Paper 7

OCEANIC CONDITIONS DURING 1976 BETWEEN SAN FRANCISCO AND HONOLULU AS OBSERVED FROM SHIPS OF OPPORTUNITY

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INTRODUCTION

During 1976 cooperating merchant ships continued to make sections of surface salinity samples and of expendable bathythermograph (XBT) observations on the San Francisco-Honolulu ship route (Fig. 7.1). Similar sections of observations were obtained most of the year, but less frequently, on the Seattle and Los Angeles to Hawaii routes. These, however, were discontinued at the end of October for lack of funds, and these two routes are not considered in this paper. The sampling was done for the National Marine Fisheries Service using funds provided by the National Science Foundation under the NORPAX program.

The San Francisco-Honolulu route crosses a Transition Zone which lies between the cooler, lower salinity, modified subarctic waters of the California Current and the warmer, higher salinity waters of the Eastern North Pacific (ENP). Laurs and Lynn (1975, 1977) indicated that the character and position of the Transition Zone, directly or indirectly, influence the offshore distribution and migration routes of albacore tuna moving from the central North Pacific into the summer fishery off the continental west coast.

Selected vertical sections of the data have been published monthly in Fishing Information[3] since March 1972. Interpretations of features in the sections were included through March 1975 (Saur 1972-75). Saur et al. (1979) discussed the characteristics of long-term mean vertical sections of subsurface temperatures from the XBT data on the San Francisco route.

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In this report we present distributions of surface salinity, sea surface temperature (SST), and heat storage (surface to 100-m layer) during 1976, and have extended the previously published 1972-75 time series of their anomalies through 1976. We discuss the 1976 distributions and differences in anomalies from the preceding years. An apparently atypical relation of positive temperature anomalies occurring with negative salinity anomalies off the Pacific coast during October-December 1976 is attributed, at least partially, to a decrease in evaporation and weak vertical mixing by winds.

OBSERVATIONS

Observational programs and procedures for making XBT observations aboard cooperating merchant ships have been described by Saur and Stevens (1972). The "surface" salinities are determined from water samples drawn at around 7 m below the surface. "Surface" temperatures from the XBT observations are representative of temperatures at about 5 m. Heat storage is presented as average temperature from the surface to 100 m as determined from the XBT observations. These observations were normally scheduled at 4-h intervals.

For 1976 the number of ship of opportunity transits, number of observations, and range of observed values are shown in Table 7.1.

Table 7.1

	Number Transits	of Obs.	Minimum	Maximum	Range
Surface salinity (o/oo)	27	814	32.37	35.59	3.22
Surface temp. (C)	31	926	10.0	25.9	15.9
Heat storage (C, 0-100 m)	30	868	10.0	25.2	15.2

The locations of the observations are shown in Figures 7.2-7.4. In these, and other figures, the location of an observation is given by its great circle distance from a reference point, 21N12', 157W42', which is in the ocean channel near Honolulu, south of Makapuu Point, Oahu.

DISTRIBUTION OF VARIABLES DURING 1976

The time-space distributions of salinity, temperature, and heat storage (0-100 m) are shown in Figures 7.2, 7.3, and 7.4, respectively. The irregularly located observations were first analyzed by the NORPAX/SURFACE II computer program to a time-space grid of 24 intervals per year by 92.6 km (50 n mi). The distributions were then computer contoured from the unsmoothed grid fields using double linear interpolation with five subintervals within each standard grid interval.

The surface salinities (Fig. 7.2) showed the underlying mean pattern (Saur 1978) of a low salinity minimum (below 33.0 o/oo) a short distance offshore in the California Current; a region where salinity increased toward Hawaii and had maximum gradients located between 2,000 km and 3,000 km along the route from Hawaii; a region of maximum salinites (above 35.0 o/oo) located between 500 km and 1,750 km from Hawaii; and somewhat lower salinities (below 35.0 o/oo) most of the year near Hawaii. The high salinities occurred where the vessel track crossed the eastern end of the high salinity Eastern North Pacific Central Waters, located between 25N and 30N (Sverdrup et al. 1942).

