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Interannual Changes in Sea Surface Temperatures and Salinities of the Coral and Tasman Seas Between 1966 and 1977

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INTERANNUAL CHANGES IN SEA SURFACE TEMPERATURES AND SALINITIES OF THE CORAL AND TASMAN SEAS BETWEEN 1966 AND 1977

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Abstract

Interannual changes in the sea surface sea temperature (SST) and surface salinity of the southwest Pacific for the period 1966 to 1977 are classifiable into four types which occur in distinct regions of the Coral and Tasman Seas:

(1) In the Coral Sea, surface salinity fluctuated widely from year to year, with little or no change in the SST.

(2) In the Tasman Sea north of around 40°S, the trend was towards lower salinity values and higher SST values from 1966 until at least 1977.

During 1972 and 1973, however, salinities fluctuated widely about the mean trend, with exceptionally low salinities in 1972 and high salinities in 1973. SSTs were well above average in both years.

(3) In the Tasman Sea off eastern Bass Strait, SST and surface salinity fell between 1966 and 1971. From 1971 onward, however, SSTs increased and surface salinities declined, paralleling the trend in the Tasman Sea to the north. The earlier feature is attributable to stronger outflow of Bass Strait waters into the adjoining Tasman Sea prior to 1971.

(4) Off western New Zealand and off southeastern Tasmania, SSTs and surface salinities increased from 1966 to 1977.

These interannual changes in surface salinity were not always related to changes in the annual rainfall. However, interannual changes in rainfall were related to changes in SST, such that SST increased as rainfall increased and vice versa.

The distribution patterns of the salinity anomalies during a 1971-1972 very low salinity event and during a 1972-1973 very high salinity event in the Tasman Sea were consistent with the circulation pattern of the East Australian Current.

Many of the interannual changes in the Tasman Sea between 1966 and 1977 can be ascribed to interannual changes in the SST and surface salinity of the East Australian Current source waters in the Coral Sea, which were then transported by the current into the Tasman Sea.

No oceanographic connection between the events in the western equatorial Pacific that preceded the 1972 El Nino and the 1971-1973 warming event in the Coral and Tasman Seas could be adduced.

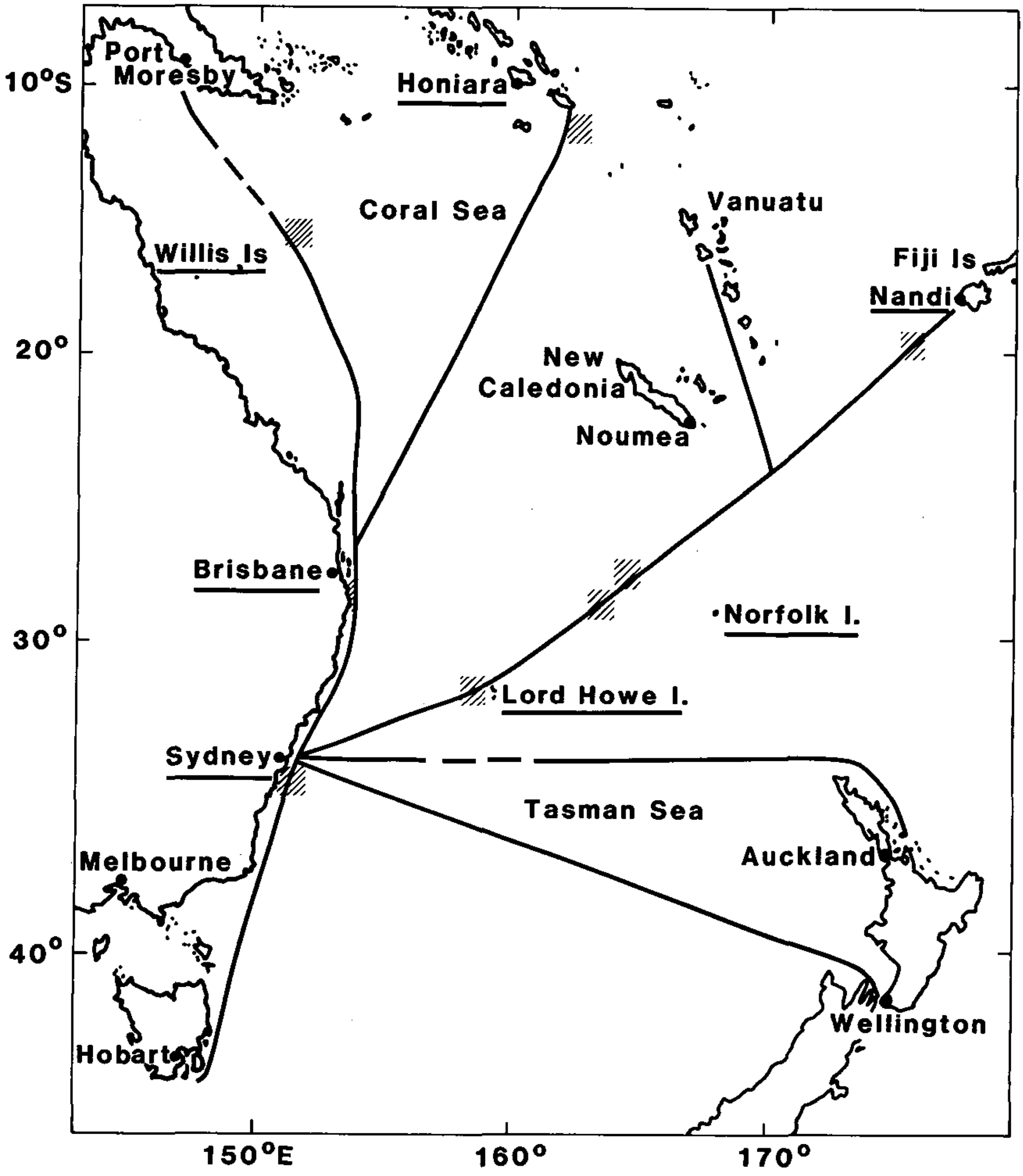


Figure 1 Chart showing the major routes of vessels taking part in the CSIRO SOOP between 1966 and 1977. The selected rainfall stations are underlined and the comparision 1° squares cross hatched.

INTRODUCTION (1)

Winter sea surface temperatures (SSTs) during 1973 were as much as 2°C above a 12-year average in the Western Tasman Sea (Rochford 1981). In that study no consideration was given to the surface salinity changes associated with this event, nor was it possible on SST evidence alone to establish the ultimate cause of this warming event.

In the interim, however, it has been shown (Donguy and Henin 1974, 1978; Donguy *et al.* 1974) that in the Coral Sea and adjoining equatorial region, surface salinity is a much more precise identifier than SST of the various kinds of water carried within the currents of this region; changes in surface salinity of the Coral and Tasman Seas between 1966 and 1977 could, therefore, provide more specific evidence of oceanographic connections within the southwest Pacific Ocean than can SSTs alone. This possibility is examined in this paper.

During 1972-73, large, unusual changes in the surface salinity and wind patterns south of the equator in the western equatorial Pacific were reported (Donguy and Henin 1976). The major, quite rapid, changes in the surface salinity patterns of the Coral and Tasman Seas that occurred between 1971 and 1973 may be linked to these major changes further to the north. By using surface salinity in addition to SST it is hoped to develop a better understanding of any oceanographic connection between these two unusual but geographically separated events.

DATA AND METHODOLOGY (2)

The SSTs and salinities of the Coral and Tasman Seas were collected by the CSIRO Ships of Opportunity Programme (SOOP) (Piip 1974). These data have been deposited with World Data Center A in Washington, USA.

Most of these SOOP data have been collected along shipping routes out of Sydney, leaving large areas of the Coral and Tasman Seas unsampled (Fig. 1). Even along these routes, sampling has been irregular, with monthly or even yearly gaps in the records. Accordingly, only those 1° squares with data for most months and years between 1966 and 1977 have been used in this report. As a result, values from only 15% of the total 1° squares within the Coral and Tasman Seas could be used.

From early 1978 until 1983, SOOP participation declined, but at present is being rebuilt. For the most part, therefore, no SOOP data are available after 1977 for time series examination.

The mean annual values of SST and salinity are calculated within the selected 1° squares of latitude and longitude, and annual anomalies are then calculated as the difference between this mean value and the mean of all annual values between 1966 and 1977. These annual anomalies will be used in this report.

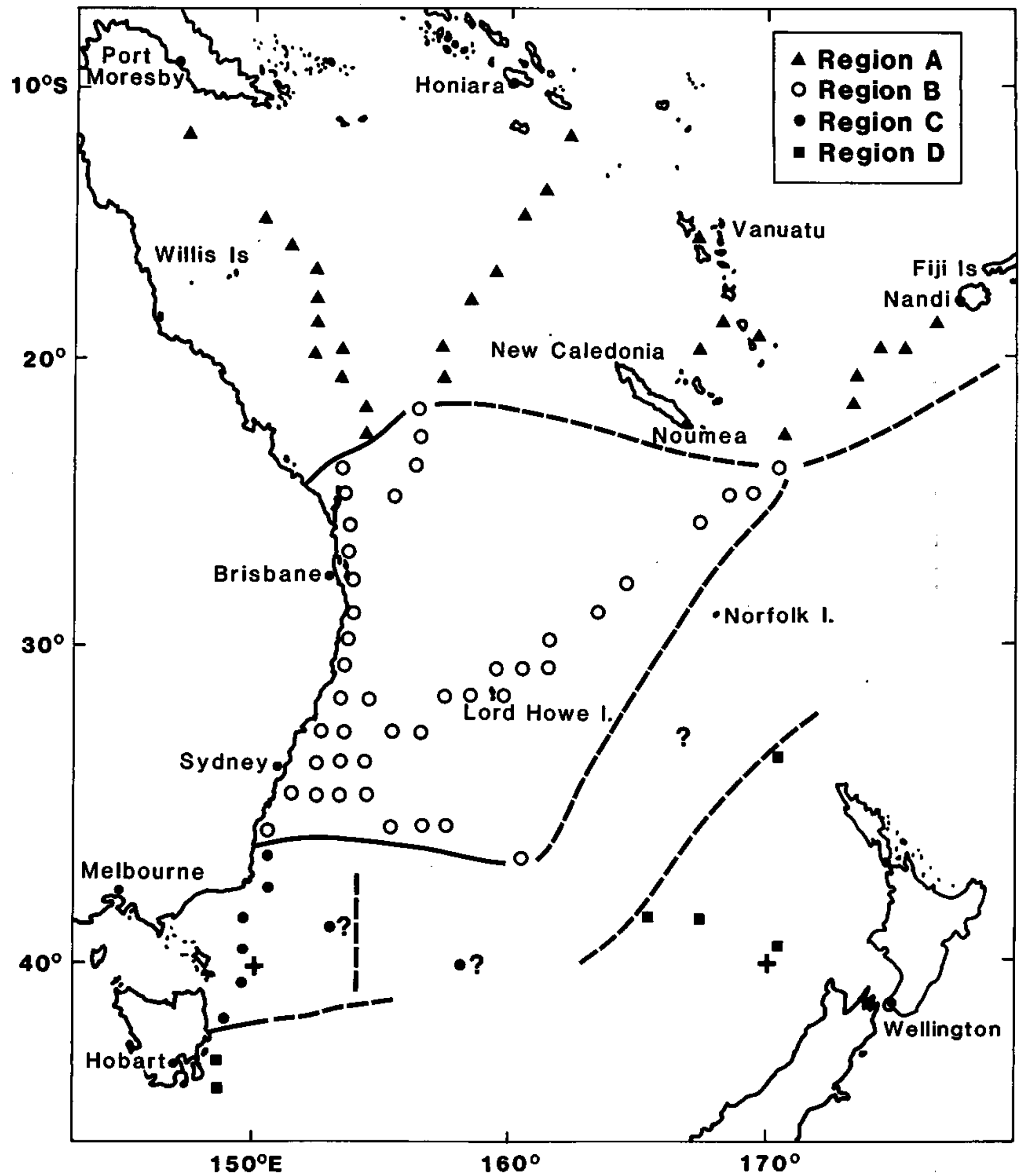


Figure 2 Chart showing the approximate boundaries of the four regions, based upon the characteristics of their interannual changes in SST and surface salinity. The positions of the 1° squares used to delineate these boundaries are shown as follows:

Region A	(▲)
Region B	(○)
Region C	(●)
Region D	(■)

RESULTS

[a] Types of Interannual Changes

The interannual changes in SST and surface salinity of the Coral and Tasman Seas are classifiable into four types, which are located in four geographically separate regions.

