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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
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RANRL TECHNICAL NOTE No. 5/80

A COMPARISON OF SEA SURFACE TEMPERATURE MAPS COVERING THE EASTERN INDIAN OCEAN (U)

BY

A. HIRST

APPROVED FOR PUBLIC RELEASE

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1980

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The SST maps in the World Ocean Atlas, Vol. II (1977) appear to be based on the most comprehensive and recent data, hence are probably the most reliable.

POSTAL ADDRESS: The Superintendent, RAN Research Laboratory
P.O. Box 706, Darlinghurst N.S.W. 2010

DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

DOCUMENT REFERENCES

a. AR number: AR-001-506

b. Document series and number: RANRL Tech Note 5/80

c. Number of pages: 30

d. Task: NAV78/052

e. Sponsor: NAVY

f. Date: 20 May 1980

g. Release authorised by: A.J. Hunter

SECURITY CLASSIFICATION

a. Authority: P.J. MULHEARN

b. Document: UNCLASSIFIED

c. Title: UNCLASSIFIED

d. Abstract: UNCLASSIFIED

e. Reclassification: N/A

DESCRITPORS:

Sea-Surface Temperature, Climatology, Meteorological Maps

COSATI CODES:

0810
0402

TITLE:

A Comparison of Sea Surface Temperature Maps Covering the Eastern Indian Ocean.

PERSONAL AUTHORS

A. HIRST

CORPORATE AUTHORS

RAN Research Laboratory, P.O. Box 706,
DARLINGHURST. N.S.W. 2010

ANNOUNCEMENT LIMITATIONS (of data on this page).

No Limitation

SECONDARY DISTRIBUTION LIMITATIONS

AUSTRALIAN: Approved for Public Release

OVERSEAS: NO PR 1 A B C D E

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INTRODUCTION

1. In recent years, the sea surface temperature (SST) has come to be recognised as an important variable in the study of oceanic and atmospheric phenomena. In particular, departures of SST from the long term seasonal average (SST anomalies) have been associated with variations in rainfall (Shulka and Misra, 1977; Hirst and Linacre, 1978) and with changes in the behaviour or frequency of synoptic pressure systems (Wright, 1974; Wendland, 1976). Hence there exists the possibility of using SST anomalies to improve weather forecasting. Reliable maps showing the mean SST pattern for each month of the year are most useful in determining SST anomalies. Further, mean SST maps are useful in ocean heat balance studies (Kenyon, 1977) and ocean climate interaction studies (Anderson and Gossard, 1953).

2. For the above reasons, mean SST maps from three recently published atlases are compared in this report. A mean SST map has been drawn from AODC* bathythermograph data for further comparison. In order to obtain an indication of the size and areal extent of SST anomalies, monthly SST anomaly maps have been prepared for August 1963, and for August 1978.

DETAILS OF THE MEAN SST MAPS

3. The region chosen for the comparison extends from 100°E to 140°E and from 2°S to 50°S, i.e. to the west and south of Australia. Oceanographic atlases which have been published since 1955, and which include mean SST maps for individual months were sought. Three suitable atlases were found:

   a. Monthly Charts of Mean, Minimum and Maximum Sea Surface Temperature of the Indian Ocean, Naval Oceanographic Office, Washington D.C., 1967. (Abbreviated to "US Navy Atlas" in this report).

The mean SST maps of the US Navy Atlas are based on ship engine intake SST measurements taken over the period 1854 to 1961. The data were obtained exclusively from the USA, Japan and Western Europe. Average sea surface temperatures were found for each 1° x 1° square. The isotherms are at 2°F intervals.

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* Australian Oceanic Data Centre, 161 Walker Street, North Sydney.

b. World Ocean Atlas; Volume I: Pacific Ocean. USSR Navy, 1976. Abbreviated to "Pacific Atlas" in this report.

The mean SST charts of the Pacific Atlas are based on oceanographic expedition data from 1925 to 1968 and on data contained in ships' meteorological radio messages from 1950 to 1967. The Indian Ocean data were obtained principally from the USSR and Australia. Average sea surface temperatures were found for each $5^{\circ} \times 5^{\circ}$ square and the isotherms were plotted by interpolation.

c. World Ocean Atlas: Volume 2: Atlantic and Indian Ocean USSR Navy, 1977. Abbreviated to "Atlantic-Indian Atlas" in this report.

4. The mean SST charts of the Atlantic-Indian Atlas are based on oceanographic expedition data from 1875 to 1972 and ships' observations from 1900 and 1970. The Eastern Indian Ocean data were obtained from many countries, principally the USA, the USSR, Indonesia and Australia. Average SSTs were found for each $5^{\circ} \times 5^{0}$ square North of 30°S and for each $10^{\circ} \times 10^{\circ}$ square south of 30°S, for "open part of the ocean". One degree squares were used "for areas with large temperature gradients (areas of the currents)". One degree squares were probably used within a few degrees of the West Australian coast, a region which is unlikely to be classed as "open ocean". The larger squares were most likely used elsewhere in the area of study, as the data were probably sparse in most areas, and the temperature gradients are not abnormally large.

5. The density of the data that were used in preparing each mean SST map in the US Navy Atlas are indicated by shading 1° squares in which over 25 measurements have been used. The World Ocean Atlases give no indication of the density of the data.

6. Only the maps showing the mean SSTs in February and in August are compared in this report. Throughout most of the region of interest, the highest mean SST occurred in February, while the lowest mean SST occurred in August. Any discrepancies between the Atlases should be revealed by comparing the mean February SST maps and by comparing the mean August SST maps.

METHOD USED TO COMPARE MEAN SST MAPS

7. All six maps were copied from the Atlases onto Lambert conformal conic projection maps. The mean SST maps of the US Navy Atlas were converted to Celcius by linear interpolation between the 2°F isotherms. The mean February SST maps are given as figures 1a, b and c. The mean August SST maps are given as Figures 2a, b and c. Figures 1d, e and f give the difference between the mean SST shown on pairs of mean February SST maps, as do figures 2d, e and f for August. The 1°C and 2°C lines were prepared by finding the points at which isotherms crossed. The $\pm$ 0.2°C lines were estimated subjectively. Any difference within the range - 0.2°C to +0.2°C is considered negligible, and may result from errors in remapping the relevant maps.

Comparison of Mean SST Maps

8. The differences between the mean February SST from the US Navy Atlas and the mean February SST from the Pacific and the Atlantic Indian Atlases are shown in figures 1d and 1e respectively. The corresponding August differences are shown in figures 2d and 2e. The figures reveal large differences up to $\pm$ 2.0°C, over extensive areas. The largest differences are south of 40°S, where the data are sparse. Hence these differences may be mainly caused by the use of different data. In areas where the data density are higher, the difference may be partly caused by the different sizes of the averaging squares.

9. Large differences occur between the SST shown in the Pacific Atlas and the SST shown in the Atlantic-Indian Atlas for February (fig. 1f), and especially for August (fig. 2f), west of 130°E. The maps are identical over the Pacific Ocean. Hence the Pacific data used in preparing the mean SST maps in each atlas are much the same. The large differences west of 130°E may partly result from the different sizes of the averaging squares, but the much greater volume of data used in producing the Atlantic-Indian SST maps probably has caused much of the difference.

10. Figures 2e and 2f show that the mean August SSTs shown in the Atlantic Indian Atlas are in general cooler than those shown in either the Pacific Atlas or the US Navy Atlas. It is not apparent why this relatively coherent difference should occur. Climatic change cannot be the cause, or else one of the other Atlases would have its mean August SSTs affected similarly.

11. An ideal mean SST map should be based on all the reliable data gathered in the past 30 or so years. This would prevent long-past climatic conditions from influencing the mean SSTs. The Pacific Atlas thus has the best time limits on the data, however it cannot be recommended because only a small proportion of the total reliable data from this period appears to have been used. No strong indications of climatic changes are apparent when figs. 1d and 1f or 2d and 2f are compared, hence the Atlantic-Indian Atlases mean SST maps are recommended, as the data used to obtain them are more comprehensive and up to date than that used in the other atlases.

A Mean SST Map for November Prepared From Bathythermograph Data

12. A mean SST map was prepared from digitised expendable and mechanical bathermograph (BT) data obtained from AODC. The BT data were taken over the period 1956 to 1975. Meaningful mean SST maps could not be drawn for February or August, as the BT data were inadequate. Instead, a mean November SST map was drawn (fig. 3b). The ocean surface was divided into areas, whose size and placement depended on the data coverage. Only the areas in which there were at least two BT's taken in each of four or more years were used. These areas are shown in fig. 3b. The SST values, and the latitudes and longitudes of the measurements, were averaged over each November in each area. The yearly November averages were then averaged to give the mean SST, latitude and longitude for November in that area. The mean SST in each area is shown in fig. 3b and a cross is marked at the mean latitude and longitude. The first number in the upper left hand corner is the number of Novembers in which data were available. The second number is the number of BTs taken in that area. The positions of the isotherms were found by linear interpolation between adjacent crosses. The mean November SST map from the Atlantic-Indian Atlas is shown in fig. 3a, and compares very well with the BT SST map. The standard deviation of the mean BT SSTs, of the ten area, from the mean November SSTs given in the Atlantic-Indian Atlas is 0.45°C. Standard deviation from the mean November SSTs given in the Pacific Atlas and the US Navy Atlas are a little higher, i.e. 0.52°C and 0.54°C respectively.

Sea Surface Temperature Anomaly Maps

13. Figure 4a shows the SST map for August 1963. This map was

copied from the Oceanographic Atlas of the International Indian Ocean Expedition (1971). The map is based on data collected by merchant ships, from which 100 km square averages were found. Few squares contained more than four measurements, and the majority contained one or none. The eratic paths of the isotherm appear to result from this lack of data.

