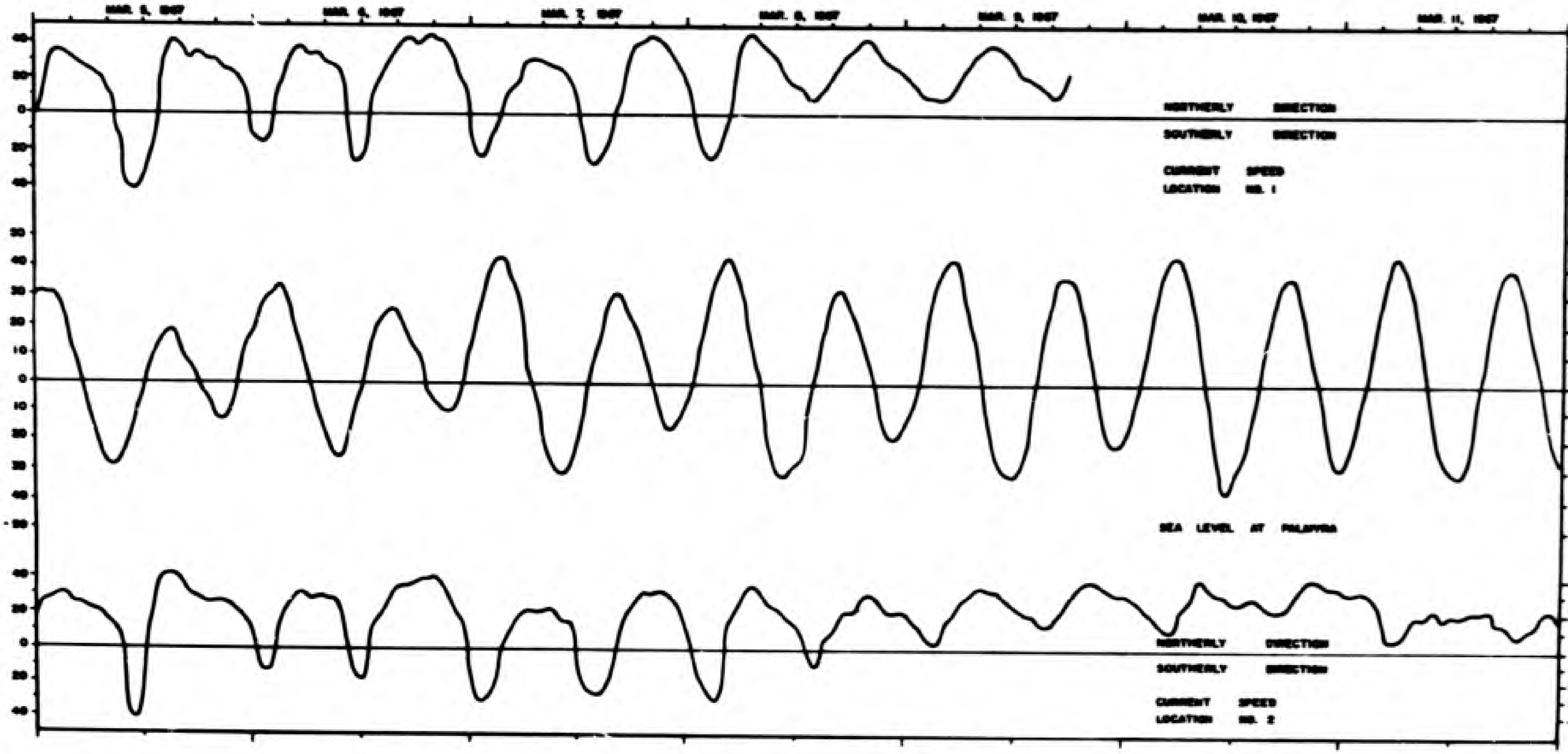


Fig. 10. Tidal currents and sea level at Palmyra Island, March 5 to March 11, 1967. Current speed is positive for flow with northerly components, and negative for flow with southerly components. Sea level is in cm relative to average sea level. For positions of current meters, see Figure 7.