Region A (Fig. 2)

Within the Coral Sea between 10° and 20°S, large, fluctuating changes in the mean annual salinity occurred from one year to the next (Figs 3, 4 and 5 are representative). SSTs on the other hand, changed very little from year to year. There was little or no evidence of a consistent trend in either surface salinity or SST during 1966 to 1977. In the extreme east of this region, however, SSTs did increase between 1966 and 1975 (Fig. 5).

Region B (Fig. 2)

Within the Tasman Sea between 20° and 36°S, and especially in the western half, the year by year changes exhibited a trend towards lower salinities and higher SSTs, with major oscillations about this trend between 1972 and 1974 (Figs 6 to 9 are representative).

Region C (Fig. 2)

This region lies east of Bass Strait. Around its southern limit, both surface salinities and SSTs have, if anything, shown a trend towards lower values between 1967 and 1975 (Fig. 10).

In the northern portion of this region, a clear trend toward lower surface salinities and SSTs was apparent between 1967 and 1971 (Fig. 11), but from then on SSTs increased and surface salinities remained below normal, in the same manner as in Region B.

Because of its location, it is likely that this region is influenced by varying inputs of Bass Strait waters for some, if not all, of the period between 1966 and 1975.

Region D (Fig. 2)

Boundaries of this region can be set only within the southeastern and southwestern Tasman Sea. SSTs and surface salinities within each of these subregions increased from 1966 to 1977, particularly off southeastern Tasmania (Figs 12 and 13 are representative).

Off southeastern Tasmania, SSTs and surface salinities have steadily increased since 1946 (Rochford 1981, Fig. 5), and the trend between 1966 and 1977 is to be seen as part of this longer-term trend. Whether this is the result of lessening influence of subantarctic waters or greater southward movement of subtropical waters cannot be determined.

In the South Island of New Zealand, air temperatures have increased since 1950 (Salinger 1982). Between 1966 and 1977 SSTs also increased off New

Zealand (Fig. 13). It is possible that these increases are causally related, either through the effect of advectively introduced warmer SSTs upon air temperatures or through a change in atmospheric conditions affecting both air and sea temperatures without advection.

In 1970-1972, surface salinities decreased to exceptionally low values throughout Regions A and B, while SSTs rose (Fig. 6). By 1973, however, these low surface salinities had changed to above-normal throughout Region A and within the periphery of Region B, while SSTs continued to increase, or remained at the high 1972 value (Fig. 6). These two salinity events, which are associated with the 1973 Tasman Sea warming event (Rochford 1981), are considered in more detail in the following parts of this section.

[b] Particular Events within Selected Years

i. The 1970-1972 Lower-Salinity, Warmer-SST Event

Figure 14 shows the distribution in time and space of the lowest annual salinity anomaly for the Coral and Tasman Seas during 1970-1972. The 1° squares available for the preparation of Fig. 14 (▲ and **O** in Fig. 2) are inadequate to indicate anything more than the very broad features of the distribution of this anomaly. Within these limitations, however, the initiation of this anomaly most probably occurred in the southeastern Coral Sea in 1971. By 1972 a low salinity anomaly of lesser magnitude was to be found throughout the western Coral Sea and much of the Tasman Sea north of 37°S. A region of especially high salinity anomaly (greater than 0.2) was found off eastern Australia between 27° and 33°S in the domain of the East Australian Current (Hamon 1965). Elsewhere in the Tasman Sea north of 37°S, salinity anomalies in 1972 were less than 0.1 below average. The region north of Lord Howe Island, which retained its low salinity anomaly into 1973, will be considered as part of the 1973 high-salinity event discussed below.

ii. The 1972-1973 Higher-Salinity, Warmer-SST Event

A swing to above-average surface salinities first occurred in 1972 in the area south of the Solomon Islands (Fig. 15), although the greatest anomalies were found off Vanuatu (New Hebrides) in 1973. In the remainder of the Coral Sea, in a relatively narrow corridor adjoining the east coast of Australia and generally in the eastern half of the Tasman Sea, surface salinities were also above average, although by less than 0.1.

At the same time, however, surface salinities were below average by as much as 0.13 in an extensive area surrounding Lord Howe Island. In this same region, SSTs were also well above average (Fig. 8), as previously noted by Rochford (1981).

VARIATIONS IN RAINFALL AND THE INTERANNUAL CHANGES IN SURFACE SALINITY (4)

The annual precipitation varies considerably from the northern Coral to the southern Tasman Seas (Rochford 1977), with precipitation greatly in excess of evaporation in the north, and evaporation in excess of precipitation in the central and southern regions. The annual salinity balance in these seas is maintained by advection of, respectively, subtropical high-salinity and tropical low-salinity waters into these two areas. The tropical waters have a higher SST than the subtropical waters (Rochford, 1977).

Interannual changes in the surface salinity of the Coral and Tasman Seas could result, therefore, either from changes in the annual precipitation input or from the advective contribution of these high- and low-salinity waters, or from a combination of the two.

The rainfall measured at only seven sites within the Coral-Tasman Seas region was considered representative of the rainfall over the adjoining open sea for the purpose of comparison with the interannual changes in surface salinity in nearby 1° squares. (Fig. 1 for locations).

At Honiara in the northern Coral Sea, rainfall variations from year to year showed only a qualitative inverse relation with interannual changes in surface salinity in five out of the eleven years (Fig. 16*a*), with 1972 as a particularly aberrant year.

At Willis Island in the western Coral Sea, rainfall variations from year to year exhibited a qualitative inverse relation with interannual changes in surface salinity in six out of the nine years (Fig. 16*b*). The exceptionally high salinity event in 1973, however, occurred in a year of normal rainfall.

At Nandi in the eastern Coral Sea, interannual changes in rainfall were qualitatively related to interannual changes in surface salinity in six out of ten years of record (Fig. 16*c*). The 1973 high-salinity year was one of increased rather than decreased rainfall, whilst the 1972 very low salinity year was one of near-normal rainfall.

The three northern sites (Figs 16*a, b, c*) (especially Honiara) lie within the monsoonal rain zone. Peak monsoonal rainfall can occur in any month between November of one year and March of the next (Pickard *et al.* 1977). Averaging by calendar years could include monsoonal rainfall that peaked early in one year and peaked also in the last months of the same year. On the other hand rainfall in the years surrounding such a year would be under-represented.

However, when November of one year to October of the next is used as the representative period for both rainfall and salinity, the relationship between rainfall and salinity anomalies at the Honiara site exhibits a direct rather than inverse correlation that is even more pronounced than before (cf Figs 16*a* and 16*d*). At the other two tropical sites, the relationship between rainfall and salinity anomalies was not significantly different when November to October, rather than a calendar year, was used. Outside the tropics, the rainfall is more evenly distributed throughout the calendar year and no significant difference in the relationship between rainfall and salinity would be expected if other than a calender year period were used.

At Brisbane, adjacent to the northwestern Tasman Sea, interannual changes in rainfall were qualitatively related to interannual changes in surface salinity in six out of twelve years (Fig. 16*e*). The high-salinity years 1967 and 1973 had above-normal rainfall; the low salinity year 1977 had below-normal rainfall.

At Lord Howe Island in the western Tasman Sea, interannual changes in rainfall were related to interannual changes in surface salinity in seven out of eleven years of record (Fig. 16*f*). The lowest salinity, recorded in 1977, occurred in a year when rainfall was well below normal.

At Norfolk Island in the central Tasman Sea, interannual changes in rainfall were inversely related to interannual changes in surface salinity only in four out of eleven years of record (Fig. 16*g*). The 1972 low salinity year was a year of below normal rainfall.

At Sydney, adjacent to the western Tasman Sea, interannual changes in rainfall were inversely related to interannual changes in surface salinity in ten out of fifteen years of record (Fig. 16*h*). This is in conformity with the finding of Hahn *et al.* (1977) that changes in salinity are inversely related to changes in rainfall at the CSIRO 100-m station off Sydney.

In summary, therefore, whilst rainfall variability contributes to the interannual variability in surface salinity of the Coral and Tasman Seas, no consistent quantitative relationship can be adduced, and in many years the changes in salinity appear to be the reverse of the expected changes in the rainfall. The exception to this is off Sydney, where a near-constant relationship between interannual changes in rainfall and salinity occurs.

Some of the discrepancies in the rainfall-salinity relationship at sites other than off Sydney may be the result of insufficient salinity data or inappropriateness of the rainfall-observing sites. Changes in evaporation rates from year to year may also contribute to these discrepancies. It is also possible that the discrepancies in this relationship at these sites are the result of increased advective inputs of high- or low-salinity waters in certain years. This possibility is examined in the discussion section.

ASSOCIATION BETWEEN INTERANNUAL VARIATIONS IN RAINFALL AND SST (5)

Priestley (1964) showed that rainfall and SST were correlated off NSW, with high-rainfall years having above-normal SSTs and vice versa. The interannual changes in these two characteristics between 1966 and 1981 off Sydney also show this correlation (Fig. 17*a*), with the especially wet year 1976 and the especially dry year 1979 at extremes of the correlation.

Off Willis Island, Nandi and Honiara, a qualitative relation between interannual changes in rainfall and SST was found for most years (Figs. 17 *b*,*c*, and *d*).

Off Lord Howe Island, Norfolk Island and Brisbane, however, half of the years did not conform to this relationship (Figs. 17*e*, *f*, and *g*). Some of these discrepancies could be due to the much smaller number of SST observations at these sites relative to the much longer, and therefore more representative, SST data set off Sydney. Moreover, the annual rainfall is based upon daily measurements throughout the year, whilst the annual SST mean is based upon irregularly spaced measurements within each month. Even with these limitations, however, four out of the seven sites examined did exhibit at least a qualitative agreement between rainfall and SST.