The surface temperatures (Fig. 7.3) showed the typical annual cooling and warming cycle with minimum temperatures in late March or early April and maximum temperatures in September superimposed on the latitudinal decrease in temperature along the route from Hawaii to San Francisco. The most rapid warming normally occurs from mid-May to mid-July, but in 1976 the warming was delayed until mid-June and was greatest in July. This was followed by a broad maximum through October and slowly decreasing temperatures in November-December.

The annual cycle of temperature is much more prominent than the annual cycle of salinity. Minimum and maximum values and total range for each gridded field are shown in Table 7.1. The greatest range of salinty at a given position was about 0.5 o/oo or only 15% of the total observed range. On the other hand, near the California coast the temperature range was 6.0C, and near 3,000 km along the route (in the Transition Zone) the annual range was 5.1C, which were 39% and 32%, respectively, of the total observed range.

The heat storage (expressed by the average temperature in the upper 100 m of water, Fig. 7.4) had a pattern similar to that of surface temperature. However, at a fixed location it did not have as large an annual range; this was only about 2C over most of the route but reached about 4C near the California coast. The smaller annual range of heat storage occurred because the effects of the seasonal warming and cooling cycle decrease with depth.

ANOMALIES DURING 1976

The time series since 1972 of anomalies of salinity, temperature, and heat storage given by Saur (1978) are extended to include 1976 anomalies (Fig. 7.5). The mean data from which the anomalies were computed did not include the 1976 data, but were for the same 8-yr period (June 1966-December 1970, January 1972-June 1975) used previously. The grid fields for the anomalies were numerically smoothed by a 5 x 3 point (60 days by 100 n mi) before being contoured.

The anomalies of surface salinity were generally small, but dominantly positive, throughout the first nine months of 1976. Two exceptions are noticeable. Along the California coast there was a pulse of below normal salinity water in January-February and another in May-July. Nearer midsection the negative anomaly (-0.2 o/oo) which had appeared near 2,700 km in late summer 1975 migrated westward along the track, decreased to near normal in winter, but then increased in intensity to -0.2 o/oo around 2,000 km in May and June 1976. This propagation speed along the route was about 3.3 cm/s as compared with observed values of 2.5 cm/s in 1972-75 and speeds of 2.9 cm/s for temperature anomalies at 170 m (generally in the thermocline) found by Dorman and Saur (1978).

The outstanding feature of surface salinity anomalies in 1976 was the appearance of significant negative anomalies (below -0.2 o/oo) at the California coast and also near the outer edge of the California Current (near 2,800 km) in October. In mid-November there was a band of negative anomalies (below -0.3 o/oo) from near the California coast to midsection. Further, anomalies below -0.4 o/oo occurred in the Transition Zone and extended toward Hawaii somewhat into the ENP region. These strong negative anomalies appeared to be returning to near normal at the end of the year.

The SST anomalies in 1976 exhibited the earlier observed coherence with distance along the track and low persistence in time. From January through April temperature anomalies were positive over most of the route except that they were negative within about the last 600 km approaching the California coast. A change to significantly negative anomalies occurred in May over the entire route because of the previously mentioned delayed onset of seasonal warming. Warming in July briefly returned the anomalies to near zero over most of the route. A narrow band of positive anomalies appeared near the California coast at that time. The anomalies over the rest of the route returned, however, to significantly negative values during August through October.

During the last quarter, positive temperature anomalies appeared progressively farther westward along the route towards Hawaii at a very rapid rate. Significant positive anomalies (above 0.5C) appeared during November over the entire eastern half of the section and persisted through the remainder of the year. The pattern of these positive anomalies was quite similar to that of the negative salinity anomalies that were previously noted.

The pattern of anomalies of heat storage in the upper 100 m differed considerably from that of surface temperature anomalies. Only during the first quarter of the year was there some correspondence of positive anomalies of heat storage and surface temperature over most of the route along with negative anomalies near the California coast. During May-July over the central portion of the route, the positive anomalies of heat storage persisted while the anomalies of SST changed to negative, indicating that the warm waters remained at depth but were covered with anomalously cool waters at the surface.