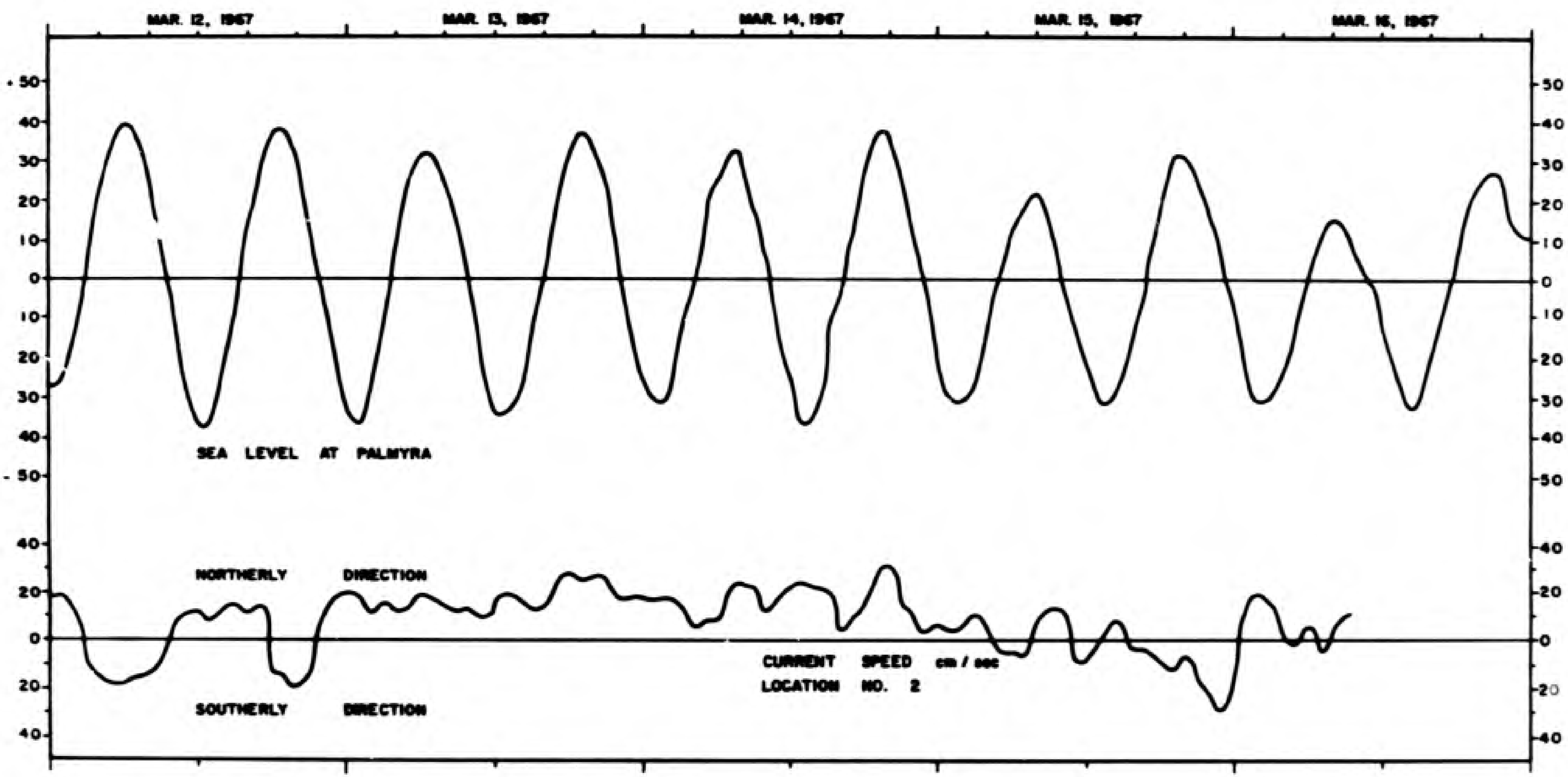


Fig. 11. Tidal currents and sea level at Palmyra Island, March 12 to March 16, 1967. Current speed is positive for flow with northerly components, and negative for flow with southerly components. Sea level is in cm relative to average sea level. For positions of current meters, see Figure 7.

During periods when semidiurnal tidal currents are pronounced, it is observed that during rising tide the tidal current is to the south, while during falling tide the tidal current is to the north. High tide and maximum tidal currents occur about 2 hours later than near the Hawaiian Islands, which is in agreement with the charts of co-tidal lines drawn by Dietrich (1963), and with an analysis by Wyrtki and Graefe (1967) for the Hawaiian Islands and indicates that the tidal currents around the Line Islands belong to the same system of a progressive amphidromic wave. Current ellipses for two selected days together with the sea level at Palmyra are shown in Figures 12 and 13. These current ellipses demonstrate again that the tide is predominantly semidiurnal. On February 22 a strong flow to the north and northwest coincided with falling tide between the hours of 0600 and 0800. At low tide the current changed direction and from 1200 to 1400 a rising tide with a strong current flowed south. With the next falling tide, between 1700 and 2200, flow was again strong to the north. A pronounced daily inequality in the tidal currents can be seen in the fact that the current does not reverse direction during rising tide around midnight. On March 7 (Fig. 13) the tidal current ellipses exhibited a similar pattern, but during this day the flood currents to the south at 0200 and at 1300 were almost of equal strength while the ebb currents at 0800 and at 2000 differed in strength.

In spite of the great similarity of the tidal ellipses at both positions, it is quite apparent that even over a distance of only one nautical mile the pattern of tidal currents can at times be appreciably different.