14. The August 1978 SST map, fig. 5a, was prepared from weekly SST maps which were derived from satellite observations of the ocean surface emission of infra-red radiation. A section of a typically weekly map is shown in fig. 5c. Sometimes the isotherms cross the coast, e.g. from Albany to the head of the Bight. The reason for this is not known. The SST was estimated from each weekly map at points separated by 2^{o} latitude along the N0, N3, N5 and N8 (N=10 to 13) lines of longitude. The four SST values at each point were then averaged to give a mean SST for the month. The standard errors of the means averaged $0.3^{o}C$ between 5^{o} and $10^{o}S$, 0.3 between 25^{o} and $30^{o}S$, and 0.5 between 45 and $50^{o}S$. Also measurements of SST by satellite can have an error of up to $1.5^{o}C$ (Bromer and others, 1976), resulting in a further error, generally less than $0.4^{o}C$ in the monthly mean SSTs (assuming random measurement error).

15. The SST anomaly is defined for this paragraph as the deviation of the monthly SST from the mean August SST, as given in the Atlantic-Indian Atlas. The SST anomaly maps were prepared by finding the points at which isotherms on the monthly SST map and isotherms on the mean SST map crossed. The August 1963 SST anomaly is shown in fig. 4b, the August SST anomaly is shown in fig. 5b. Both maps show extensive areas in which the SST anomaly was greater than 1.0 or less than -1.0. These areas have a larger scale in fig. 5b than in fig. 4b, partly because of the eratic paths of the isotherms shown in fig. 4a.

16. Unfortunately, the differences between the mean SST maps in the various atlases are of a similar size to the SST anomaly. Hence in the computation of the SST anomaly from monthly data, the mean SST maps should be used with caution. Where monthly data are available over a sufficient number of years, mean monthly SSTs should be computed, in a similar manner to the mean November BT SSTs shown in fig. 3b, and then compared with the mean SST maps given in the atlas, as a check on the atlas maps.

CONCLUSIONS

17. a. The mean SST maps in the US Navy Atlas differ from the corresponding maps in both World Ocean Atlases by up to $\pm 2.0^{\circ}C$.

b. The mean SST maps in the Pacific Atlas differ from the corresponding maps in the Atlantic-Indian Atlas in the region west from $130^{\circ}E$ by up to $\pm 2.0^{\circ}C$.

c. As the SST maps in the Atlantic-Indian Atlas appear to be based on the most comprehensive and recent data, they are probably the most reliable of the three sets.

d. A mean SST map produced from limited BT data are in surprisingly good agreement with the mean SST maps in the Atlases.

e. Anomalous SSTs occurred over large areas of the ocean during the August of 1963 and 1978, according to the SST data used. The anomaly was sometimes greater than $\pm 2.0^{\circ}C$

f. The mean SST maps in the Atlantic-Indian Atlas are recommended but they should be used with caution in the computation of SST anomalies.

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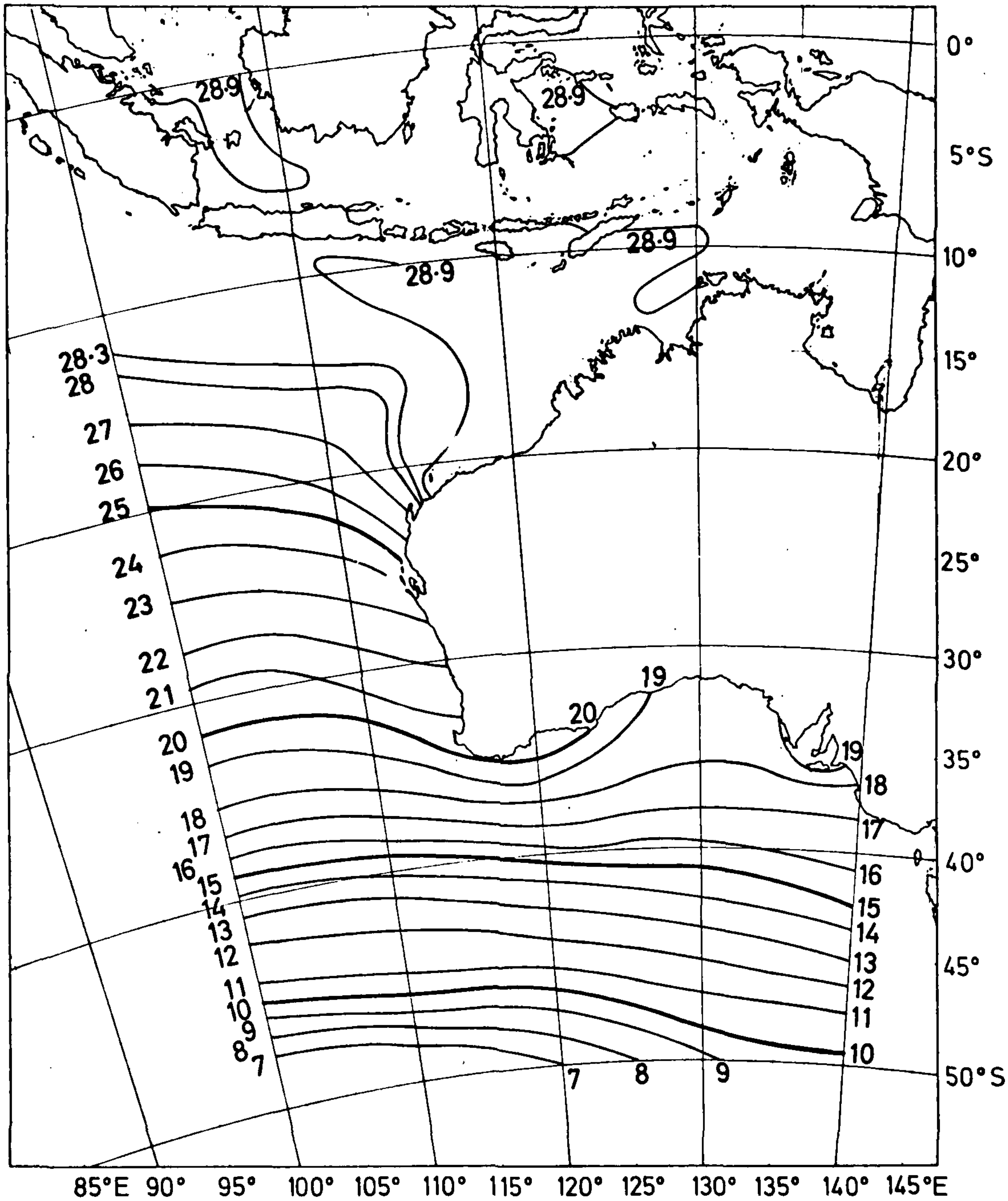

Fig. 1 (a) Mean February SST given in U.S. Navy Atlas.

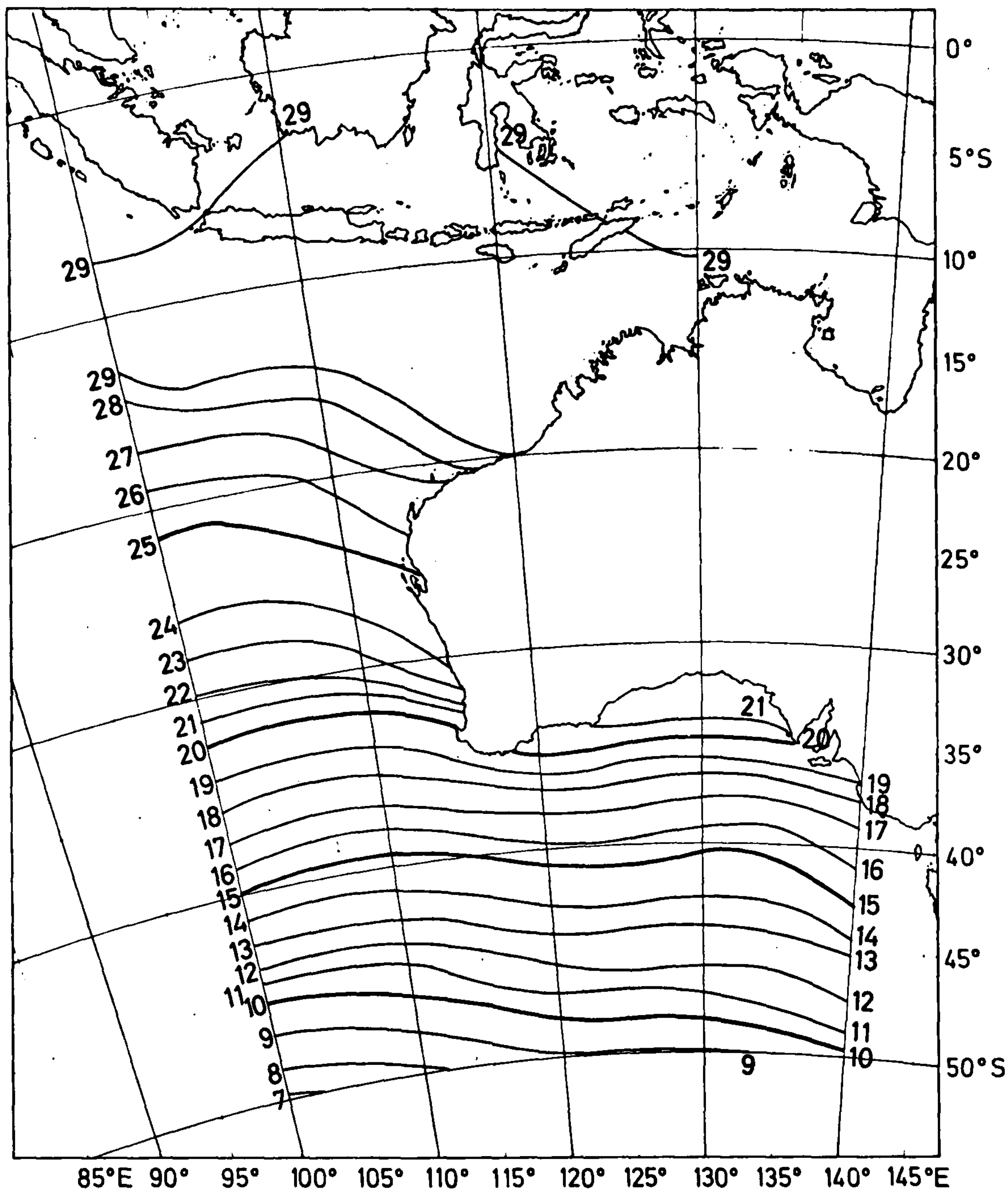

Fig. 1 (b) Mean February SST given in the Pacific Atlas.