Toward the last half of the year negative heat storage anomalies progressively appeared over a larger portion of the route at the Hawaiian end of the section. Otherwise, the patterns of significant heat storage anomalies were very spotty.

DISCUSSION

The oceanic conditions in 1976 on the San Francisco-Honolulu route began with the relation between surface salinity and surface temperature anomalies which has been typical for at least the period 1972-75. This historical relation had banded and westward-migrating positive (or negative) salinity anomalies over the eastern half of the route accompanied by positive (or negative) surface temperature anomalies over most of the route. This relation continued in the first quarter of 1976 when positive salinity anomalies were associated with positive temperature anomalies.

During midyear the relation broke down and 1976 ended with a strongly atypical relation between salinity and temperature anomalies. Negative salinity anomalies occurred simultaneously for 1,500 km along the eastern part of the route with positive temperature anomalies--a reversal from the previous relation.

For the years 1972-75 an heuristic model with anomalies dominated by advective processes could explain the association of positive salinity anomalies in the outer California Current region with wider spread positive temperature anomalies. The California Current is the fastest portion of the eastern limb of the major (clockwise) gyre of the central North Pacific. Along the

San Francisco-Honolulu route the average current flows from northwest to southeast, essentially normal to the route. An increase in speed of the North Pacific Gyre would bring in more cool, low salinity, modified Subarctic Water which, on the route, would appear first in the California Current region and later in the Transition Zone. This would result in more negative salinity and temperature anomalies in these areas. Over the western half of the route, an increase in speed of the gyre would also result in increasingly negative temperature anomalies (due to meridional gradients of temperature) but would not result in significant negative salinity anomalies because meridional salinity gradients are weak or nonexistent in that area (Reid 1969). The increase (or decrease) in speed of the gyre could result from long-term forcing by winds. This simple model assumes that the variability from heat exchange and vertical mixing is negligible.

The patterns of salinity and temperature diverged greatly from this model in the last three months of 1976. Dickson and Namias (Paper 2) noted that during 1976 the upper air (700 mb) patterns also changed noticeably. During the first three seasons the anomalous circulation was strongly zonal across the central North Pacific. But during the last three months, a high pressure ridge established itself over the eastern North Pacific and west coast of North America. The ensuing fair weather and 1976-77 winter drought over the western United States were documented in the Monthly Weather Review.[4]

The breakdown in October through December 1976 of the earlier relation between salinity and temperature anomalies indicated a change in balance of oceanic processes. If we consider that surface salinity is a quasi-conservative property and the low anomalies were due to increased advection to the south, we must look for processes that would change a negative temperature anomaly to positive. The possibility that increased anomalous heat exchange and less vertical mixing by weaker winds contributed to positive anomalies was explored using monthly mean data compiled by 5-deg quadrangles at the Southwest Fisheries Center. Anomalies were computed for two quadrangles for the last three months of 1974, 1975, and 1976 (Table 7.2). One of the quadrangles (35N-40N, 125W-130W) lies over the California Current west of San Francisco and is crossed by the ship route. The other (40N-45N, 125N-130W) is the adjacent quadrangle to the north, through which waters normally flow before crossing the route. Heat exchange anomalies were computed from the 1961-71 means given by Clark et al. (1974). Wind speed anomalies were computed from the 1961-76 monthly means published in 1976 issues

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[4]Professional journal of the American Meteorological Society, Vol. 105, Nos. 2-5, February-May 1977.

of *Fishing Information*.

The anomalies showed that wind speeds were lower and heat gained by the ocean was much higher in 1976 than in the previous two years. The decreased wind speeds along with occurrence of warm, moist air resulted in less evaporation and sensible heat loss and, consequently, more heat retention by the ocean (Table 7.2). Decreased wind speeds also permitted more stratification in the ocean and thus a greater positive surface temperature anomaly from the excess heat gain.

The major characteristics of anomalies which stand out in Table 7.2 are:

1) In both quadrangles there was a month to month consistency of heat exchange anomalies in 1976, particularly as compared with 1974. The same consistency occurred in the anomalies of wind speed.