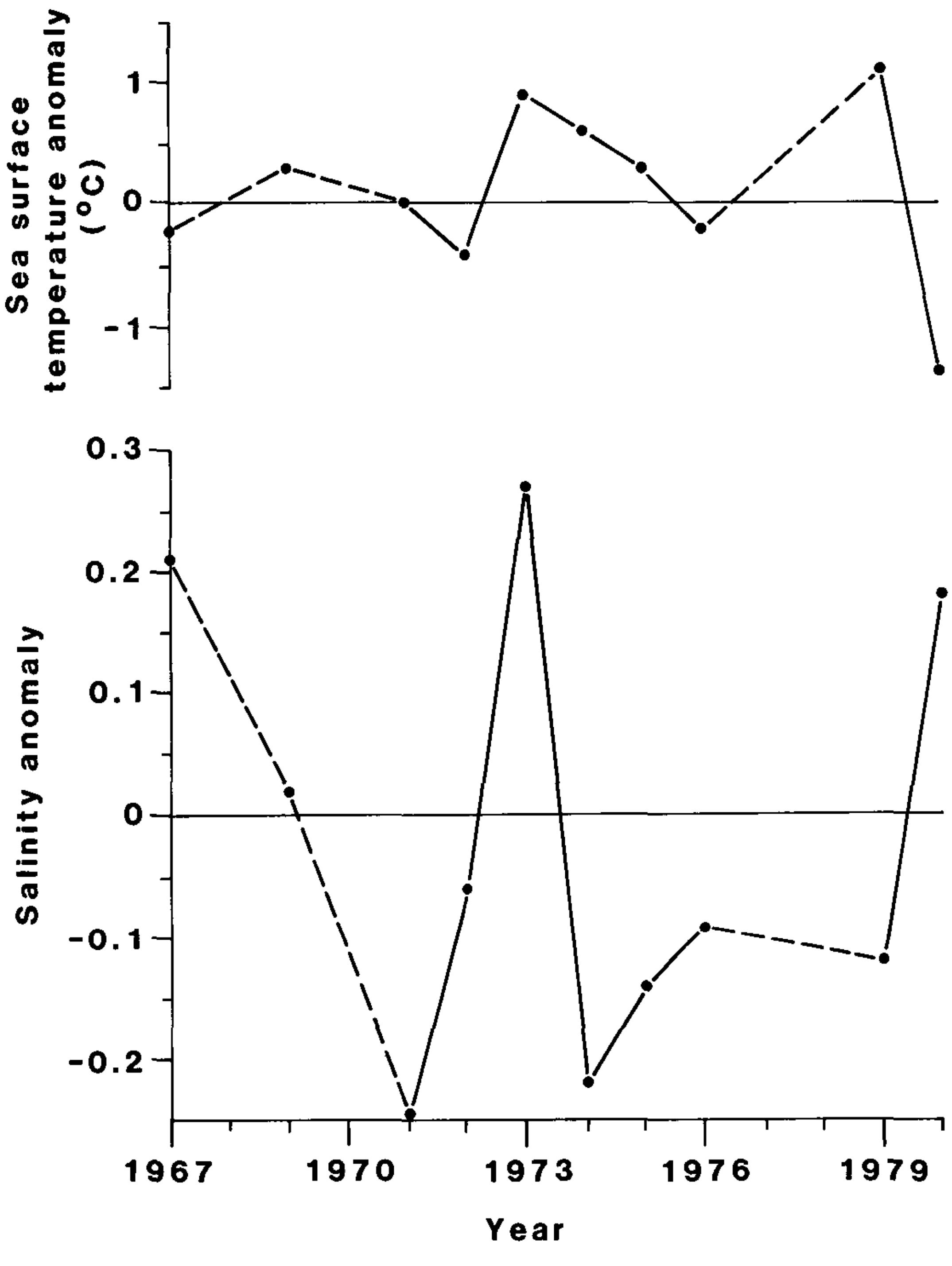


Figure 3 The interannual changes in the mean SST and surface salinity (expressed as departure from the overall mean) at a 1° square bounded by 15° - 15° 59' S and 151° - 151°59E.

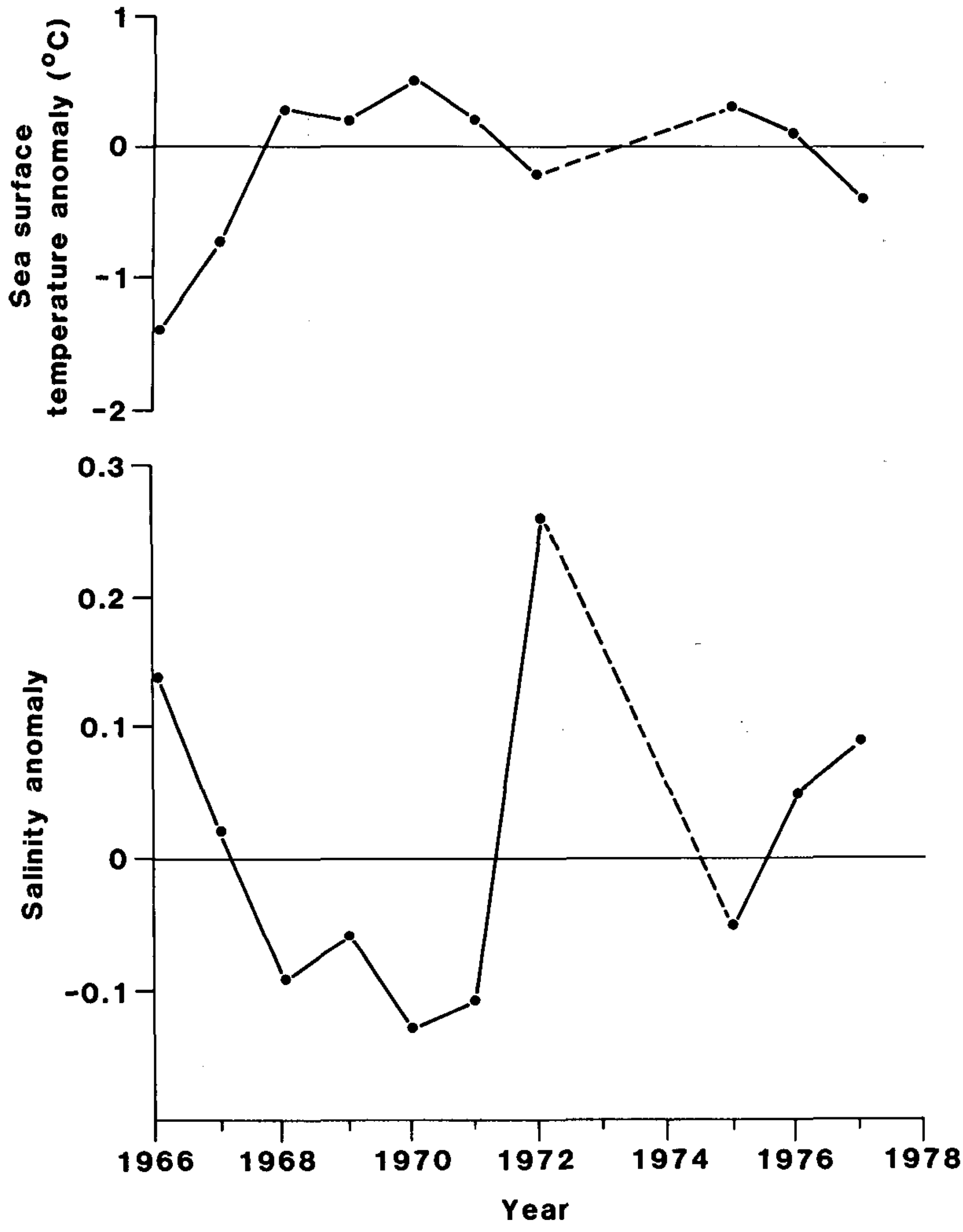


Figure 4 As for Fig 3 at a 1° square bounded by 11°-11°59'S and 162° - 162°59'E.

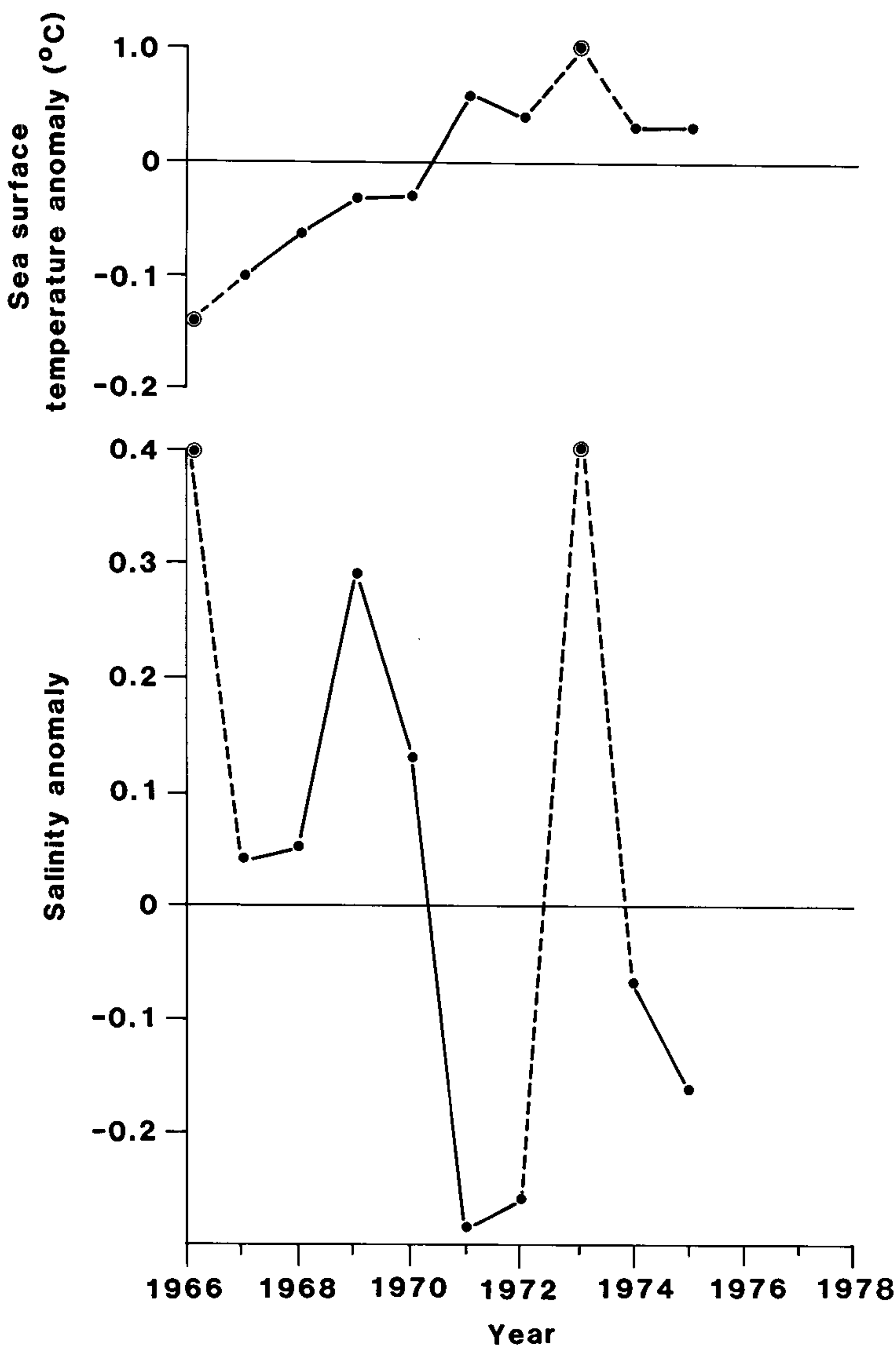


Figure 5 As for Fig 3 at a 1° square bounded by 19°-19°59'S and 175° - 175°59'E.

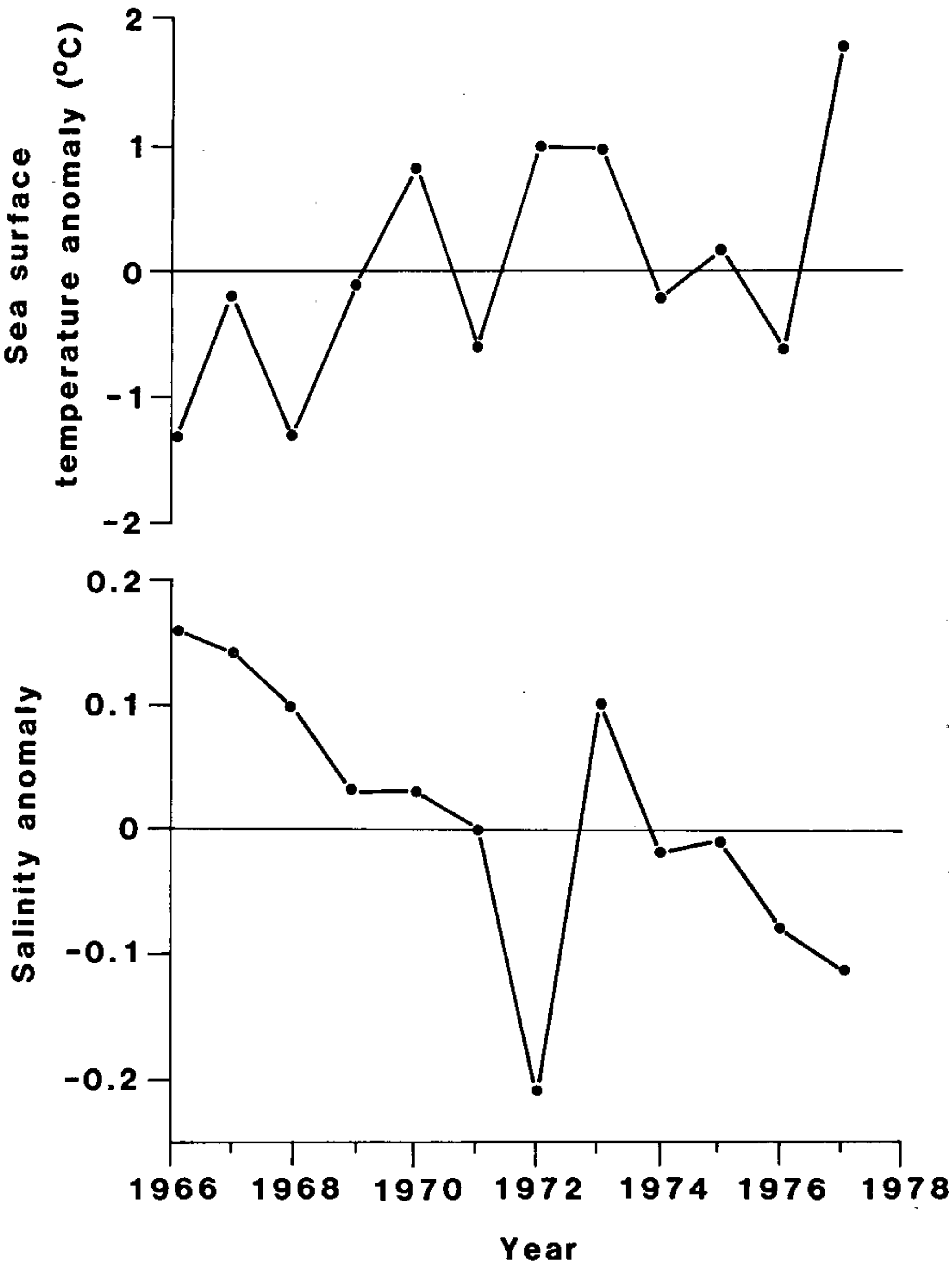


Figure 6 As for Fig 3 at a 1° square bounded by 28°-28°59'S and 153°-153°59'E.