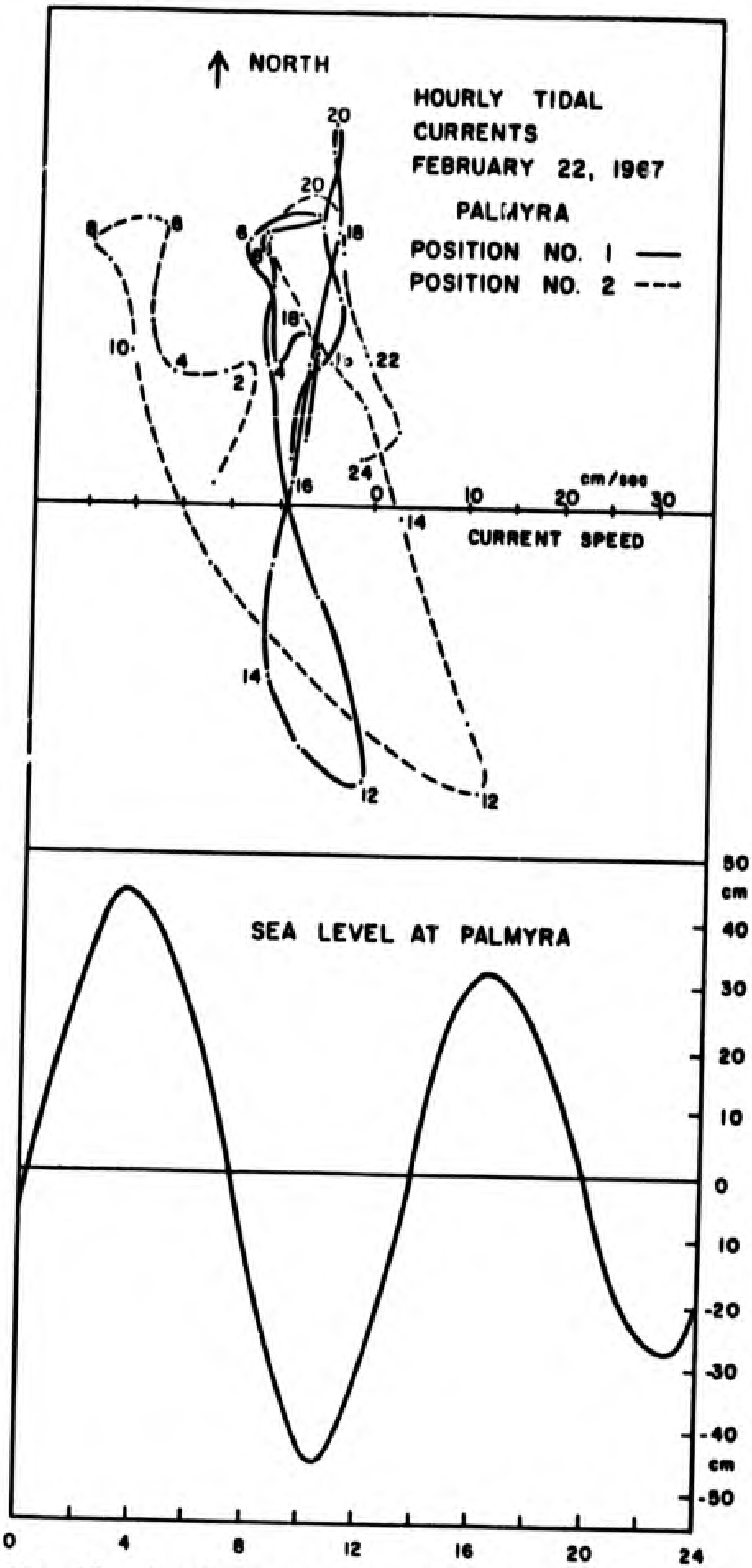


Fig. 12. Speed and direction of hourly average tidal currents and sea level at Palmyra on February 22, 1967. Numbers at the tidal ellipses give time in hours.