2) Above normal retention of heat by the ocean because of reduced evaporation was the major component in 1976. Above normal incoming radiation and lower flux of sensible heat were secondary terms. Year to year changes of effective back radiation were relatively small.

3) The total heat flux anomaly in 1976, the anomaly from decreased evaporation, and the wind speed anomaly were larger in magnitude in the area to the north of the route (upcurrent) than in the immediate area of the XBT observations.

The data presented in Table 7.2 indicated that processes (heat exchange and vertical mixing) previously considered small as compared with advective processes were, at least partially, responsible for the late 1976 reversal of the relation of salinity anomalies to temperature anomalies observed in 1972-75. We are mindful that this argument is based on the assumption that the salinity anomalies resulted from advection and that the temperature anomalies were atypical. It is not immediately apparent how one could interpret the data if the temperature anomalies were assumed to be advective and it were necesssary to explain the salinity anomalies as atypical.

ACKNOWLEDGMENTS

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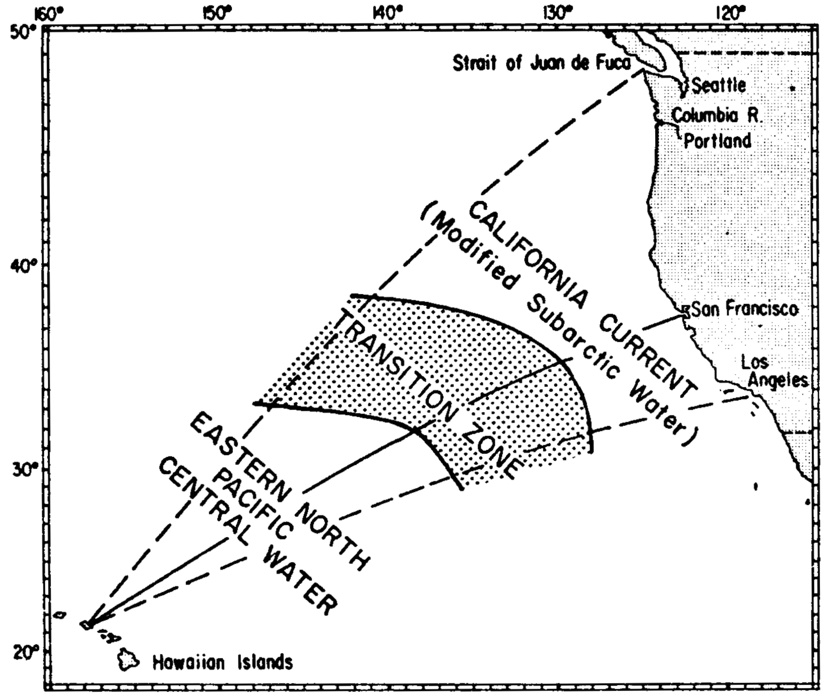


Figure 7.1.—Three oceanic domains (schematic) in the eastern North Pacific Ocean crossed by cooperating merchant ships taking surface salinity and expendable bathythermograph observations during 1976. Observations reported herein were taken on the San Francisco to Honolulu route (solid line).

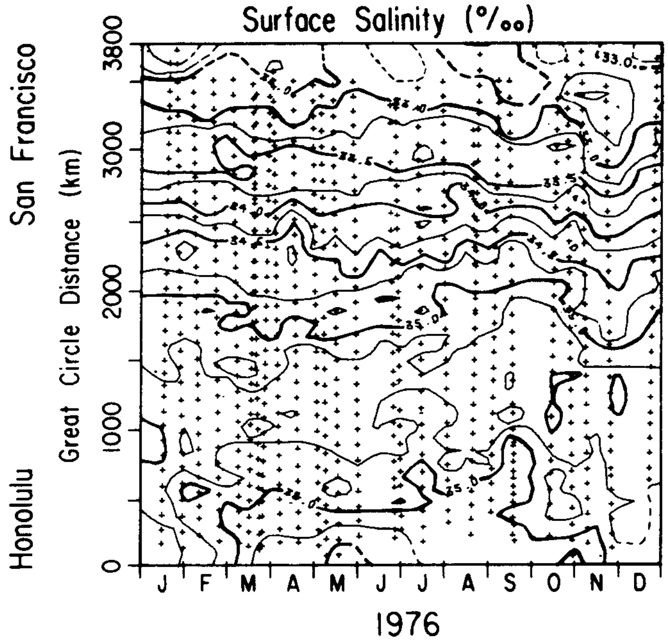


Figure 7.2.—Surface salinity in parts per thousand (‰) between San Francisco and Honolulu during 1976. Symbols (+) indicate the locations of observations in time and distance. Contour interval is 0.25‰.