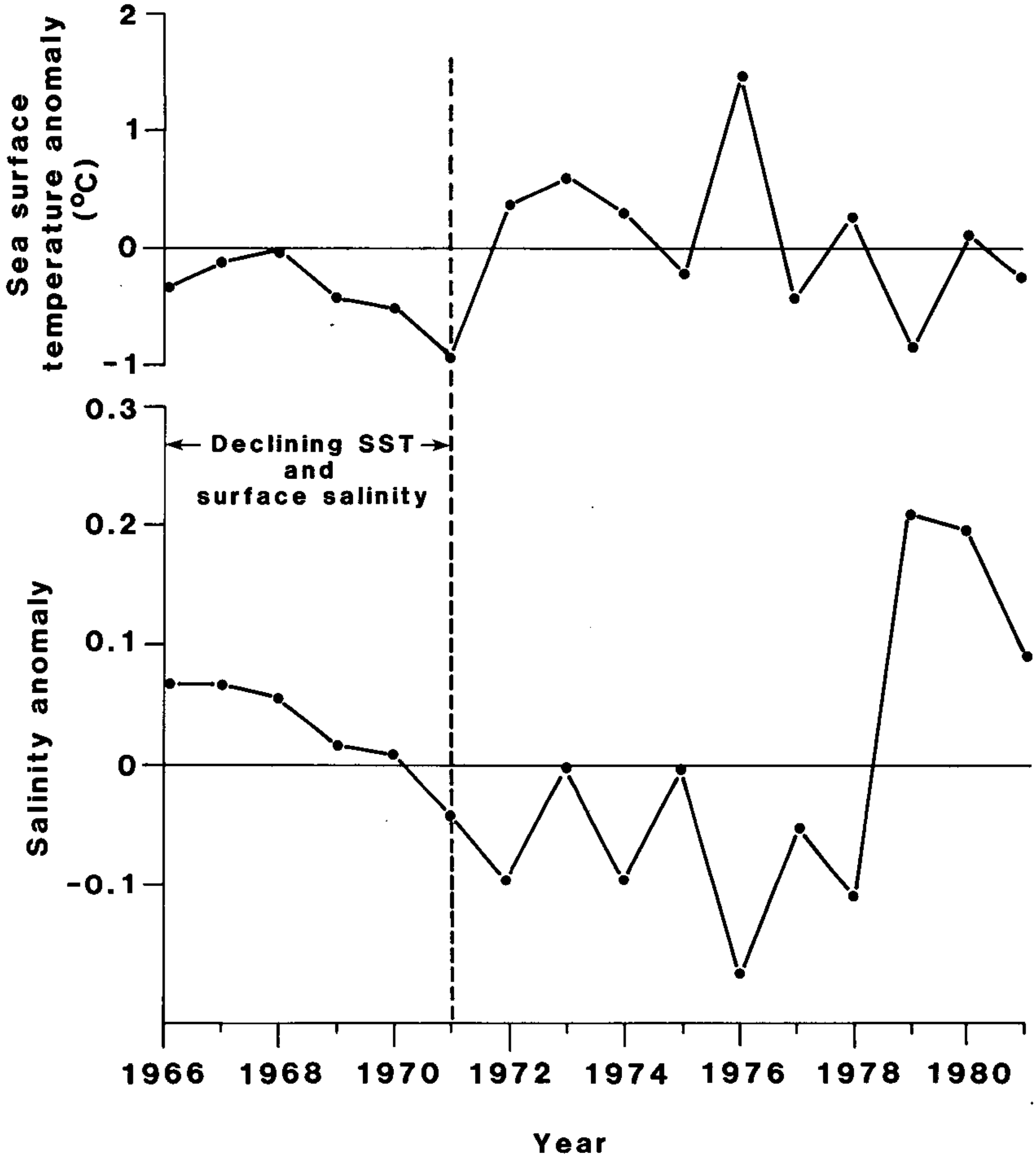


Figure 7 As for Fig 3 at a 1° square bounded by 34°-34°59'S and 151°-151°59'E.

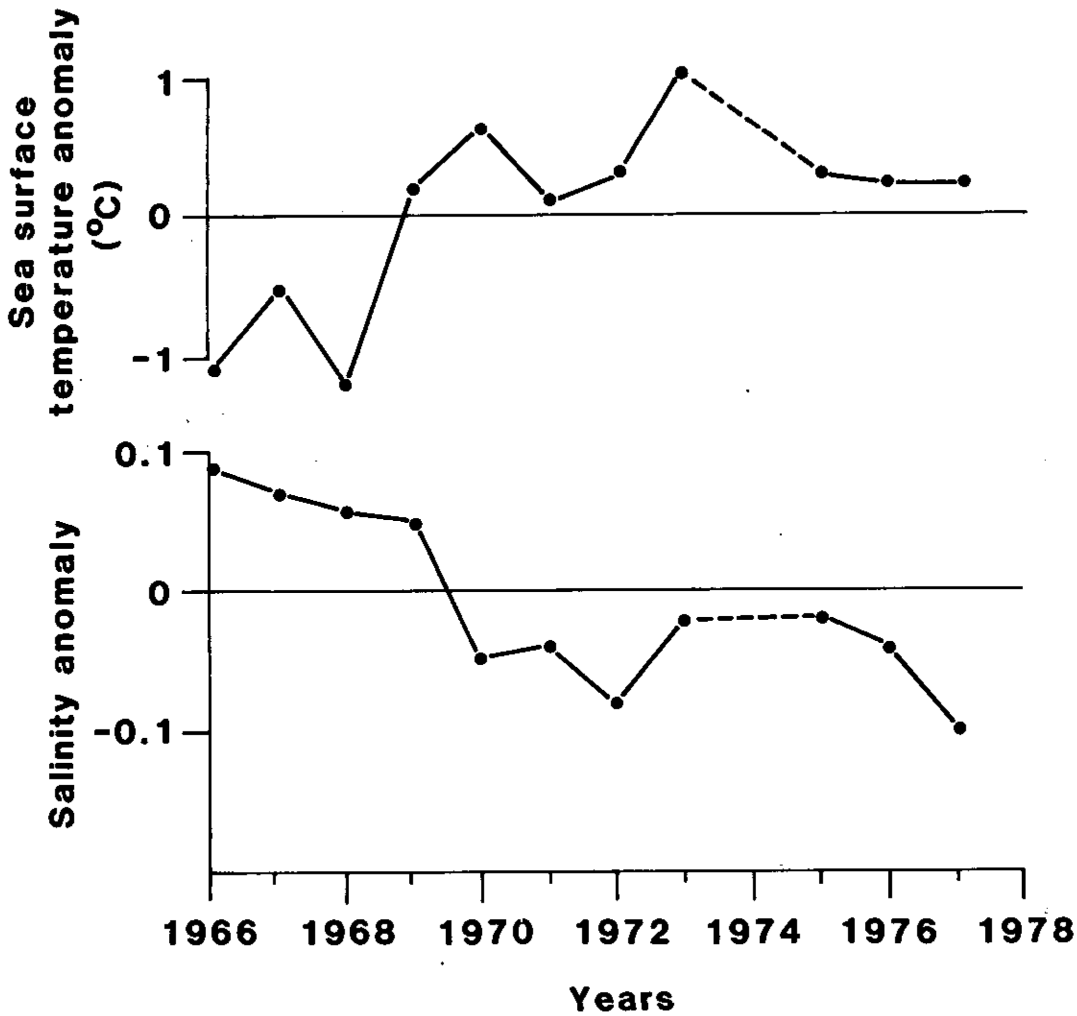


Figure 8 As for Fig 3 at a 1° square bounded by 31°-31°59'S and 158°-158°59'E.

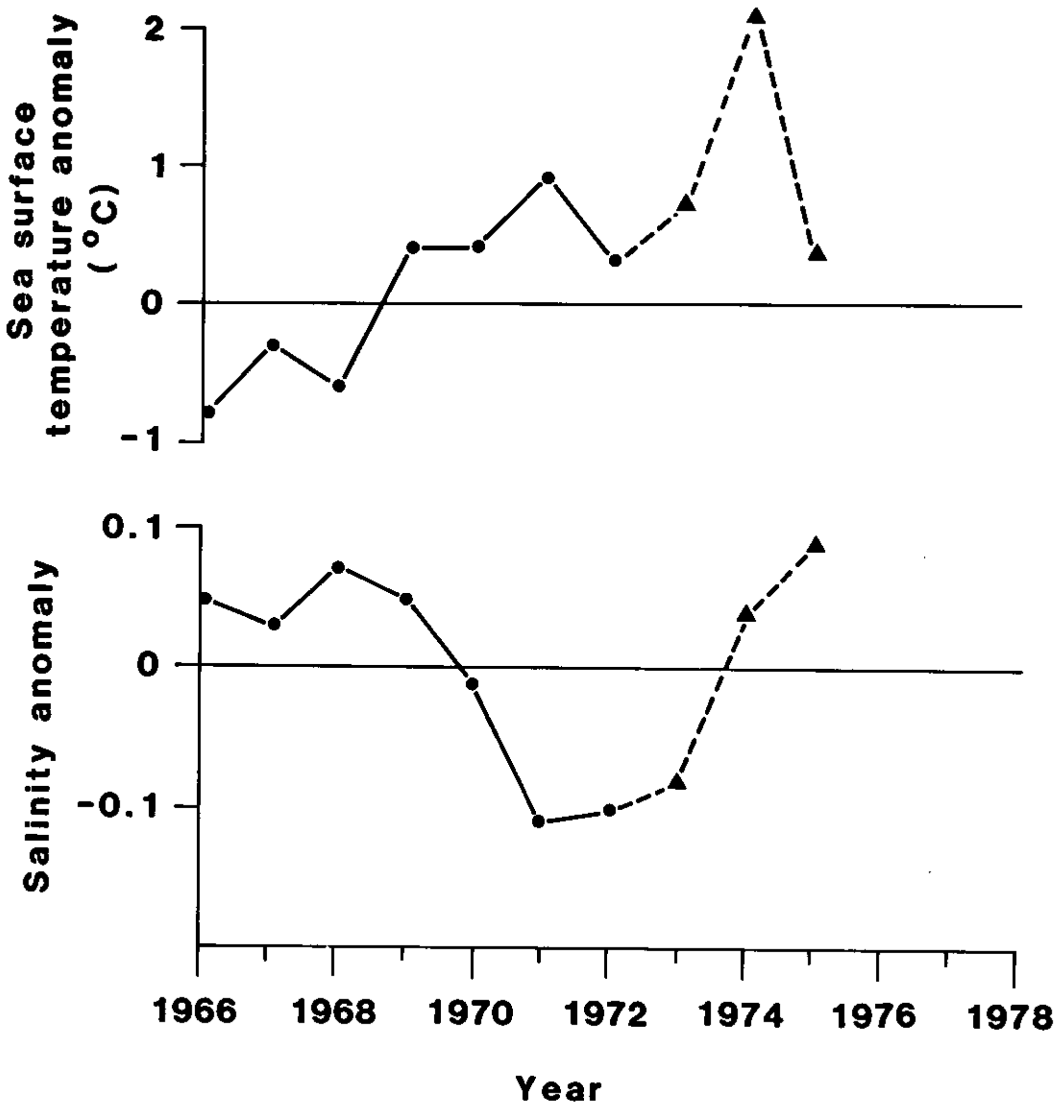


Figure 9 As for Fig 3 at a 1° square bounded by 28°-28°59'S and 163°-163°59'E. (●) 27°-27°59'S and 164°-164°59'E. (▲).