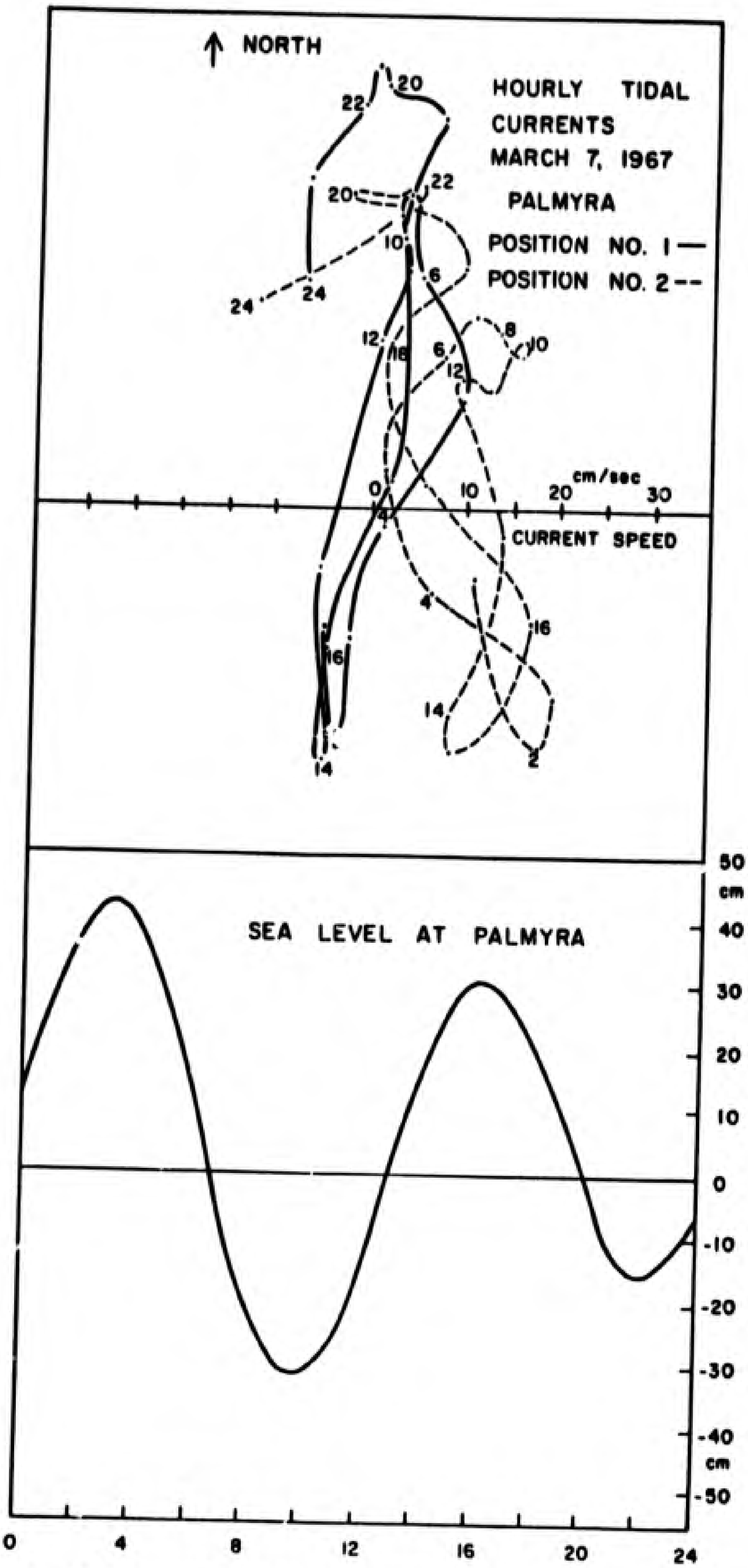


Fig. 13. Speed and direction of hourly average tidal currents and sea level at Palmyra on March 7, 1967. Numbers at the tidal ellipses give time in hours.

## CURRENT MEASUREMENTS AT THE ANCHOR STATION

On the second voyage, the SURVEYOR was anchored at a seamount approximately 250 nautical miles east of Palmyra. This seamount ascends from a depth of approximately 5000 m to a depth of less than 1200 m. The first anchoring was done at 6°25.8'N, 157°46.5'W in 1536 m of water, with 2750 m of wire, at 1030 hours on March 14. Current measurements started at 1800 and were terminated when the ship broke from its mooring at 0013 on March 15.

A second attempt to anchor the ship was successfully made on the afternoon of the same day. This time, the ship was anchored at 6°25.2'N, 157°53.2'W in 1250 m of water, with 3000 m of wire, at 1530 on March 15. This position was maintained until March 22 at 0300 when the anchor cable again broke. Current measurements were made during this entire period except for the period from 0200 to 1700 on March 16 and from 0700 to 2000 on March 17, when repairs had to be made on the current meters and on the sea cable.

On March 22 at 1530 the ship was anchored for a third time at 6°24.0'N, 157°49.8'W at a depth of 1350 m, with 3000 m of wire. This position was maintained until the anchor station was left at 1850 on March 25. During this period current measurements were continuous.

The results of the measurements made at the anchor station are shown in Figures 14 through 17. The diagrams give in graphical form the ship's heading, wind speed and direction, and current speed and direction at 20, 100, 180, and 260 m depths, and show, in addition, the variations of the thermal structure during the period, based on bathythermograph observations. Measurements were also made at 60, 140, 220, and 300 m depths, but they are not shown in the diagrams.

During the entire period moderate trade winds were blowing with directions varying between northeast and east. Wind speeds were generally between 7 and 12 m/sec. The ship's heading during most of the time was southeast and was very steady.

The position of the anchor station was chosen with the hope of making direct current measurements within the Equatorial Countercurrent. This current usually extends from approximately 9°N to 4°N and, consequently, the location of the seamount at 6°25'N appeared to be ideal for such measurements. The observations show, however, that there was little evidence of the Countercurrent at this position during this period. Currents at 20 m during the first two days were to the northeast and north. Their speed was in excess of 100