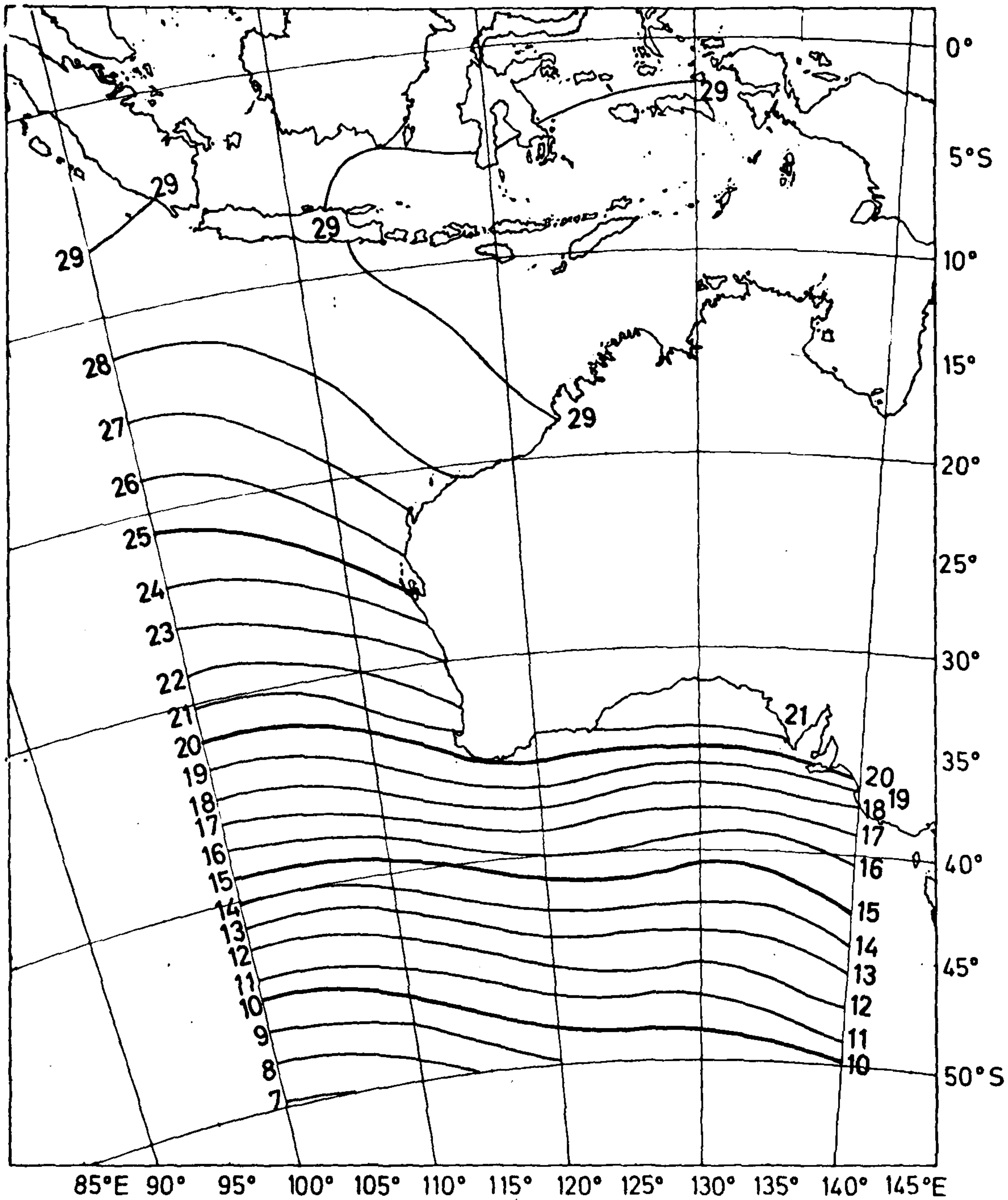

Fig. 1 (c) Mean February SST given in the Atlantic-Indian Atlas.

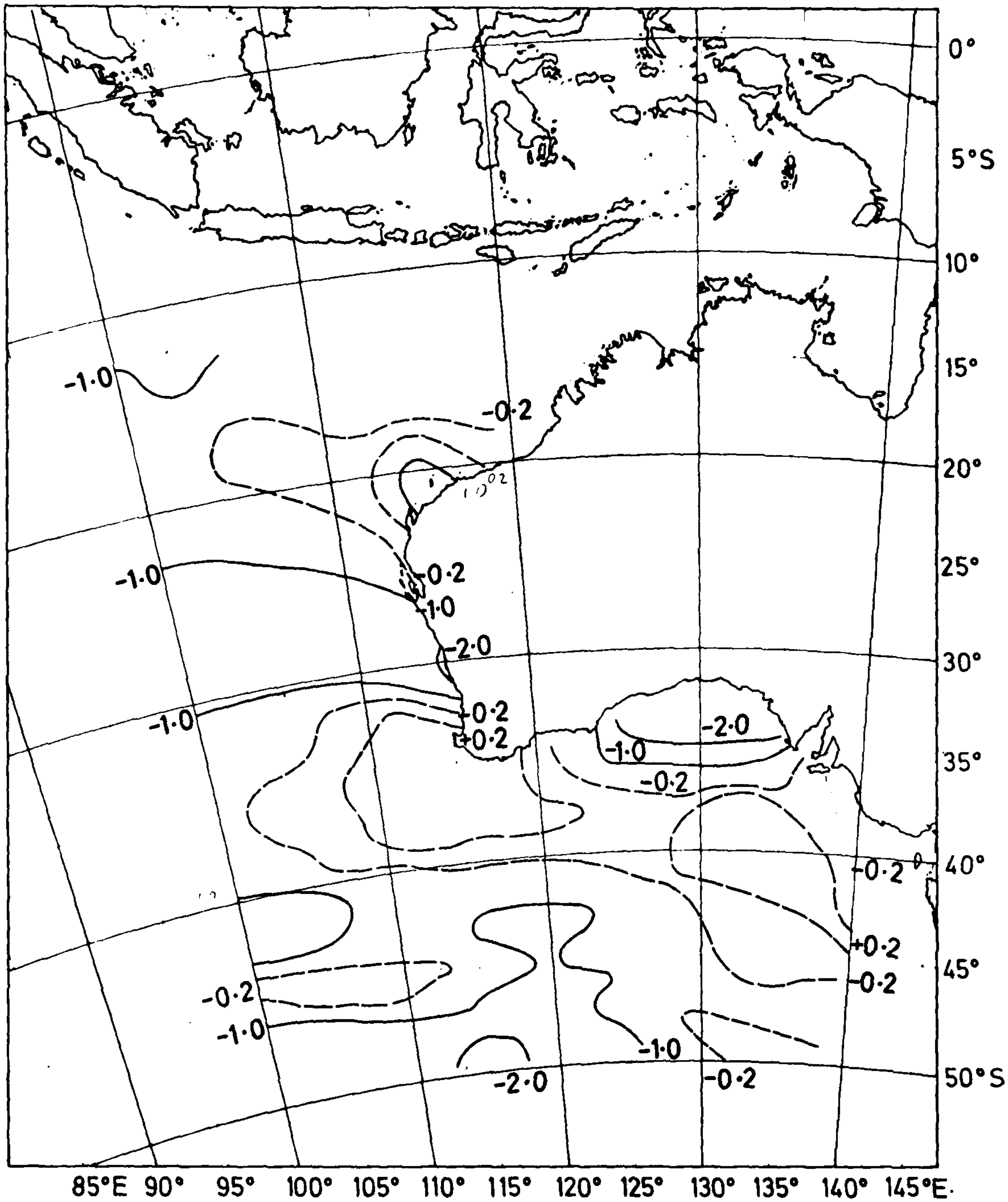

Fig. 1 (d) The deviation of the mean February SST given in the U.S. Navy Atlas from that given in the Pacific Atlas.