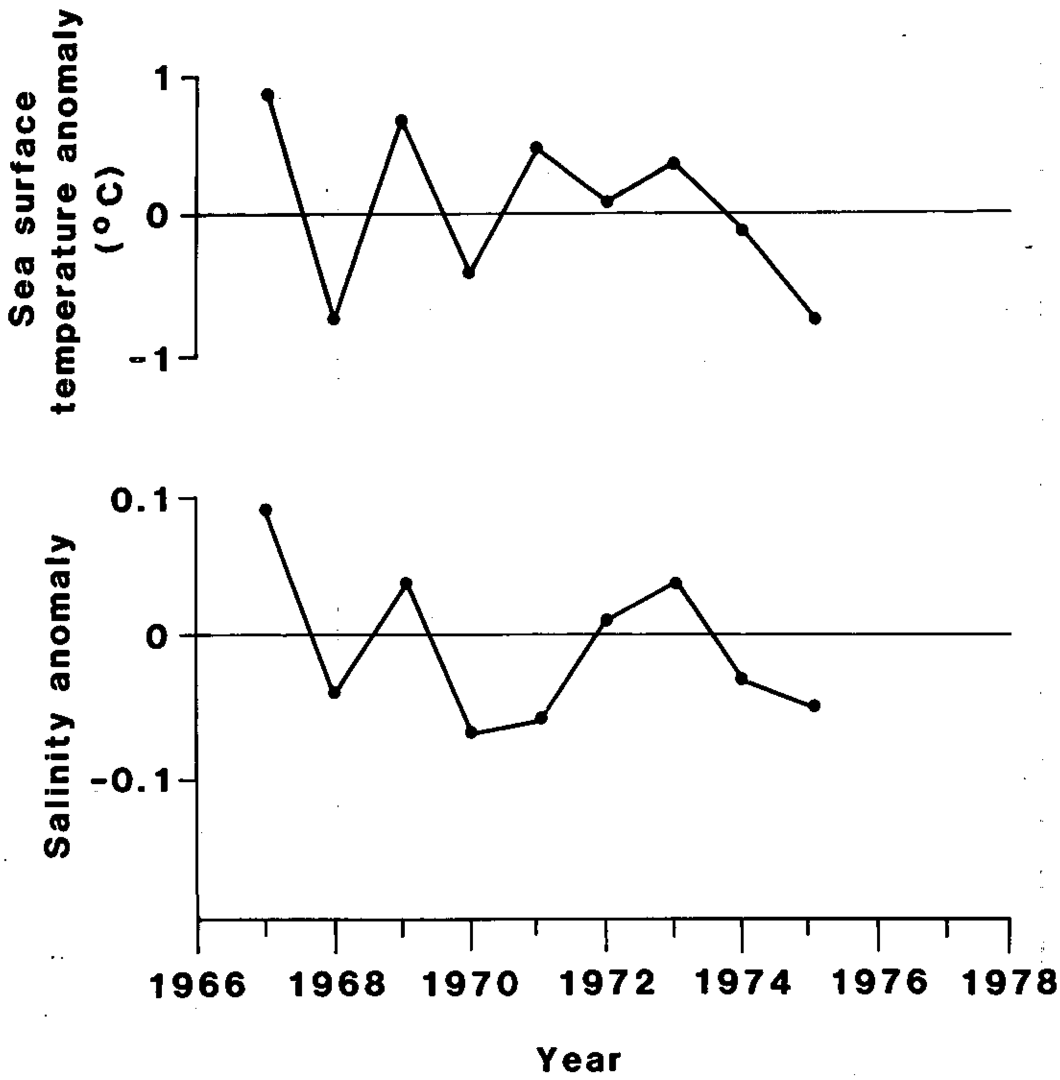


Figure 10 As for Fig 3 at a 1° square bounded by 40°-40°59'S and 149°-149°59'E.

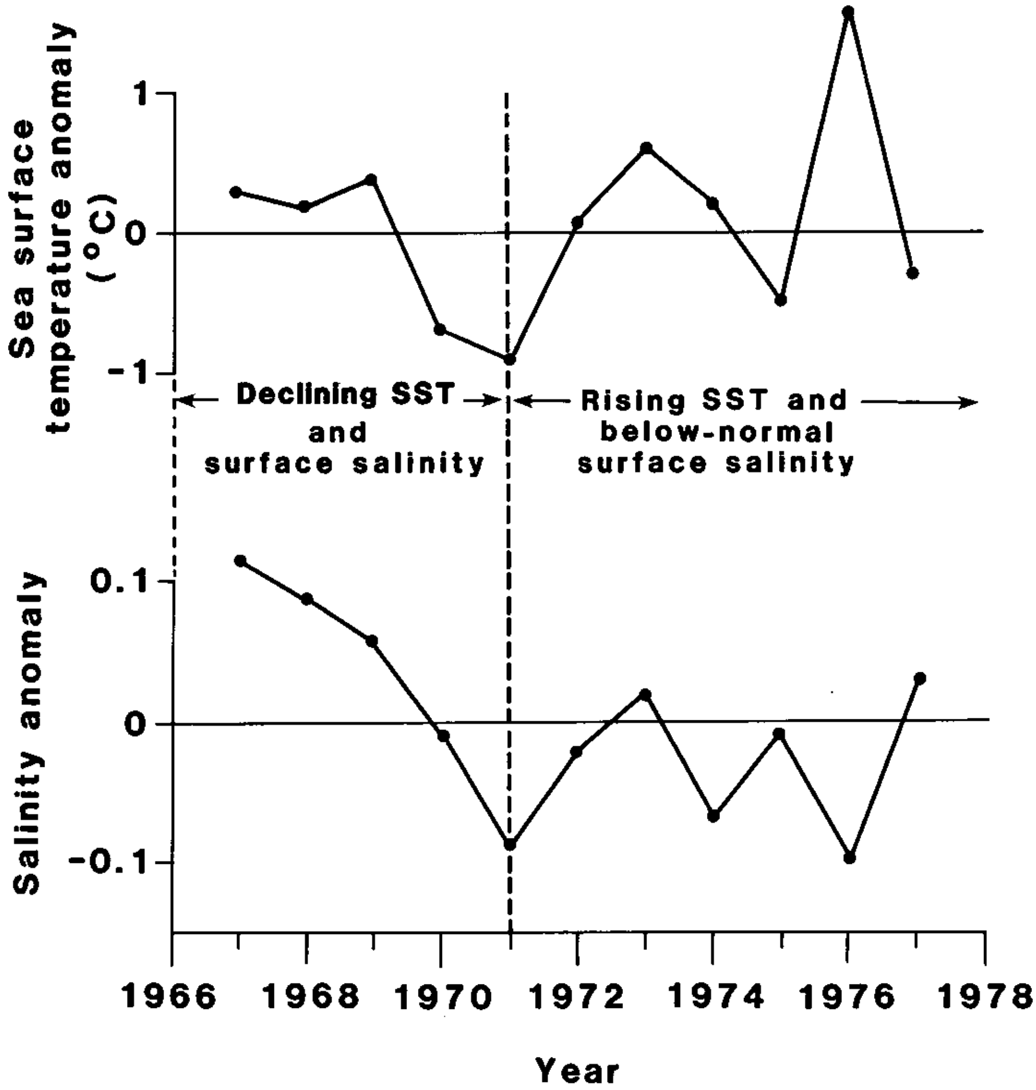


Figure 11 As for Fig 3 at a 1° square bounded by 36°-36°59'S and 150°-150°59'E.

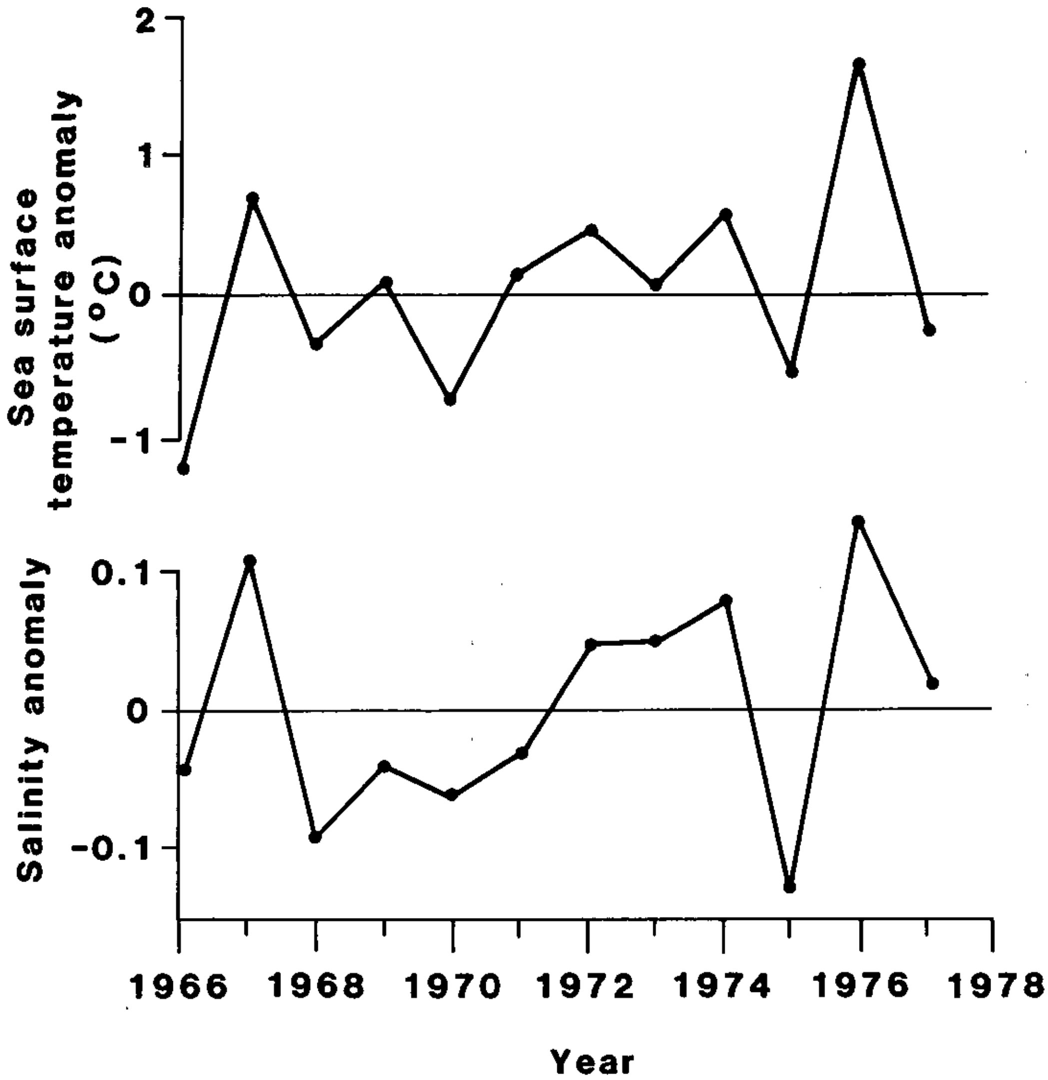


Figure 12 As for Fig 3 at a 1° square bounded by 42°-42°59'S and 148°-148°59'E.