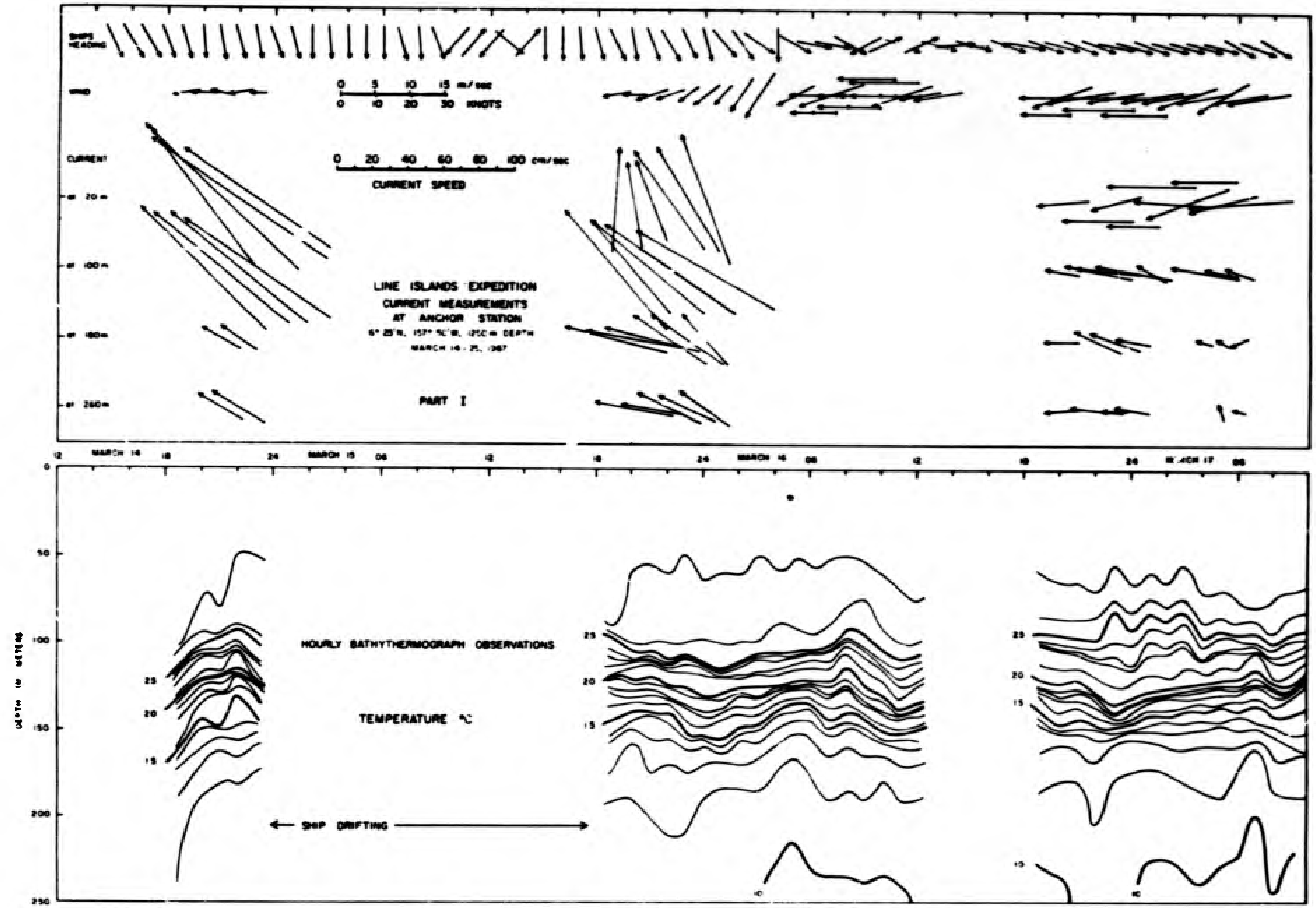


Fig. 14. Current measurements and bathythermograph observations at the anchor station, March 14-25, 1967. Part I.