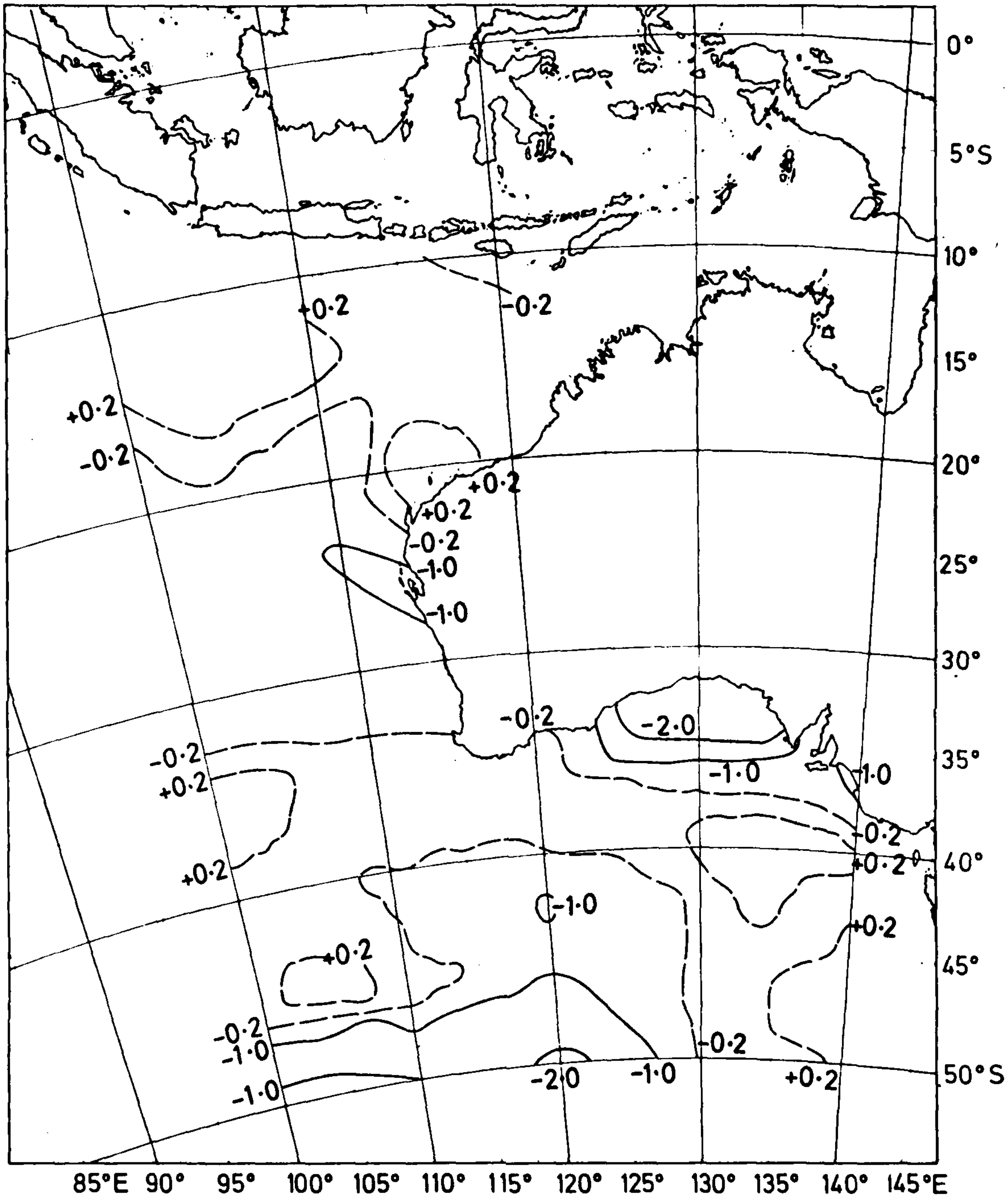

Fig. 1(e) The deviation of the mean February SST given in the U.S. Navy Atlas from that given in the Atlantic–Indian Atlas.

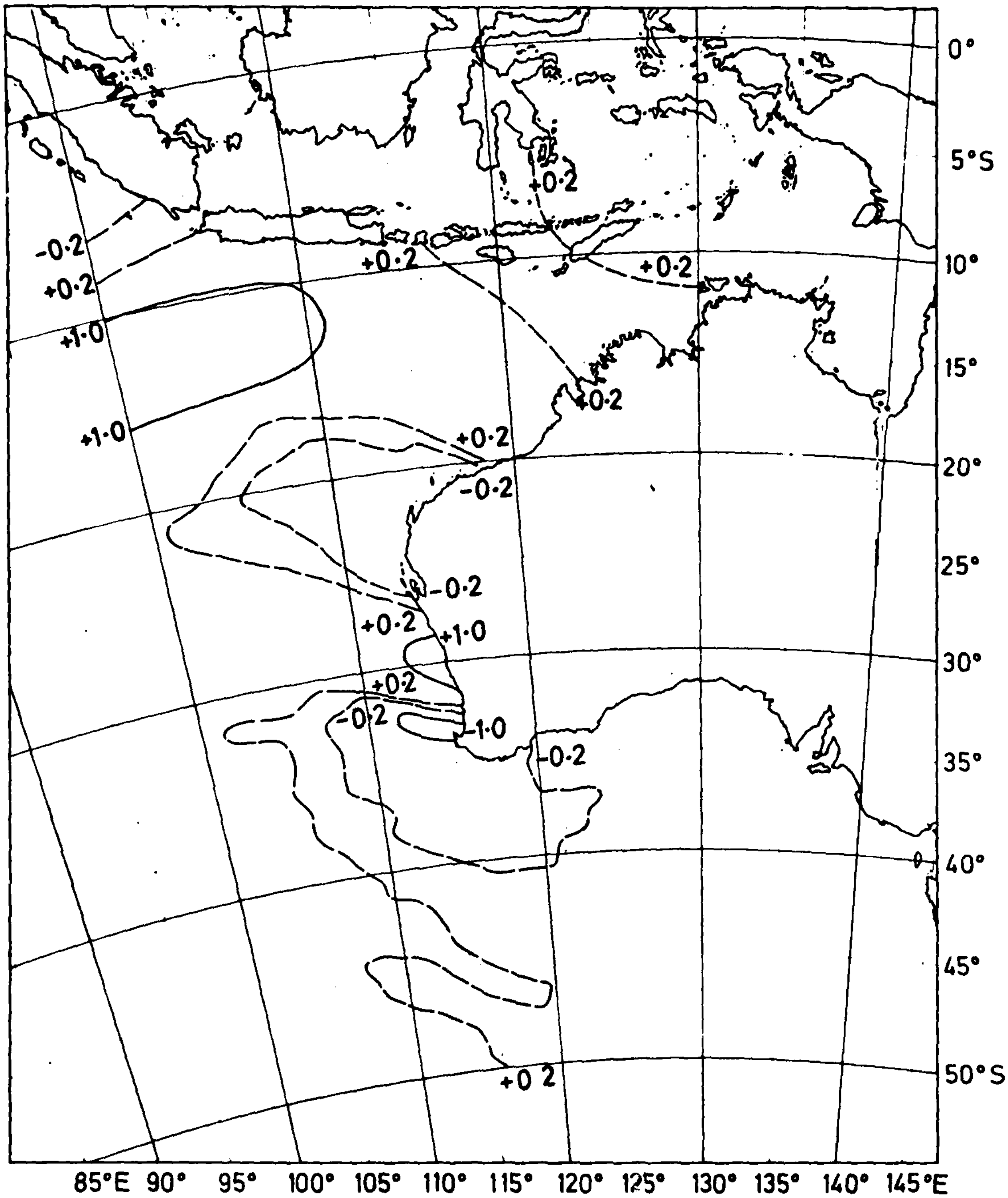

Fig. 1(f) The deviation of the mean February SST given in the Pacific Atlas from that given in the Atlantic-Indian Atlas.

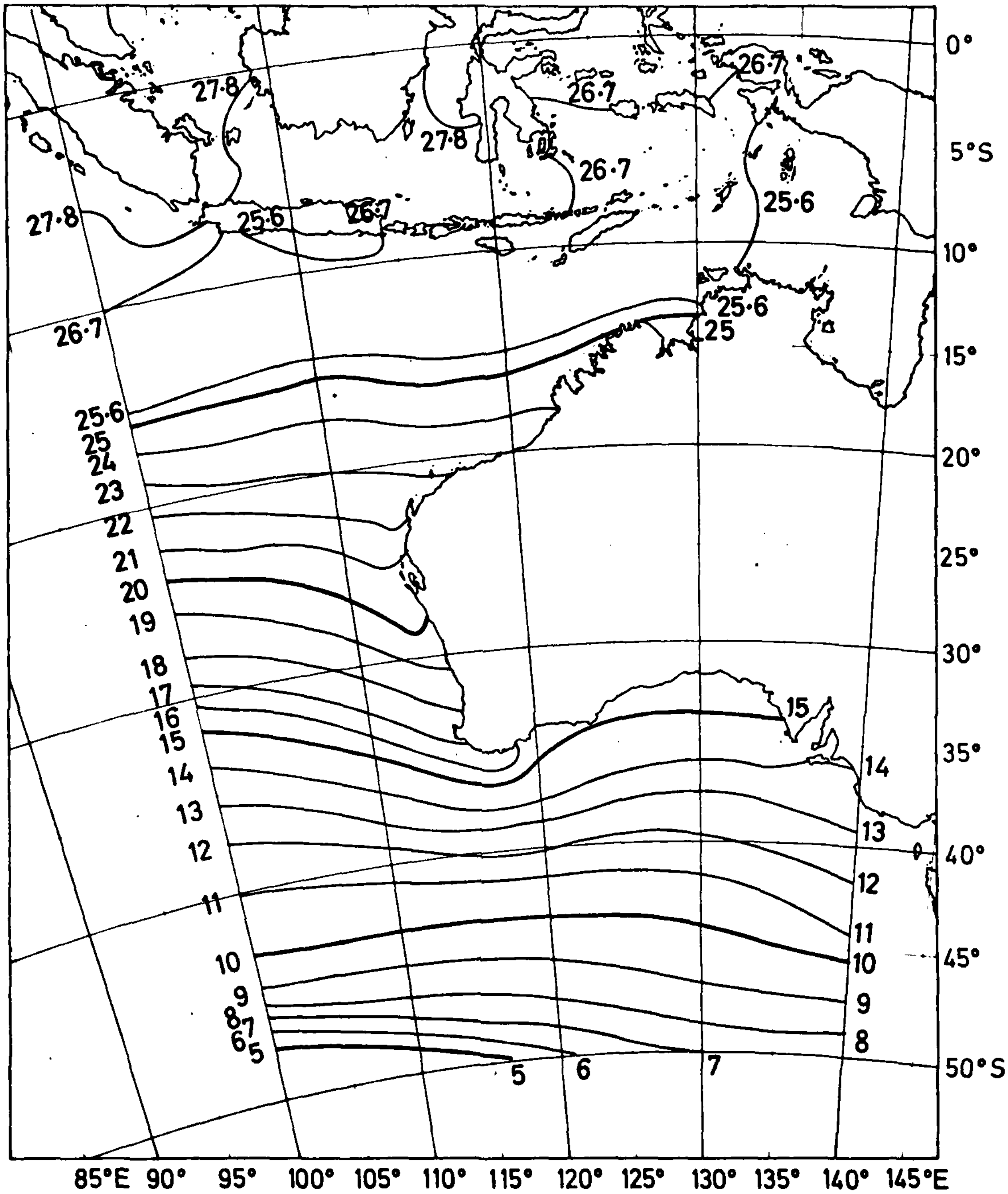

Fig. 2 (a) Mean August SST given in the U.S. Navy Atlas.