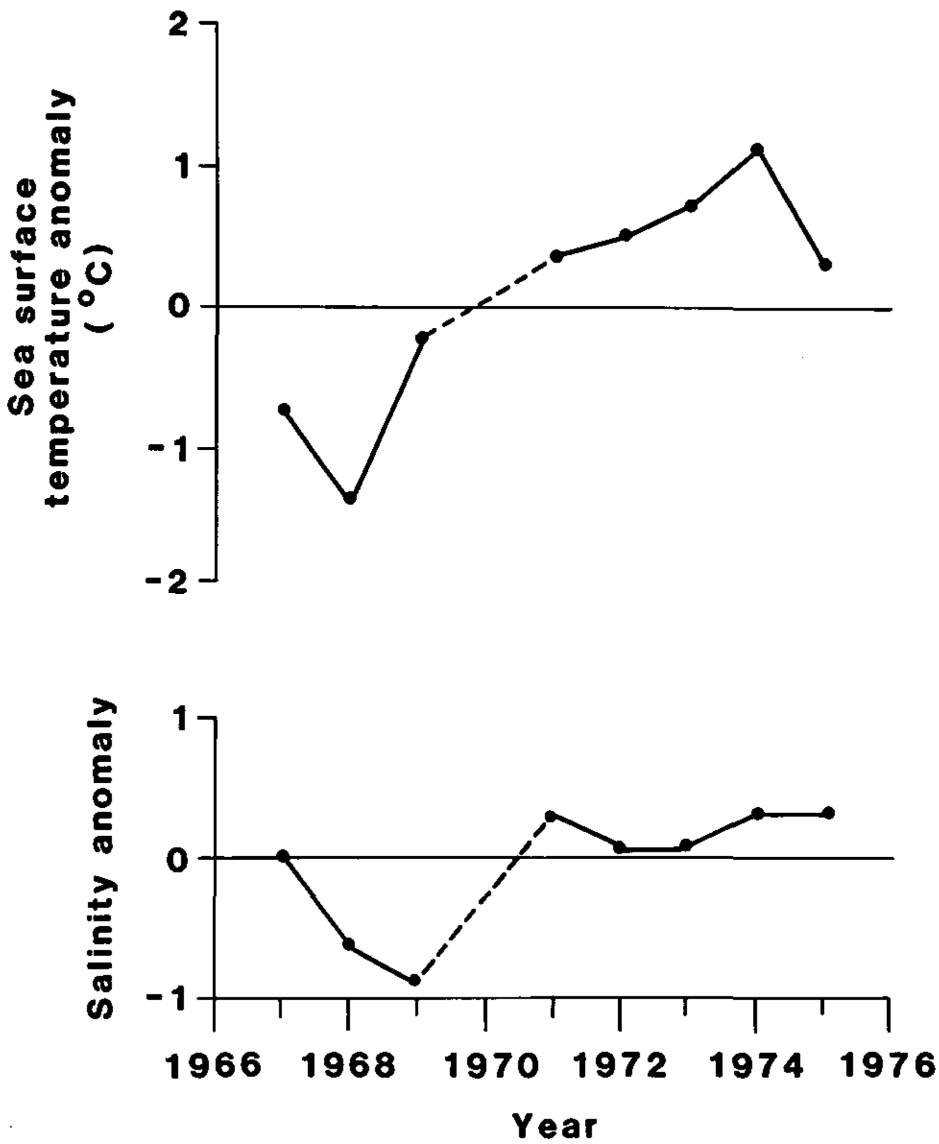


Figure 13 As for Fig 3 at a 1° square bounded by 39°-39°59'S and 170°-170°59'E.

DISCUSSION AND CONCLUSIONS (6)

[a] *Changes in Advection in Relation to Varying Rainfall Patterns*

A basic problem in trying to establish causes of the climatological changes in the surface waters of the ocean is how to separate changes due to local air-sea exchanges from those due to advection of waters with different properties to those normally present.

From the degree of conformity between changes in surface salinity and rainfall off Sydney and to a lesser extent at other sites around the Coral and Tasman Seas it must be assumed that local rainfall has played a role in the fashioning of surface salinity at these sites in most years between 1966 and 1977. It is also generally true for these sites that high and low rainfall years occur when the SST is also higher or lower than normal.

High rainfall years would, of necessity, also be years of much greater cloud coverage, in which less solar radiation reached the ocean surface. Assuming other elements of the surface heat budget remain constant, the cloudiness would create lower SST rather than the higher SST generally found in years of high rainfall. As an hypothesis, therefore, it is suggested, that years of above-normal rainfall are also years of increased advection of warmer and lower salinity waters into the Coral and Tasman Seas. This increase in SST then promotes an increase in rainfall and further lowers the surface salinity. Conversely, years of below normal rainfall are years of reduced advection of these warmer waters or of abnormal advection of colder waters.

[b] *Interannual Changes in the Surface Salinity of the Coral and Tasman Seas and their Probable Causes*

Surface salinity increases from the northern Coral Sea to around 30°-40°S in the Tasman Sea (Rochford 1977). An increase in the southward advection of warmer waters from the Coral Sea would also decrease surface salinities to below normal within the region affected by the increased advection.

Conversely, any increase in the northward advection of colder subtropical waters would increase the surface salinity within the region affected by the increased advection.

The advection patterns of the western margin of the southern Coral Sea and the Tasman Sea north of around 35°S are largely controlled by the East Australian Current (EAC). Year-to-year variations in the annual transport or in the kinds of water constituting the EAC could cause interannual changes in the surface salinity of the Tasman Sea.

The distribution pattern of the low-salinity event of 1970-72 (Section 3(b) i) is consistent with an input of lower salinity waters into the EAC in the southwest Coral Sea and their transport to the southwest off eastern Australia, and then eastward at around 35°S along the path followed by the current (Hamon 1965). The track of satellite buoy number 1640 (Cresswell and Wood 1977) in the Tasman Sea shows an anti-cyclonic movement to the north around longitude 150°E and then eastward into the region north of Lord Howe Island. Abnormally warm waters could thus ultimately accumulate in the Lord Howe Island region, which was apparently the case in the winter of 1973

(Rochford 1981). Accumulation of waters of low salinity in 1973 (Fig. 15) in this same region would also occur.

The swing to abnormally high surface salinities, still with above-normal SSTs, in the Coral Sea in 1972 and the subsequent increase in the surface salinities of the western margin of the Tasman Sea during 1973-74 (Section 3 [b] ii), also fit into a distribution pattern consistent with southward and ultimately eastward transport by the EAC of these more saline Coral Sea waters, reducing the previously below normal salinity to normal or slightly above normal values in 1973-74. However, the SSTs in these years are still above normal because of the warm SSTs associated with the above-normal surface salinities of the 1972-74 event.

If variations from year to year in the SST and surface salinity of the EAC have been the major cause of the 1966 to 1977 changes in the Tasman Sea, then the source waters of the current must have changed from the earlier below-normal SSTs and above-normal surface salinities, to above-normal SSTs and below-normal surface salinities between the years 1966 to 1972, before reverting to the 1966 condition. Donguy and Henin (1978) prepared biennial and, latterly, quarterly charts of the surface salinity pattern in the western Equatorial Pacific between 1970 and 1975. From these charts, the southern limit of equatorial waters of less than 35.0 salinity along 170°E has been derived (Fig. 18). Between 1970 and early 1972, the position of this boundary moved southward, but in late 1972 and early 1973 it shifted some 1000 km to the north. After 1973 this boundary again moved southward.

The year-by-year shift in the southern limit of these warm, lower salinity, equatorial waters to a latitude well within the eastern entry to the Coral Sea supports the previous suggestion that EAC source waters in the Coral Sea may have changed in a manner consistent with greater entry of these equatorial waters into the Coral Sea. In 1971, when this boundary along 170°E was at its southernmost position (Fig. 18), surface salinities of the northeast Coral Sea were at their minimum value for the 1966 to 1977 period (Fig. 14). A similar southward displacement of equatorial, low salinity, surface waters into the northwestern Coral Sea could also account for this abnormal low-salinity event in that region in 1971.

Data presented at a Great Barrier Reef Conference in September 1983 suggested that the EAC originates near the continental margin off Queensland at around 18°S. This is the region where any interannual changes in SST and surface salinity would have their major impact on the characteristics of the EAC waters.

Although some earlier critical years are missing from the record, it is likely that 1971 was a year of much reduced surface salinity at around 17°S (Fig. 3), with little contribution from the local rainfall (Fig. 16*b*).

It is considered likely, therefore, that some at least of the interannual changes in SST and surface salinity of the Tasman Sea between 1966 and 1977 are attributable to a long-term change in the source waters of the EAC and the transfer of these waters southward and ultimately eastward within the Tasman Sea domain of the current.

[c] The 1972-1973 warming event in the Tasman Sea

Based upon SSTs alone, the 1973 winter warming event in the Tasman Sea was seen as a progression through the Coral Sea and into the Tasman Sea of an SST anomaly first detected in the eastern Coral Sea around 1970-71 (Rochford 1981). Interannual changes in surface salinity in conjunction with changes in SST make it clear that there were two separate events: a low salinity/high temperature anomaly propagating through the Coral Sea into the Tasman Sea between 1970 and 1972, and a high salinity/high temperature anomaly propagating through the Coral Sea into the Tasman Sea between 1972 and 1973.

The sharp rise in surface salinity in 1973 was an exceptional event; it did not halt the 1966 to 1976 decline in surface salinity. However, 1973 did mark the end of the year-by-year rise in SST.

Interannual displacements to the south of the boundary between tropical low-salinity and tropical high-salinity waters along 170°E preceded these 1972-73 salinity changes in the Tasman Sea. An oceanographic mechanism to link the two events could not be established because of the lack of appropriate Coral Sea data.