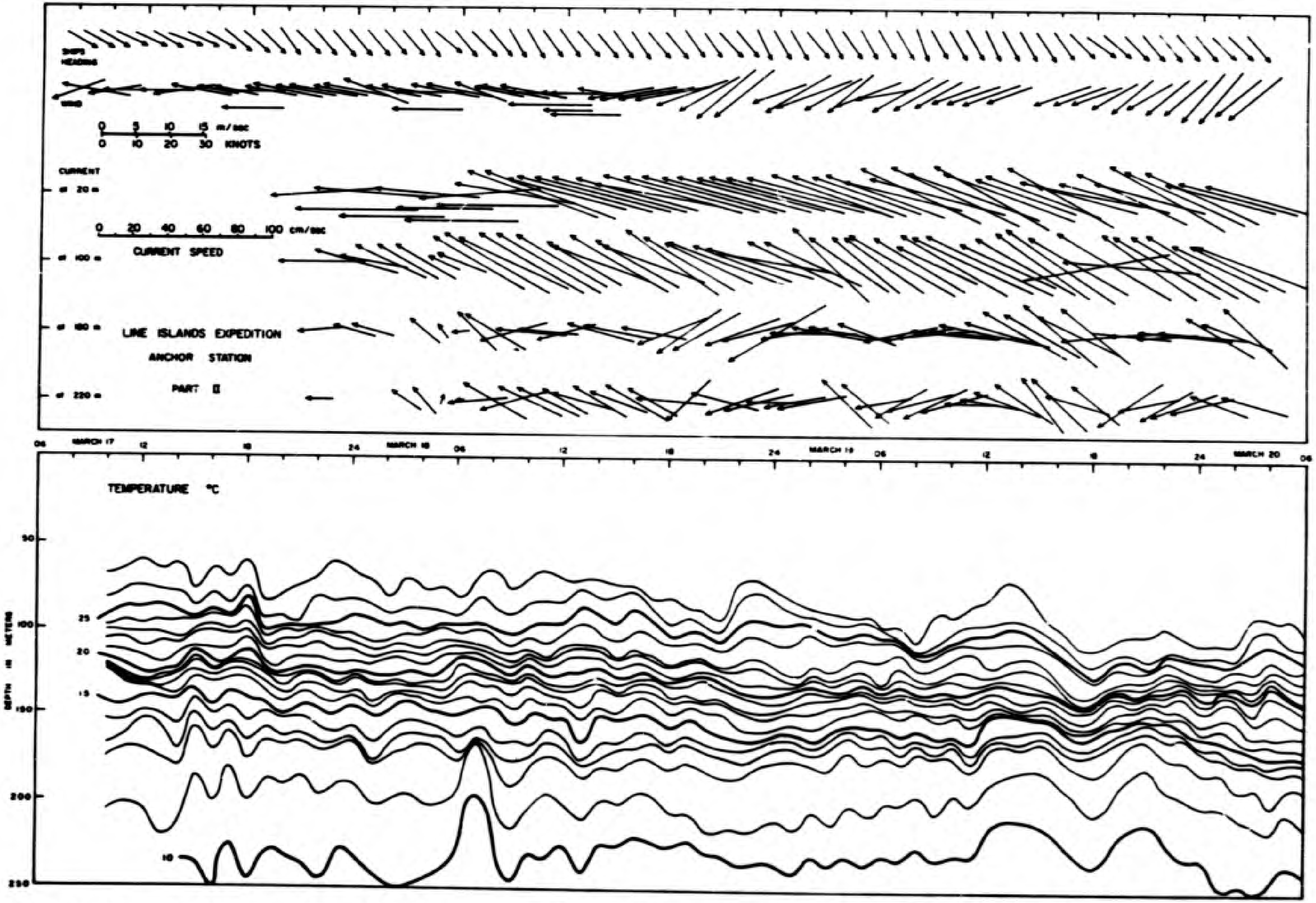


Fig. 15. Current measurements and bathythermograph observations at the anchor station, March 14-25, 1967. Part II.

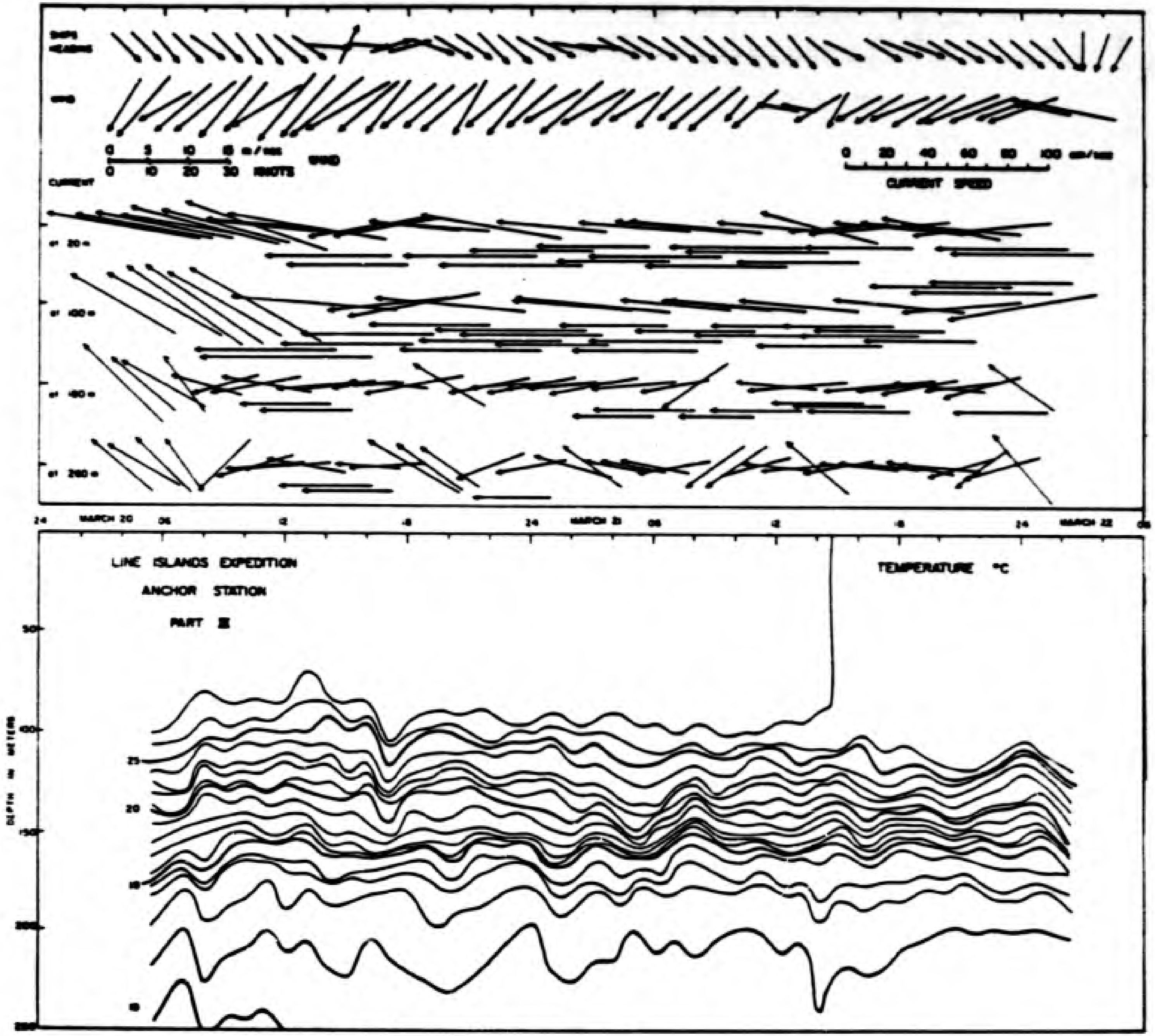


Fig. 16. Current measurements and bathythermograph observations at the anchor station, March 14-25, 1967. Part III.