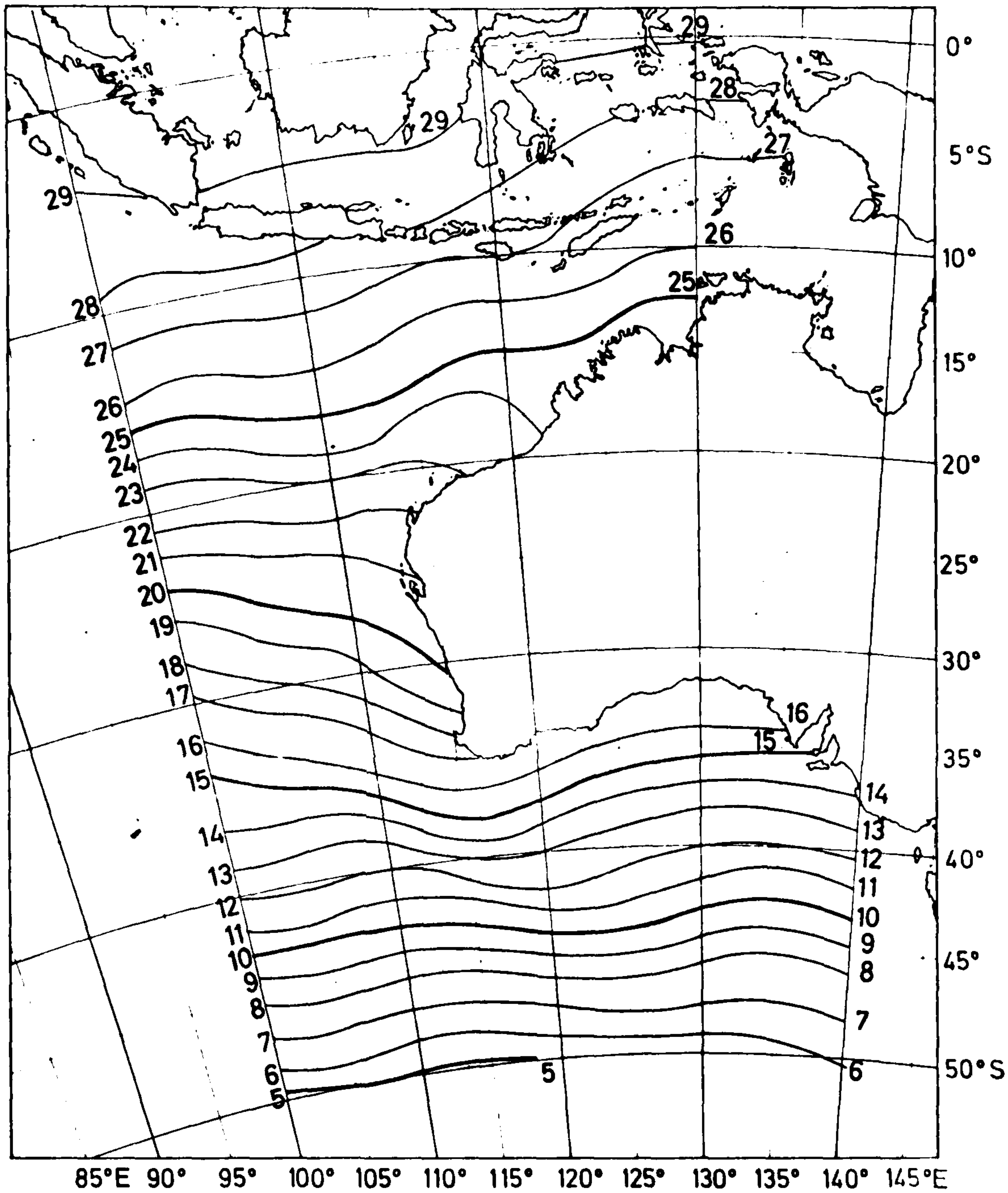

Fig. 2(b) Mean August SST (e_{sat}) given in the Pacific Atlas.

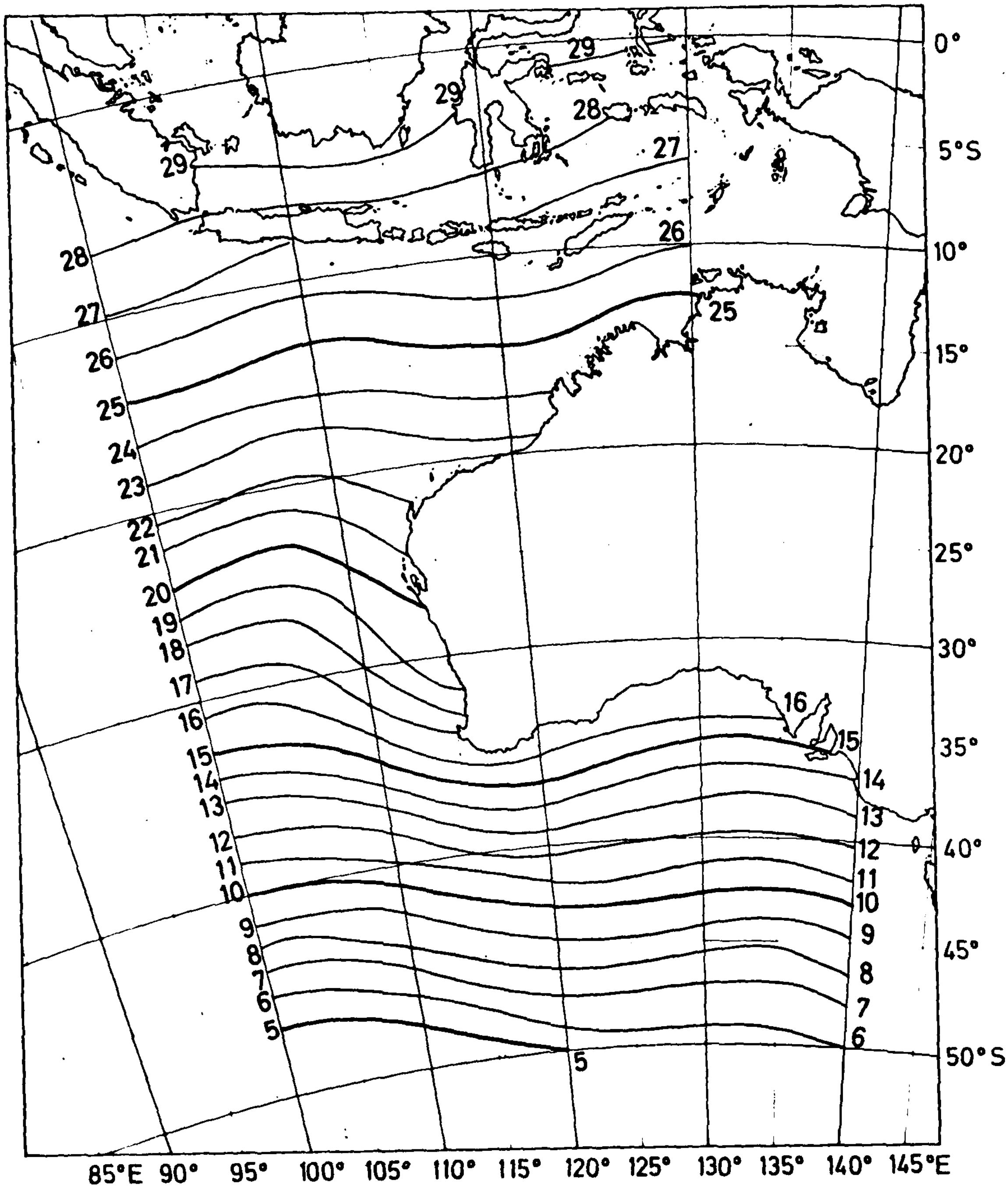

Fig. 2(c) Mean August SST given in the Indian Atlantic Atlas.