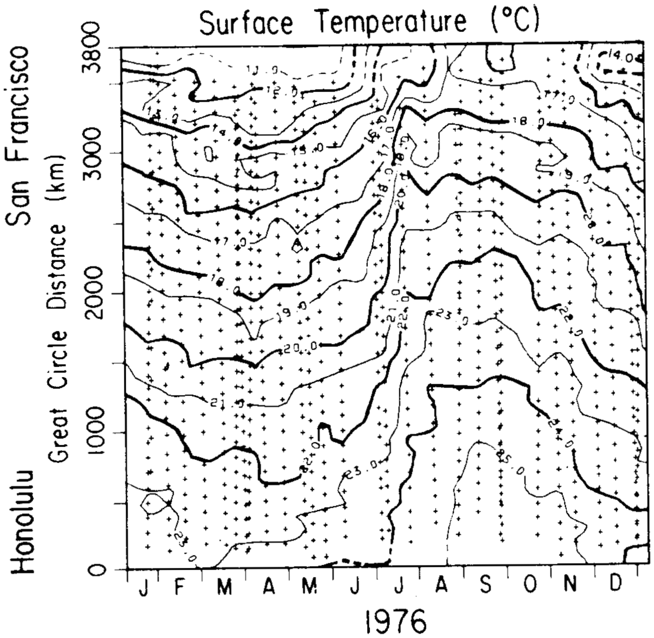


Figure 7.3.—Sea surface temperature in degrees Celsius (C) between San Francisco and Honolulu during 1976. Symbols (+) indicate the locations of observations in time and distance. Contour interval is 1.0C.