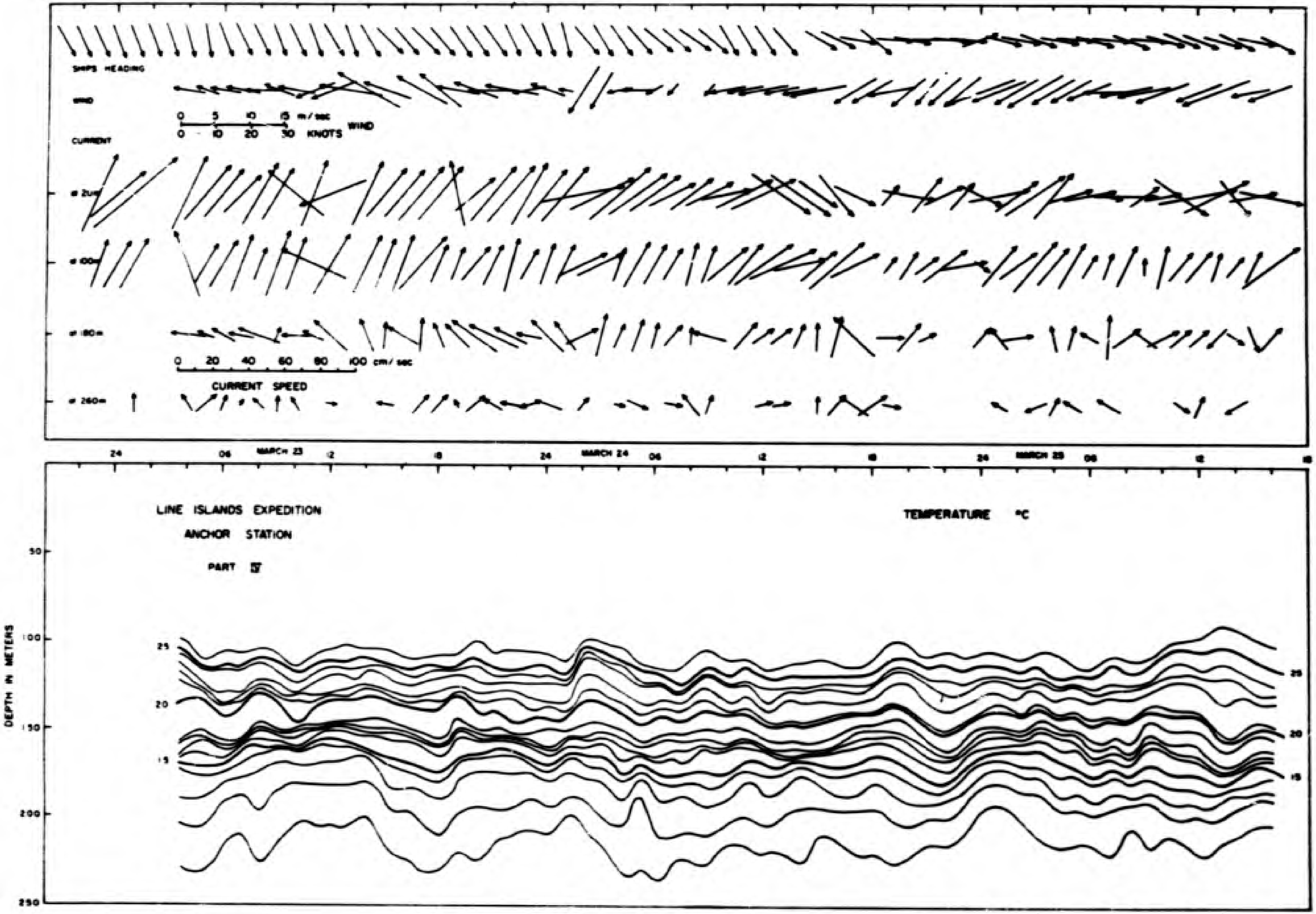


Fig. 17. Current measurements and bathythermograph observations at the anchor station, March 14-25, 1967. Part IV.

cm/sec and the fast-moving surface layer extended to a depth of 140 m. Below that depth currents were appreciably weaker but had the same direction.

After the re-anchoring on March 16 the current pattern had changed. Currents were in general weaker and flow was to the west.

Beginning on March 18, an uninterrupted series of current measurements of slightly longer than four days duration is available. During the time the flow at 20 m depth varied in direction between 260° and 310° with speeds near 80 cm/sec. At 100 m depth the flow was slightly more to the north with speeds still between 60 and 70 cm/sec. This high-speed surface layer normally flowing to the west usually extends to about 140 m depth, about to the center of the strongly developed thermocline. At 180 m depth, flow was still westward but the speed had decreased to less than 50 cm/sec. At this depth and at 220 m there was a strong indication of tidal currents. The direction of the flow varied between about 230° and 330°, with flow alternating, with a period of approximately 12 hours between these two directions, indicating that a north-south flowing tidal current is superimposed on the general flow to the west. It is interesting to observe that such tidal fluctuations are not indicated in the measurements within the high-speed surface layer. Beginning on March 20 the flow in the surface layer down to 140 m depth was much more strongly to the west than before.