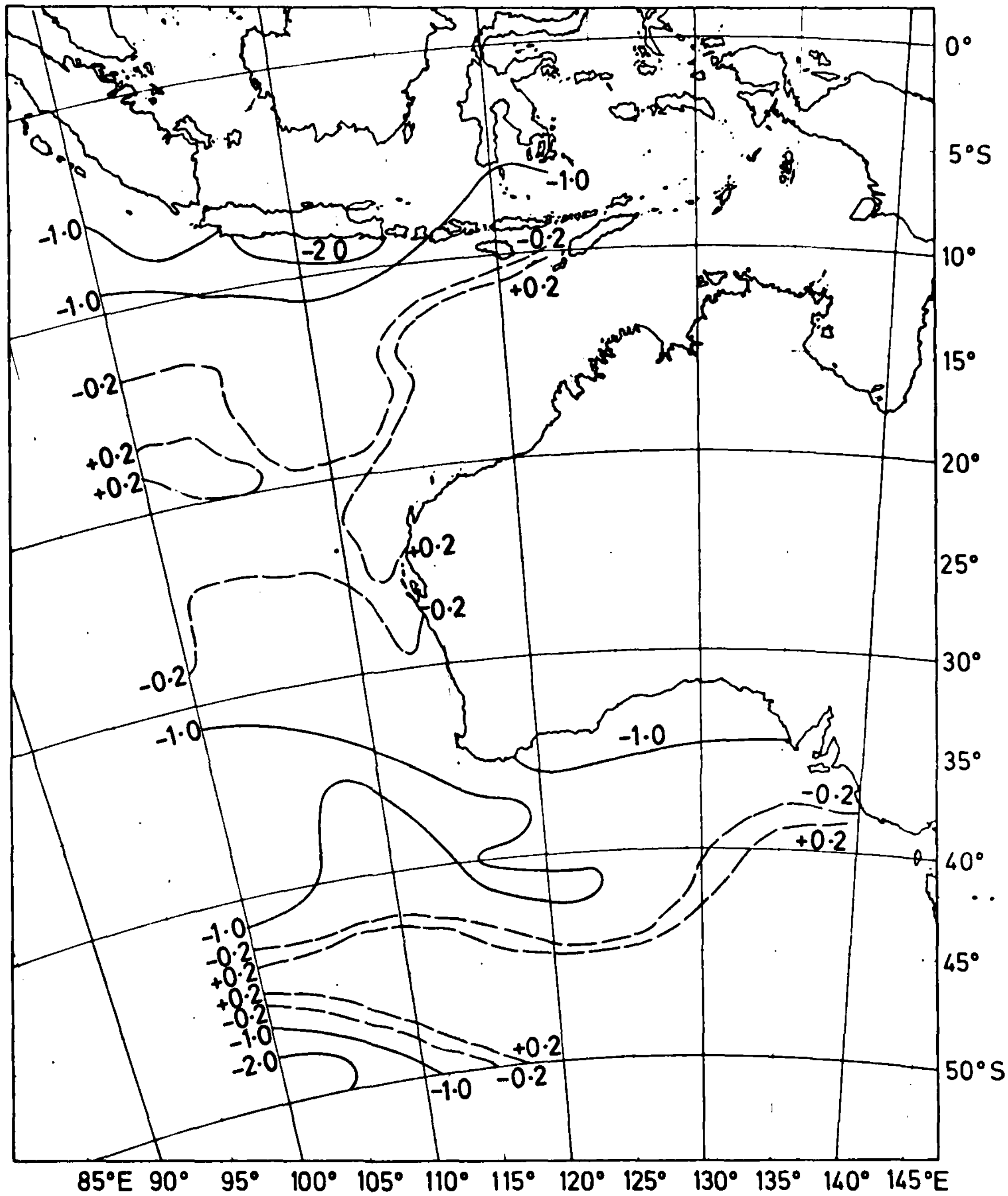

Fig. 2 (d) Deviation of the mean August SST given in the U.S. Navy Atlas from that given in the Pacific Atlas.

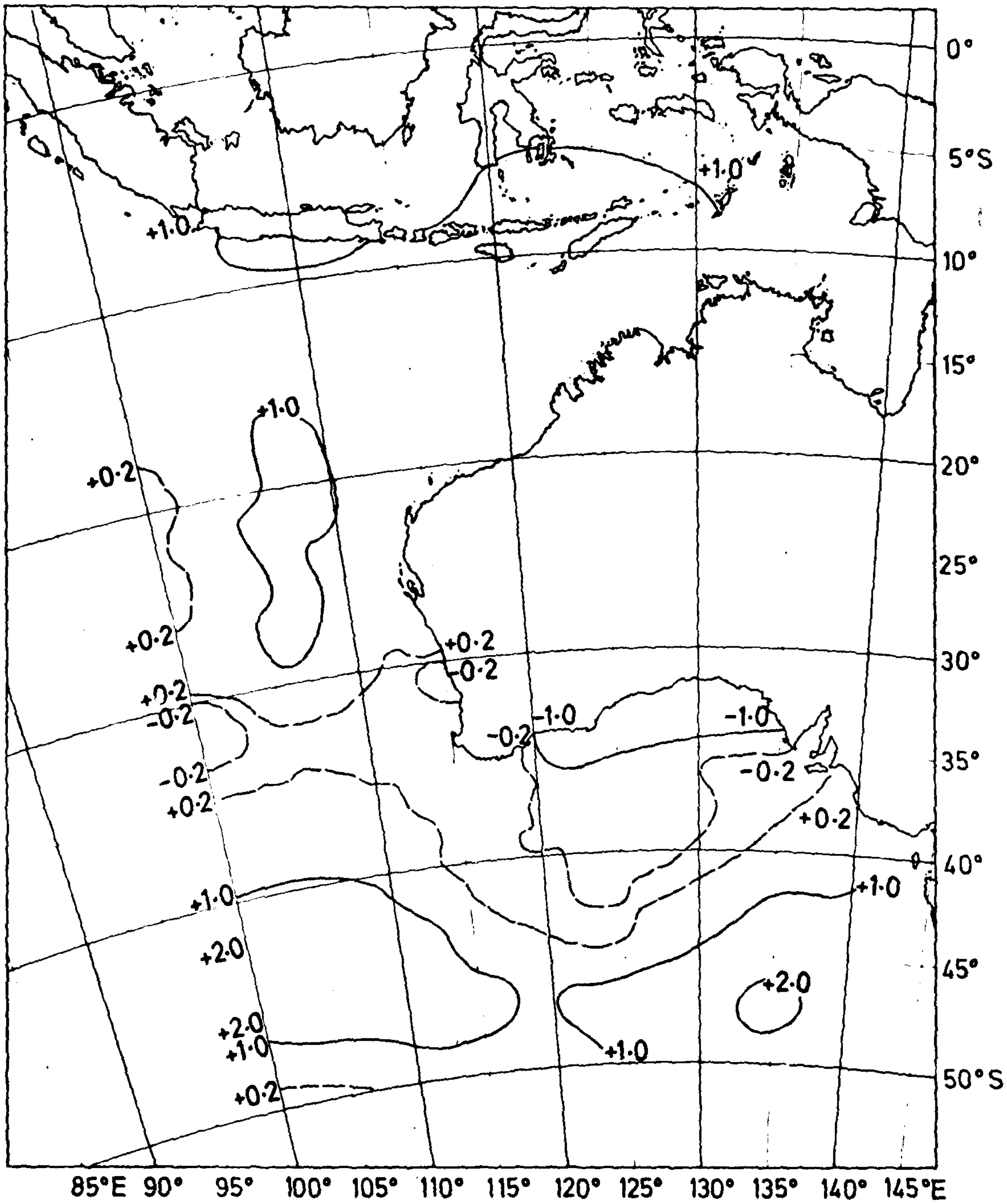

Fig. 2(e) Deviation of the mean August SST given in the U.S. Navy Atlas from that given in the Atlantic-Indian Atlas.

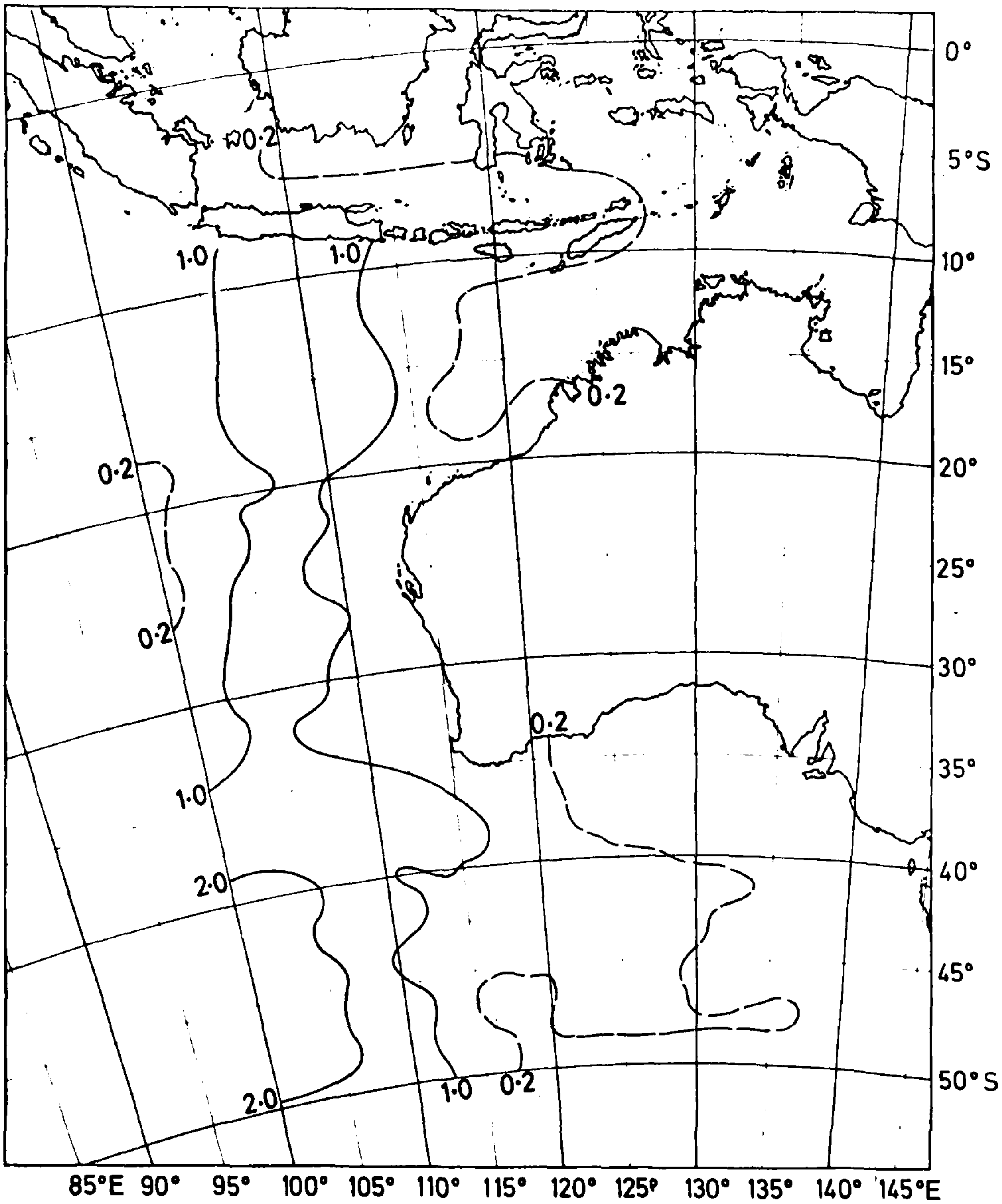

Fig. 2 (f) Deviation of the mean August SST given in the Pacific Atlas from that given in the Atlantic-Indian Atlas.