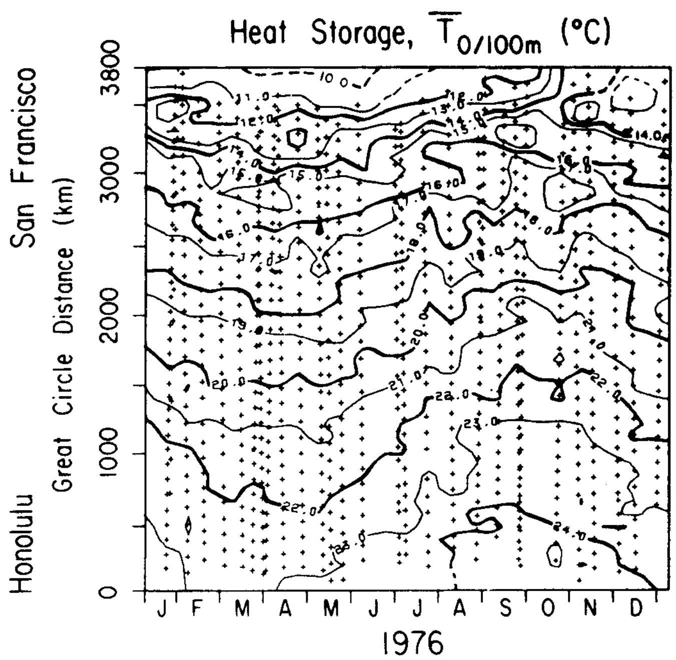
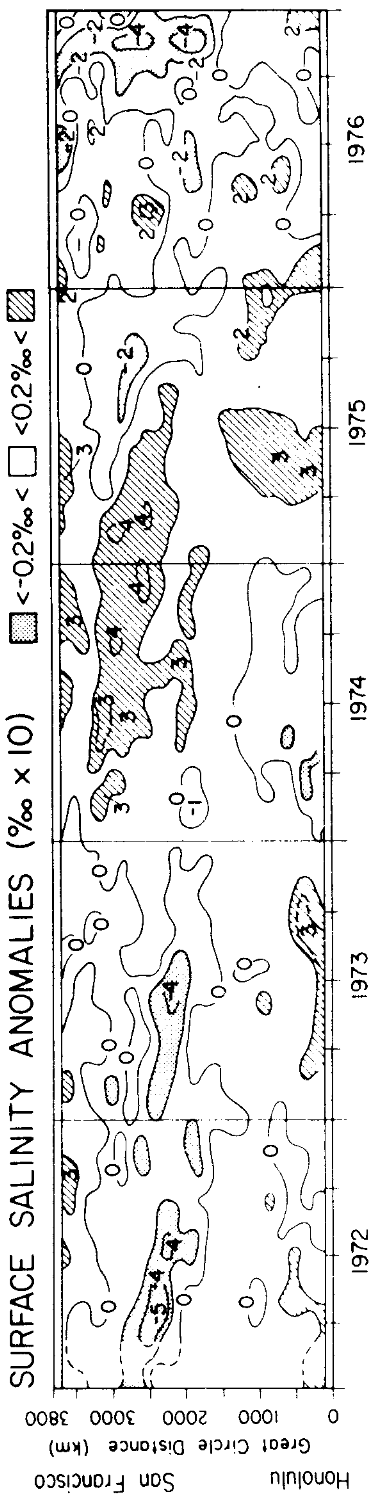
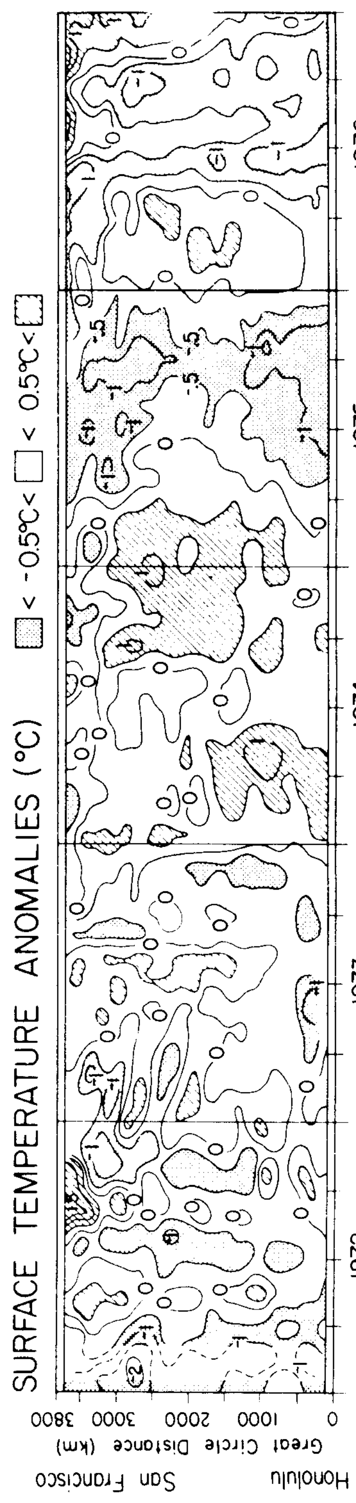


Figure 7.4.—Heat storage for the surface to 100-m layer, expressed as average temperature (T) 0-100 m in degrees Celsius (C), between San Francisco and Honolulu during 1976. Symbols (+) indicate the locations of the expendable bathythermograph observations. Contour interval is 1.0C.