Figures 14 - 18

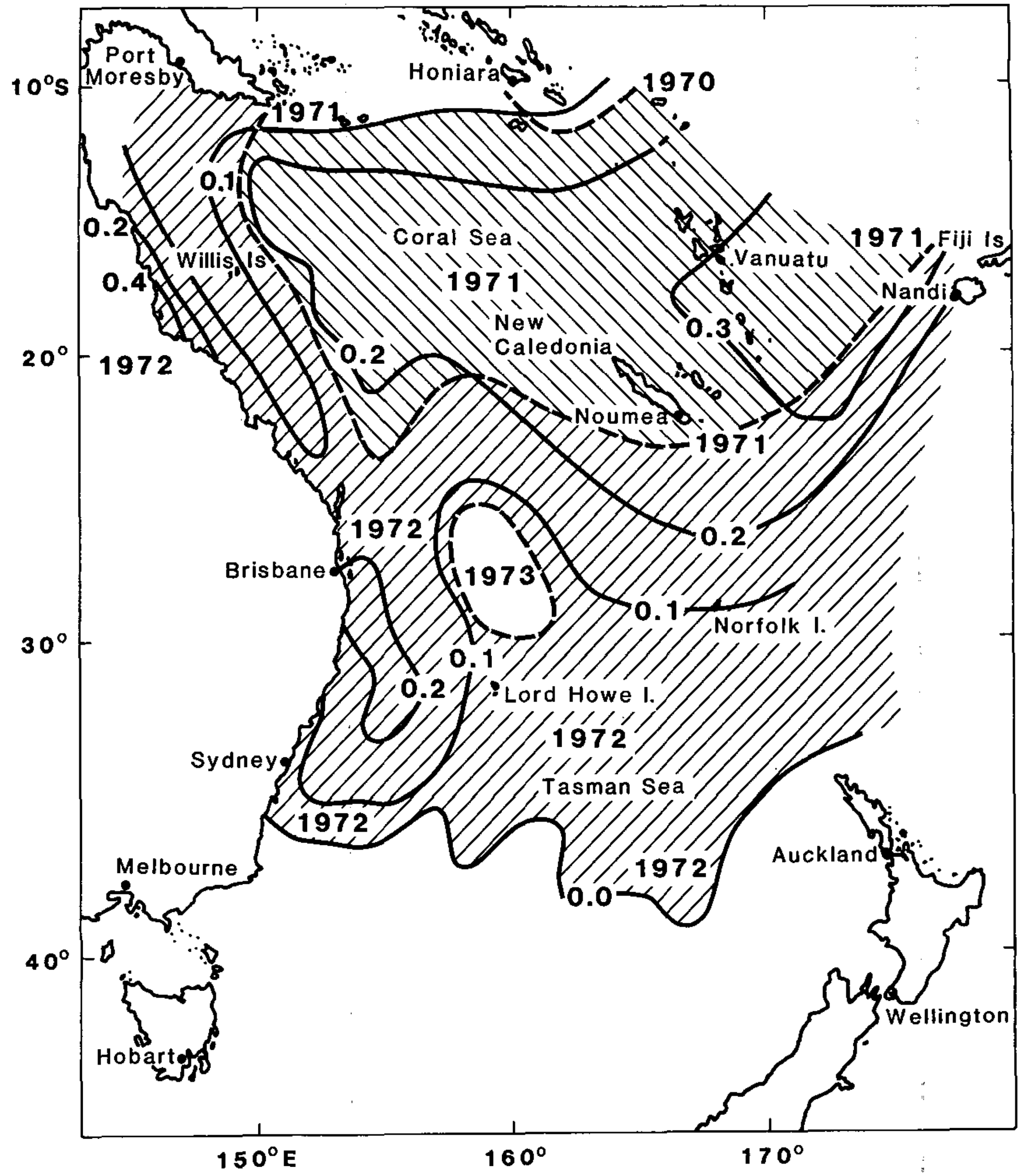


Figure 14 Contours in 0.1 salinity intervals (heavy lines) showing the distribution of the maximum surface salinity anomalies during the 1970-1972 lowered salinity event (Section 3[b]i). The year by year shift in occurrence of this anomaly is indicated by the dashed line contours.

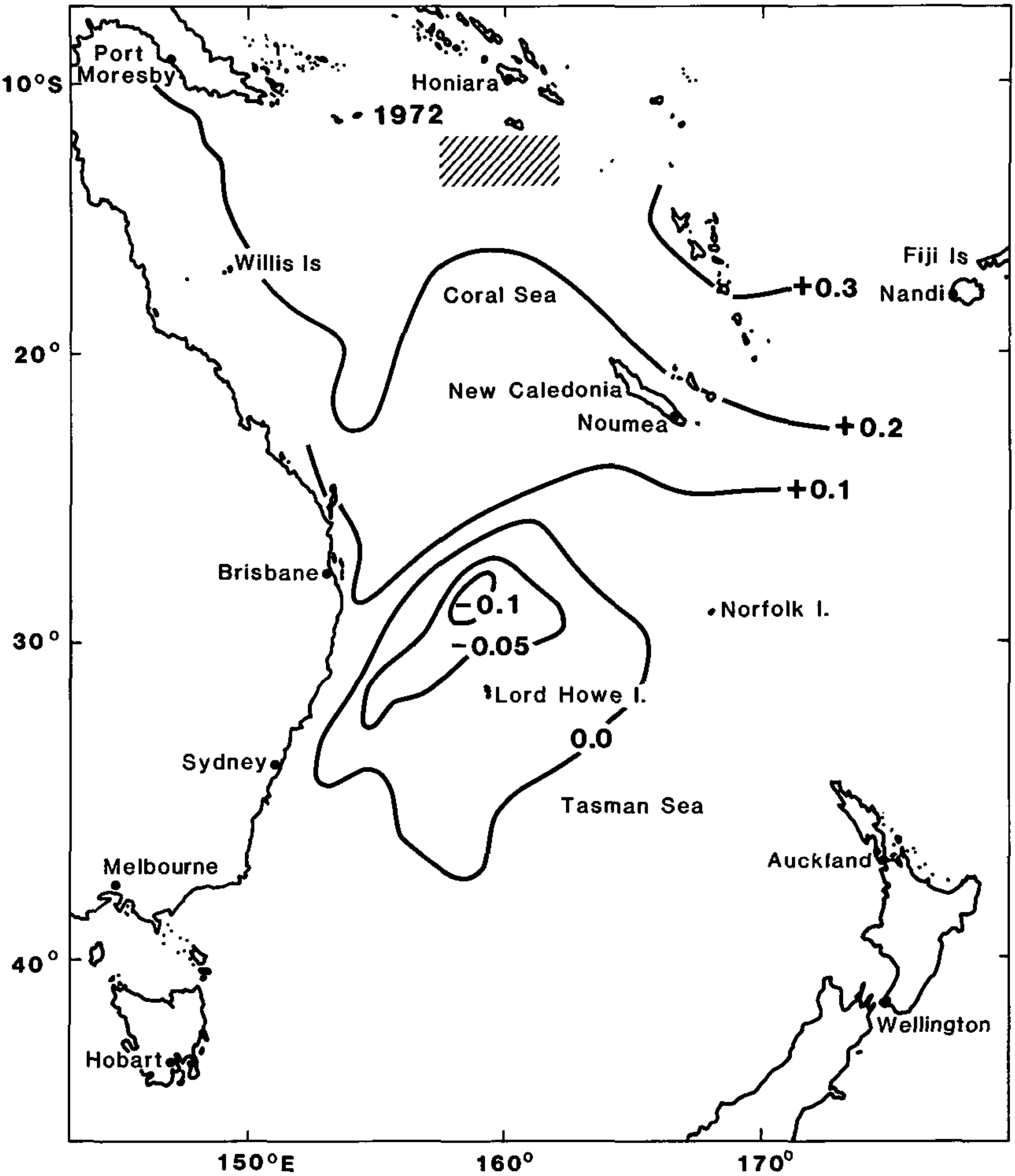


Figure 15 Contours in 0.1 salinity intervals showing the distribution of maximum above and below average surface salinity anomalies during the 1972-1973 higher salinity event (Section 3[b]ii). These anomalies occurred during 1973 except within the 1972 cross-hatched region in the northern Coral Sea.

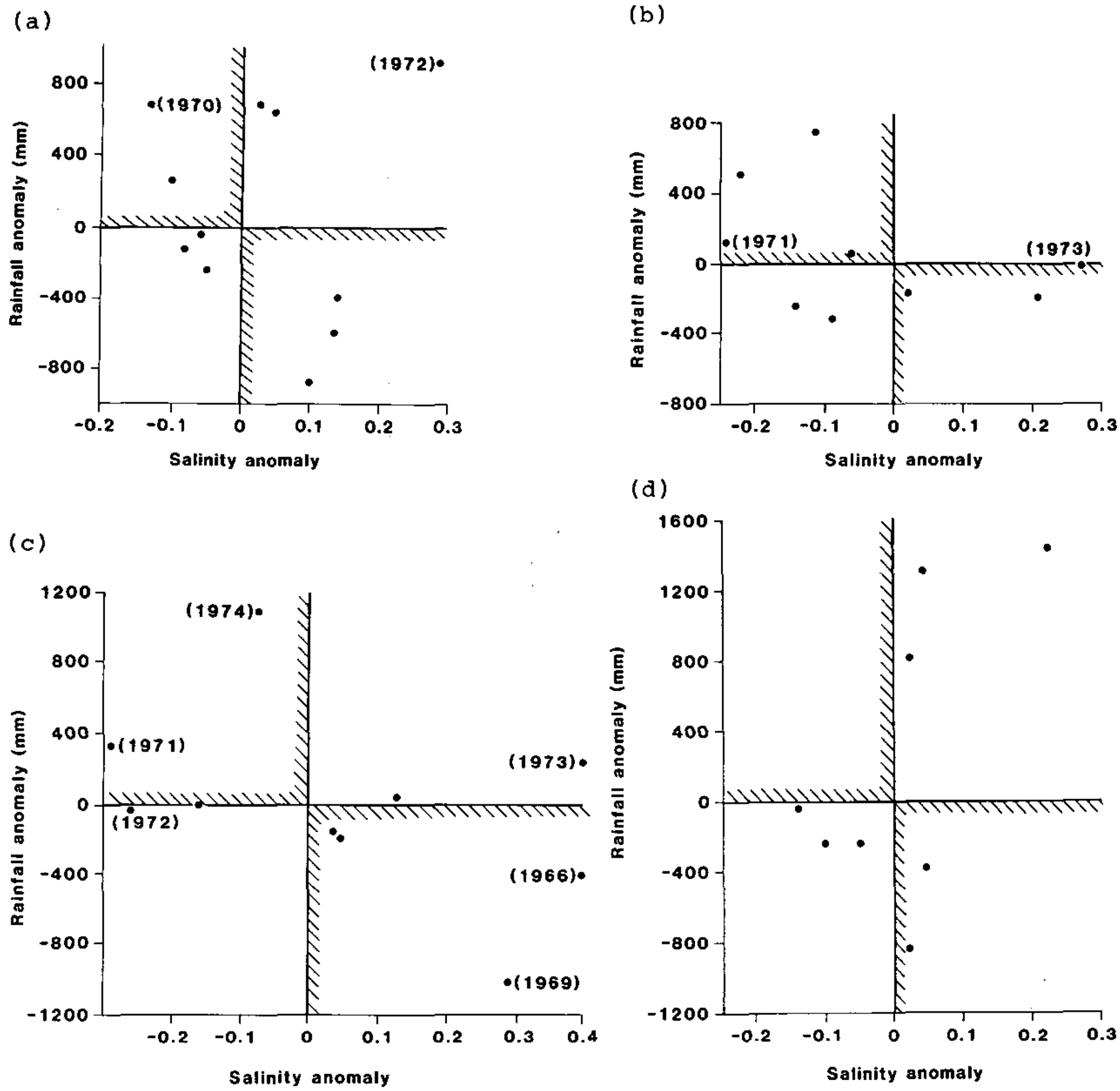


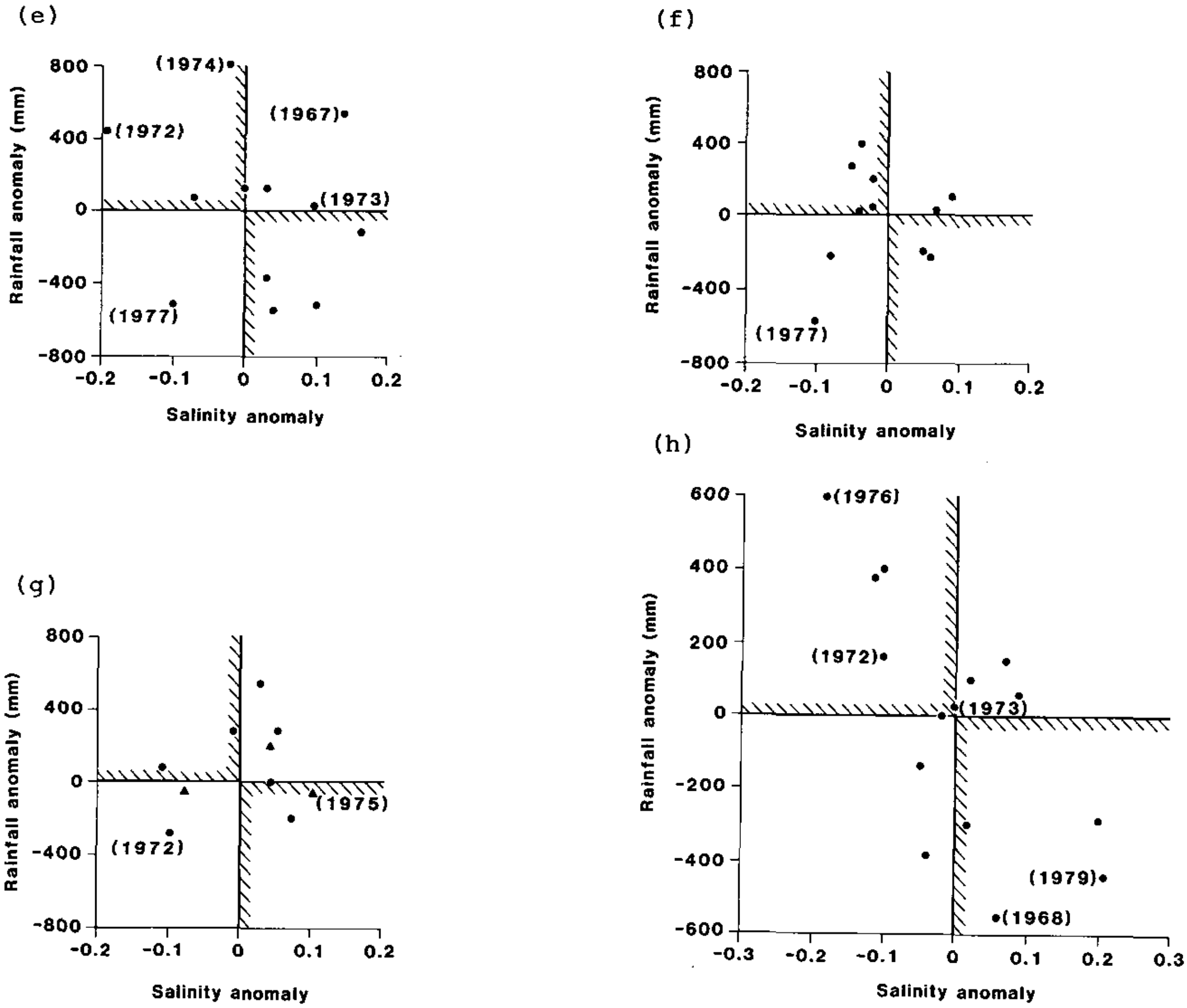
Figure 16 The relationship between departures from average in surface salinity and rainfall at the sites shown in Fig 1. Quadrants that would indicate an inverse relationship are marked (\\\\\\)

(a) Rainfall at Honiara, surface salinity in a 1° square 11°-11°59'S, 162°-162°59'E.