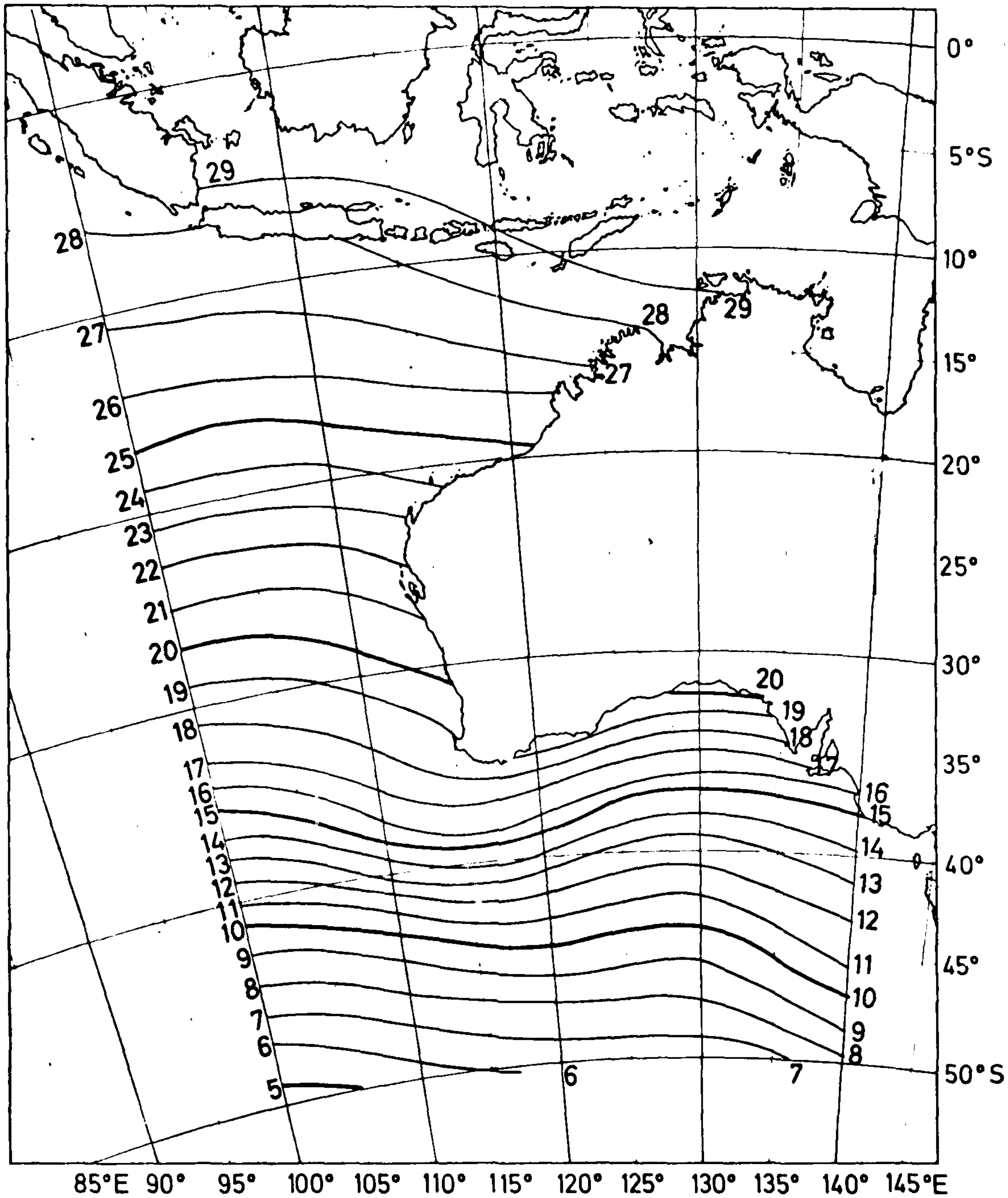

Fig. 3(a) Mean November SST given in Atlantic-Indian Atlas.