After re-anchoring on the 23rd, the flow pattern had changed substantially (Fig. 17). Flow in the surface layer was then to the north with speeds of approximately 40 cm/sec. Later on it shifted to the east and speeds decreased to less than 30 cm/sec; at 100 m depths, direction of the flow was between north and northeast with speeds similar to those at the surface. At 180 m depth, flow during March 23 was still chiefly to the west and it was only on subsequent days that it turned to the north and northeast. Below 180 m depth, currents were very weak during this final period and no tides were apparent in the observations.

During the 11 days of the anchor station, the temperature structure remained virtually unchanged. A well-developed mixed layer was present at all times. It was approximately 70 m deep at the beginning and deepened to about 100 m during the last few days of the anchor station. During the entire period the 20° isotherm fluctuated between 112 and 154 m depth. The fluctuations were irregular and no sign of internal waves or tides was apparent.

The most surprising fact that appeared from the current measurements made at the anchor station is that the Countercurrent was absent. Flow was to the west and northwest with fairly high speeds. This may be partly explained by the fact that moderate trade winds were found at this position within the doldrums where, usually, weak variable winds should prevail. However, the observed flow to the west and north agrees very well with the measurements made from anchored current meters near Palmyra during the period preceding the anchor station (see Fig. 7).

Between February 20 and March 14 the average daily flow at the west point of Palmyra was to the north with velocities as high as 27 cm/sec, except for 2 days when a weak flow to the south occurred. Consequently, these observations indicate that the northward and westward movement of water during this time was a fairly wide-spread phenomenon. It was observed at two locations, which are usually situated in the southern portions of the Equatorial Countercurrent. The geostrophic calculations based on the section made in the middle of February and shown in Figure 2 show a well-developed Countercurrent flowing east and extending southward to 5°N. This situation must have changed in the following weeks. It is known that the Equatorial Countercurrent is not always continuous with respect to longitude, especially not during the period January to April when the Intertropical Convergence is in a southerly position, as has been shown for the eastern Tropical Pacific Ocean by Wyrtki (1965).

A similar situation might also develop in the central Pacific Ocean at the same time. Surface current observations also indicate that the Equatorial Countercurrent has a tendency to entrain water from the south and to discharge water to the north. Our current observations at the anchor station and near Palmyra may have been made during just such a period when strong entrainment of water from the south into the Countercurrent was occurring. During the last days of the current measurements the flow turned first to the north and then to the east and the Countercurrent apparently was again forming in the fashion one would expect under normal conditions.

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# REFERENCES

*Barkley, R. A.* (1962). A Review of the Oceanography of the Central Pacific Ocean in the Vicinity of the Line Islands, Honolulu Biological Laboratory, U. S. Bureau of Commercial Fisheries, 37 pp.

*Charney, J. G.* (1960). Non-Linear theory of a wind-driven homogeneous layer near the equator, Deep-Sea Res., 6, 303-310.

*Dietrich, Gunter.* (1963). General Oceanography, John Wiley & Sons, New York, 588 pp.

*Graefe, V.* (1967). Digital Recording of in situ Depth-Temperature-Salinity Data, Limnol. & Oceanog. (in press).

*Knauss, John A.* (1966). Further measurements and observations on the Cromwell Current, J. Marine Res., 24, 2. 205-240.

*Montgomery, R. B., and E. D. Stroup.* (1962). Equatorial Waters and Currents at 150°W in July-August, 1952. Johns Hopkins Oceanog. Studies No. 1, 68 pp.

*Reid, J. L., Jr.* (1965). Intermediate Waters of the Pacific Ocean, Johns Hopkins Oceanog. Studies No. 2, 85 pp.

*U. S. Navy Hydrographic Office.* (1944). World Atlas of Sea Surface Temperatures, H.O. Publ. 225, Washington, D. C.

*Wyrtki, Klaus.* (1965). Surface currents of the Eastern Tropical Pacific Ocean, Inter-Am. Tropical Tuna Comm., Bull., 9, 5, 271-304.

*Wyrtki, Klaus.* (1967). Circulation and water masses in the Eastern Equatorial Pacific Ocean, Int. J. Oceanol. & Limnol., 1, 2, 117-147.

*Wyrtki, Klaus, and V. Graefe.* (1967). Approach of tides to the Hawaiian Islands, J. Geophys. Res., 72, 8, 2069-2071.

*Wyrtki, Klaus, and R. Kendall.* (1967). Transports of the Pacific Equatorial Countercurrent, J. Geophys. Res., 72, 8, 2073-2076.

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13. ABSTRACT

In support of meteorological observations during the Line Islands Expedition the U.S.C.& G.S. Ship SURVEYOR made oceanographic observations between the Hawaiian Islands and 3°S. A hydrographic section from Hawaii southward crossed the North Equatorial Current and the Countercurrent, the transports of which were 22.1 million $m^3$/sec and 27.7 million $m^3$/sec, respectively. Two sections across the Equatorial Undercurrent, parallel to each other at a distance of 90 miles, revealed a fine structure of the Undercurrent not previously observed.

Two current meters anchored near the island of Palmyra showed predominantly semidiurnal tides and a superimposed flow to the north. Current measurements during 11 days at 6.5°N from the anchored ship indicated that the Countercurrent was not present during most of this period. Flow was mostly to the west and north.

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