SURFACE SALINITY ANOMALIES (‰ x 10)
< -0.2‰ < < 0.2‰ <
1972
1973
1974
1975
1976
Great Circle Distance (km)
0
1000
2000
3000
3800
Honolulu
San Francisco


SURFACE TEMPERATURE ANOMALIES (°C)
< -0.5°C < < 0.5°C <
1972
1973
1974
1975
1976
Great Circle Distance (km)
0
1000
2000
3000
3800
Honolulu
San Francisco

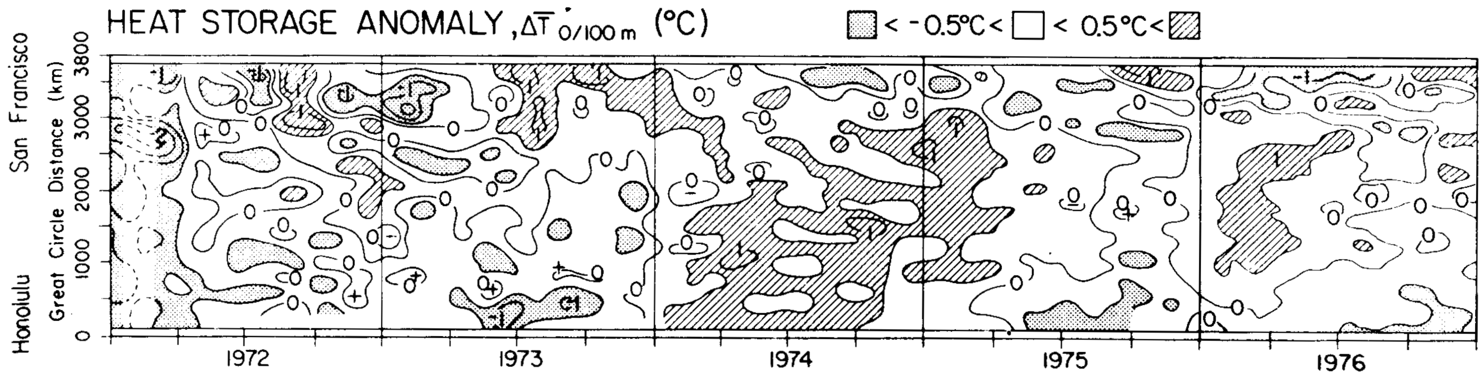


Figure 7.5.—Anomalies on the San Francisco-Honolulu route, January 1972-December 1976. Analyses in all three panels were smoothed before contouring (see text). Upper: Salinity anomalies; labels on contours are the anomaly multiplied by 10. Center: Sea surface temperature anomalies; contour interval is 0.5C. Lower: Heat storage anomalies for the surface to 100-m layer, expressed as departure from the mean of average temperature (T) 0-100 m in degrees Celsius.

TABLE 7.2. Anomalies of heat exchange (cal cm^{-2} d^{-1}) and of wind speed (knots) at two 5-degree quadrangles in the California Current Region. Quadrangles lie a) on San Francisco to Honolulu ship route and b) upcurrent from route. Positive (negative) values indicate anomalous heat gain (loss) by the ocean.

	1974			3-mo	1975			3-mo	1976			3-mo
	Oct	Nov	Dec	mean	Oct	Nov	Dec	mean	Oct	Nov	Dec	mean
On route (lat. 35°-40°N, long. 125°-130°W):												
Incoming radiation	19	-4	9	8	-12	3	-18	-9	7	3	23	11
Effective back radiation	-10	-6	1	-5	7	-7	19	6	-3	-6	-10	-6
Evaporation	-3	-58	26	-12	-18	-40	54	-1	13	19	17	16
Sensible heat flux	-4	-16	13	-2	10	-4	14	7	1	-3	11	3
Total (net) heat flux	2	-84	49	-11	-13	-48	69	3	18	13	39	23
Wind speed (knots) anomaly	-1	-2	0	-1	1	1	-1	0.3	-3	-3	-2	-2.7
Upcurrent from route (lat. 40°-45°N, long. 125°-130°W):												
Incoming radiation	-3	-10	4	-3	-20	11	-10	-6	20	15	17	17
Effective back radiation	13	-9	6	3	18	-3	16	10	1	-2	-5	-2
Evaporation	57	-73	39	8	8	22	60	30	44	35	61	47
Sensible heat flux	17	-31	26	4	21	12	15	16	18	15	24	19
Total (net) heat flux	84	-122	76	13	26	43	81	50	82	63	97	80
Wind speed (knots) anomaly	-1	4	-1	0.7	4	2	-1	1.7	-2	-3	-5	-3.3