(b) Rainfall at Willis Island, surface salinity in a 1° square 15°-15°59'S, 151°-151°59'E.

(c) Rainfall at Nandi, surface salinity in a 1° square 19°-19°59'S, 175°-175°59'E.

(d) Rainfall at Honiara, surface salinity, in 1° square 110°-11°59'S, 162°-162°59'E., based upon November to October interval.



(e) Rainfall at Brisbane, surface salinity in a 1° square 28°-28°59'S, 153°-153°59'E.

(f) Rainfall at Lord Howe Island, surface salinity in a 1° square 31°-31°59'S, 158°-158°59'E.

(g) Rainfall at Norfolk Island, surface salinity in a 1° square 27°-27°59'S, 164°-164°59'E. (▲)
28°-28°59'S, 163°-163°59'E (●)

(h) Rainfall at Sydney, surface salinity in a 1° square 34°-34°59'S, 151°-151°59'E.

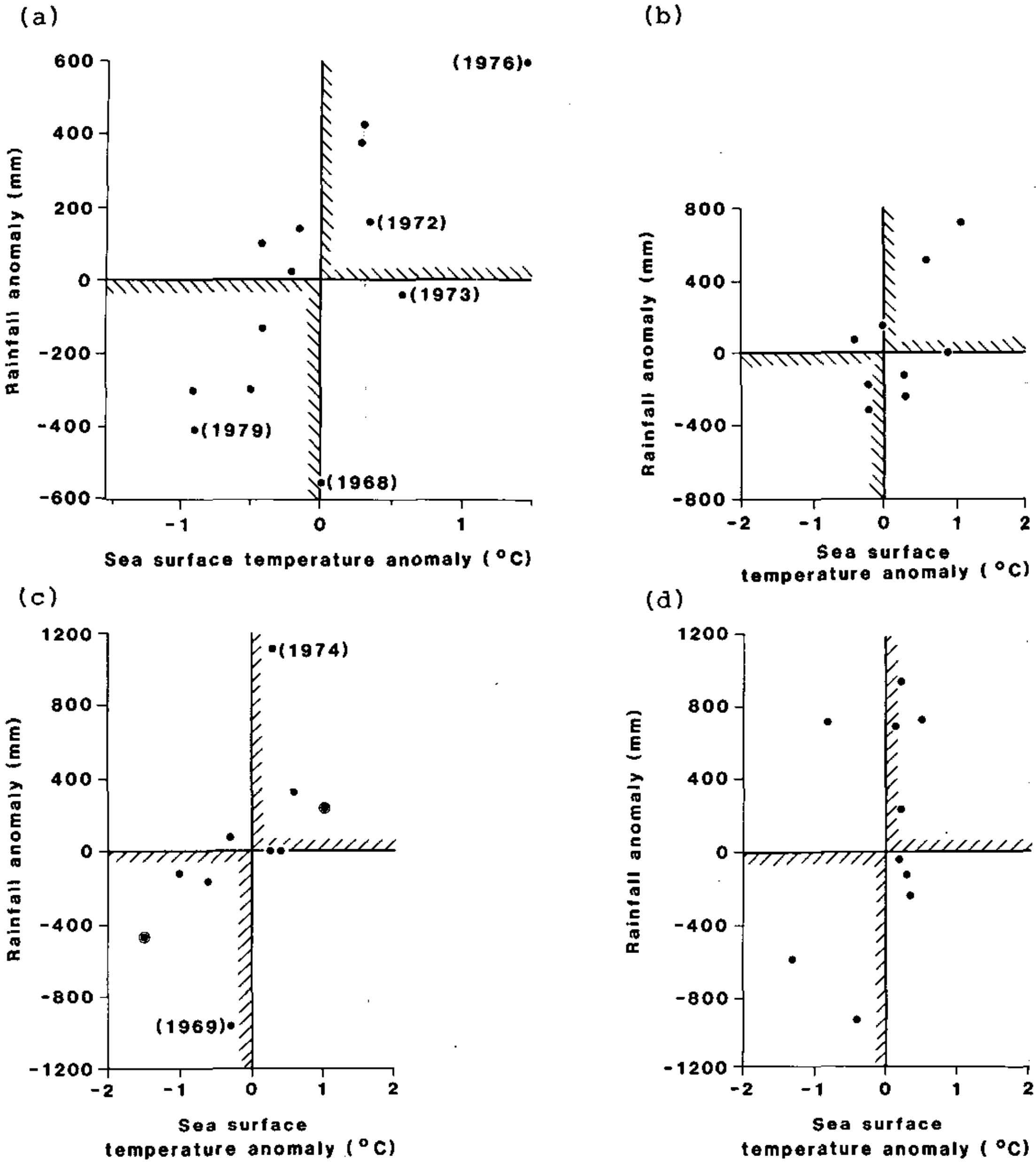


Figure 17 The relationship between departures from average in SST and rainfall at the sites shown in Fig 1. Quadrants which would indicate a direct relationship are marked (\\\\\\\)

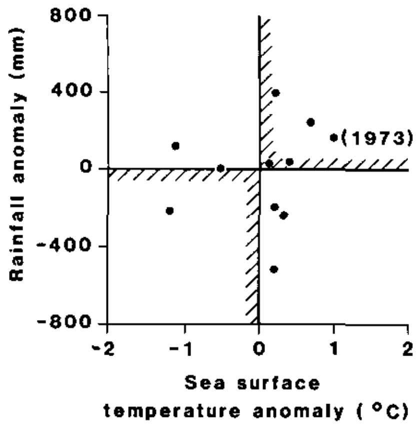
(a) Rainfall at Sydney, SST in a 1° square 34°-34°59'S, 151°-151°59'E.

(b) Rainfall at Willis Island, SST in a 1° square 15°-15°59'S, 151°-151°59'E.

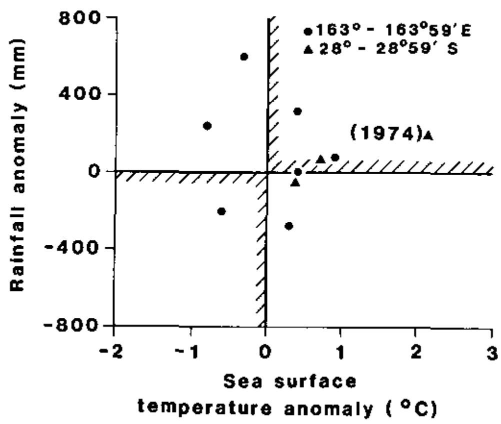
(c) Rainfall at Nandi, SST in a 1° square 19°-19°59'S, 175°-175°59'E.

(d) Rainfall at Honiara, SST in a 1° square 11°-11°59'S, 162°-162°59'E.

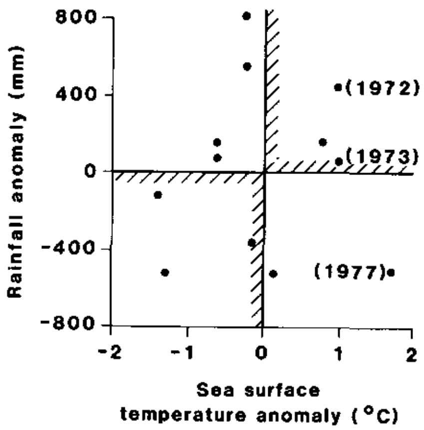
(e)



(f)



(g)



(e) Rainfall at Lord Howe Island, SST in a 1° square 31°-31°59'S, 158°-158°59'E.

(f) Rainfall at Norfolk Island, SST in a 1° squares 27°-27°59'S, 164°-164°59'E. (▲) 28°-28°59'S, 163°-163°59'E. (●)

(g) Rainfall at Brisbane, SST in a 1° square 28°-28°59'S, 153°-153°59'E.

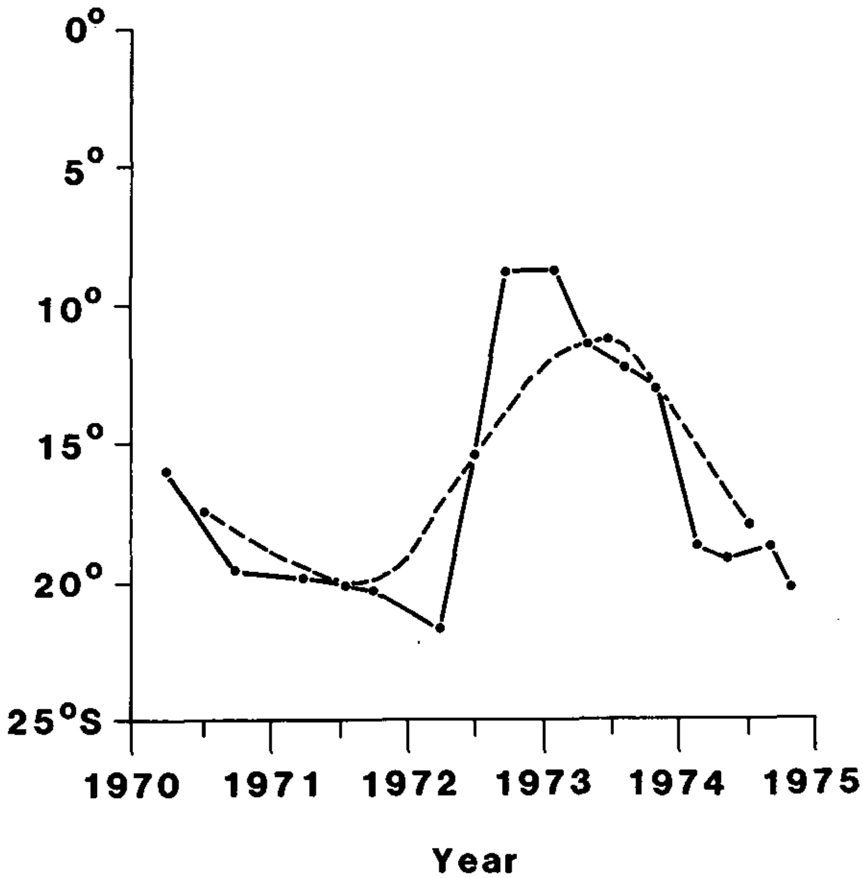


Figure 18 Year-by-year changes along 170°E in the southern boundary of equatorial waters with surface salinities of less than 35. The position of this boundary (●) has been taken from the surface salinity charts of Donguy and Henin (1978). The mean annual position is shown by the dashed line.

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