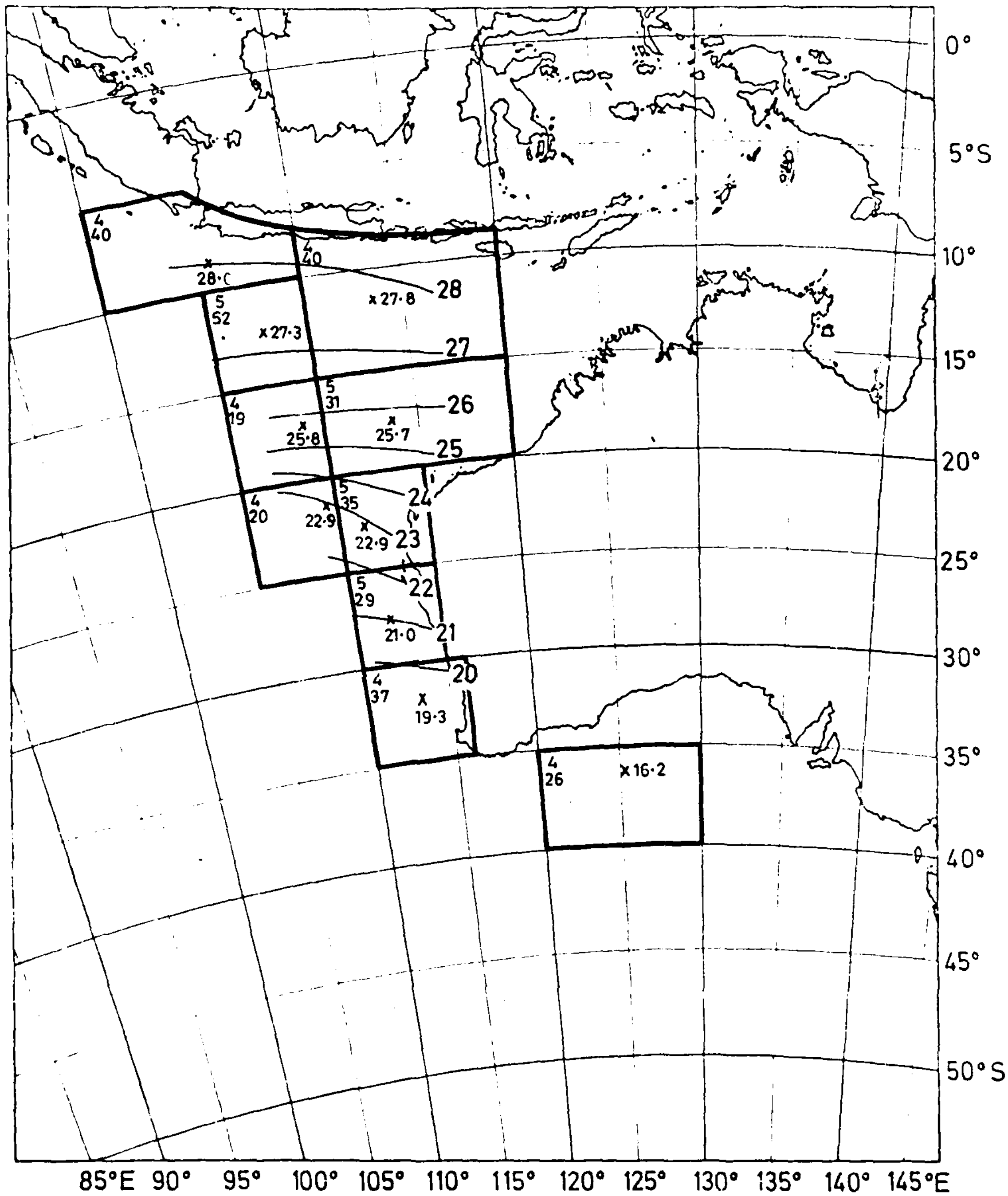

Fig. 3(b) Mean November SST derived from AODCBT data

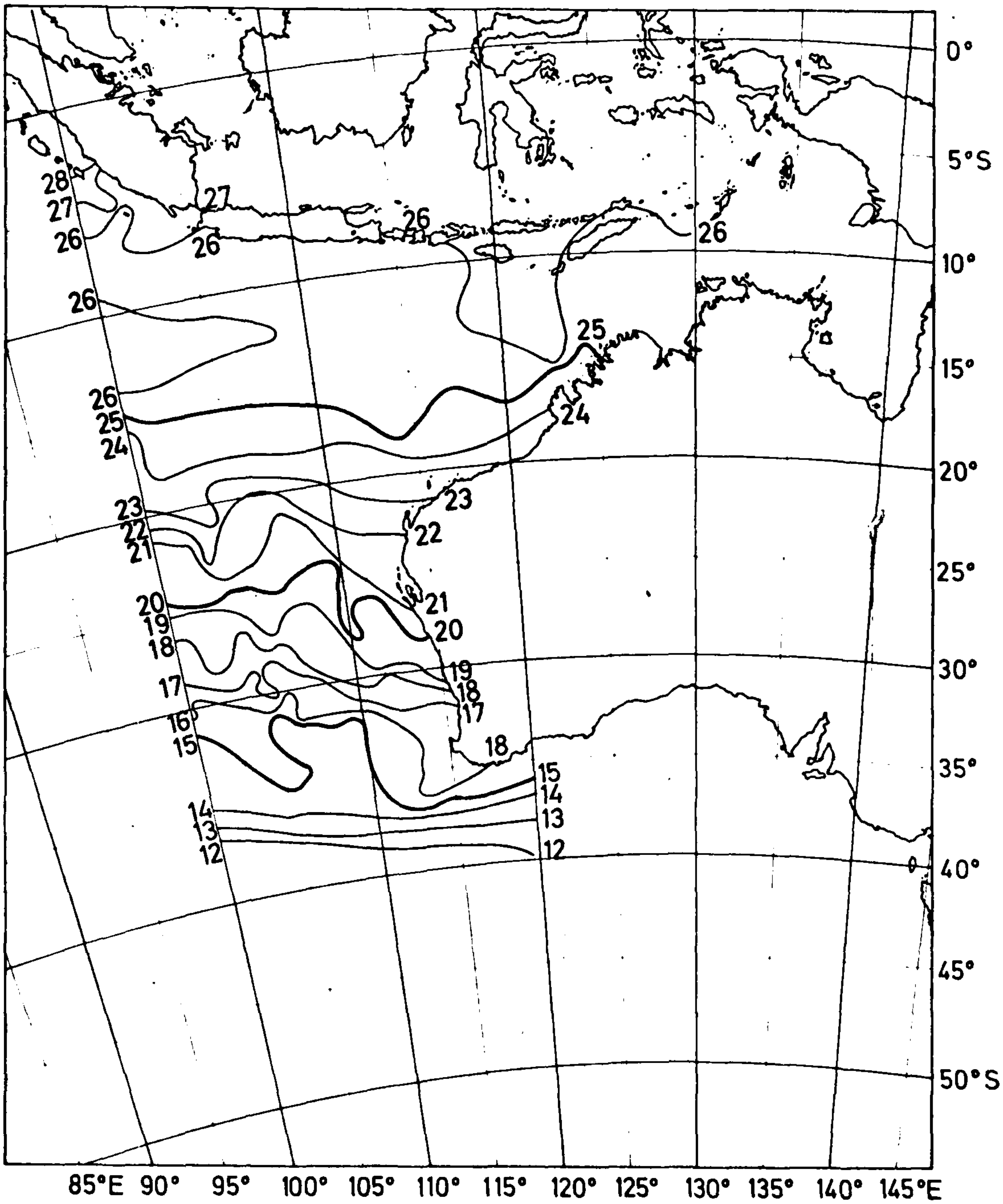

Fig. 4 (a) August 1963 SST as given in the International Expedition Atlas.

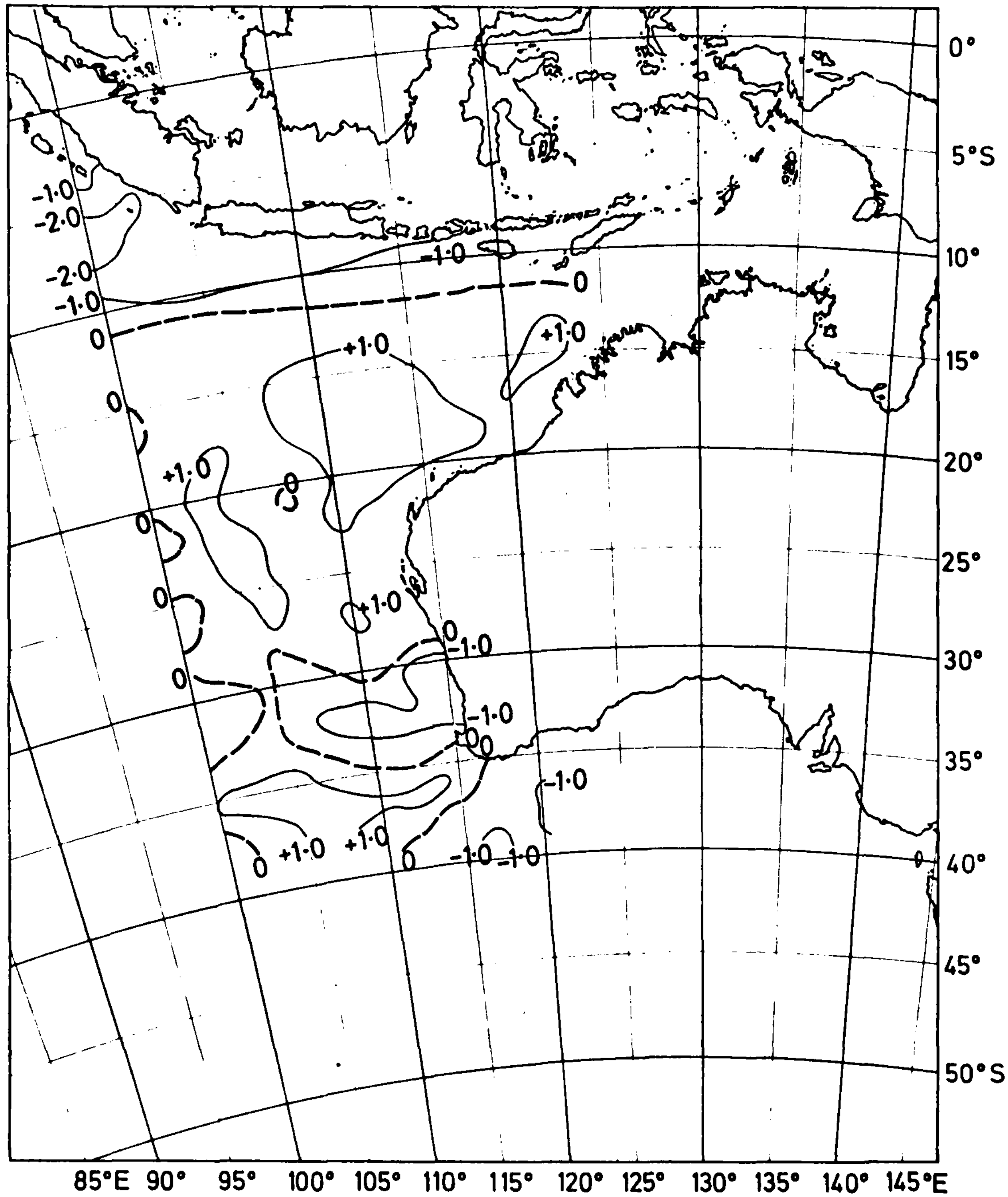

Fig. 4 (b) August 1963 SST anomaly.

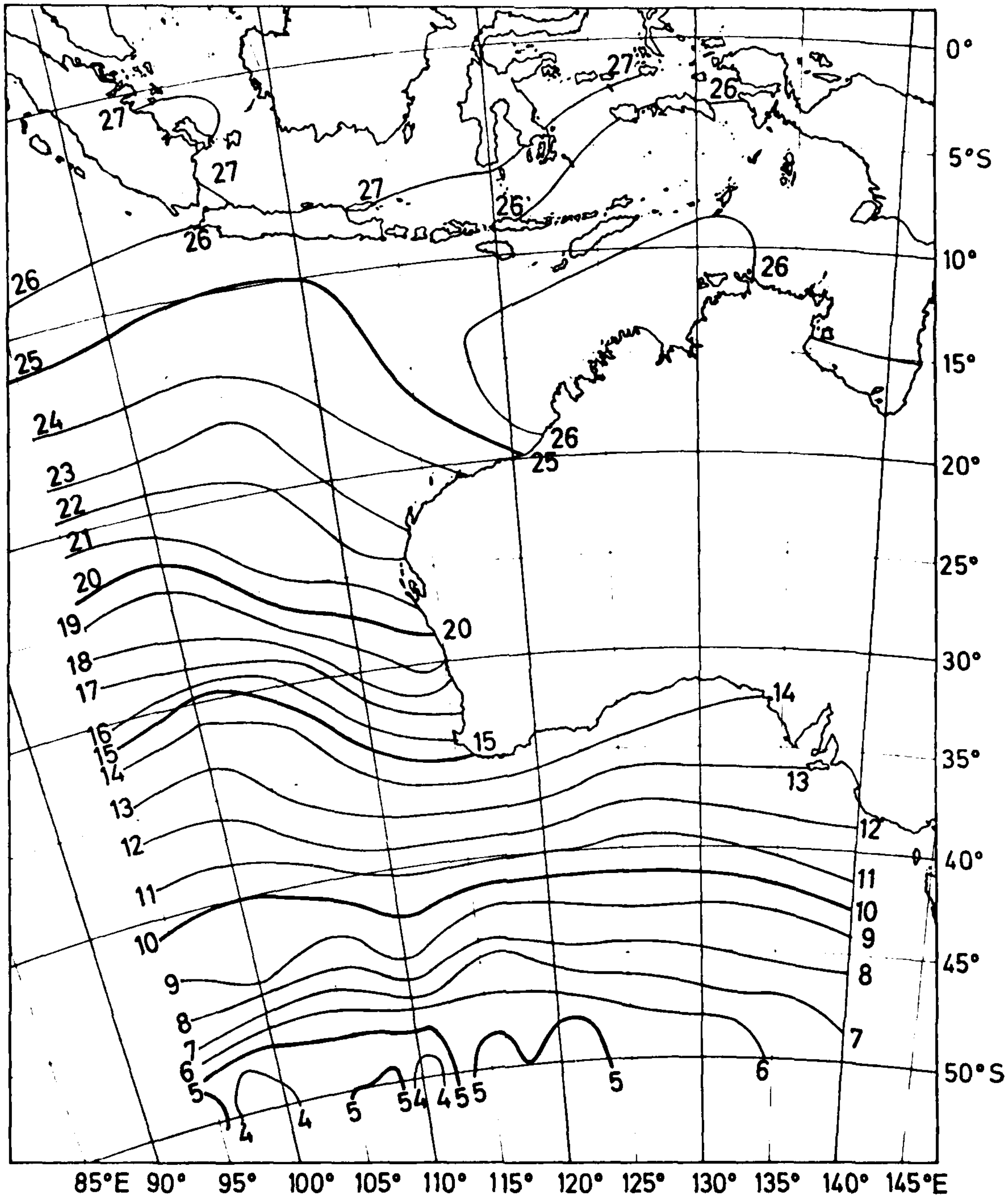

Fig. 5(a) August 1978 SST using Satellite SST measurements.

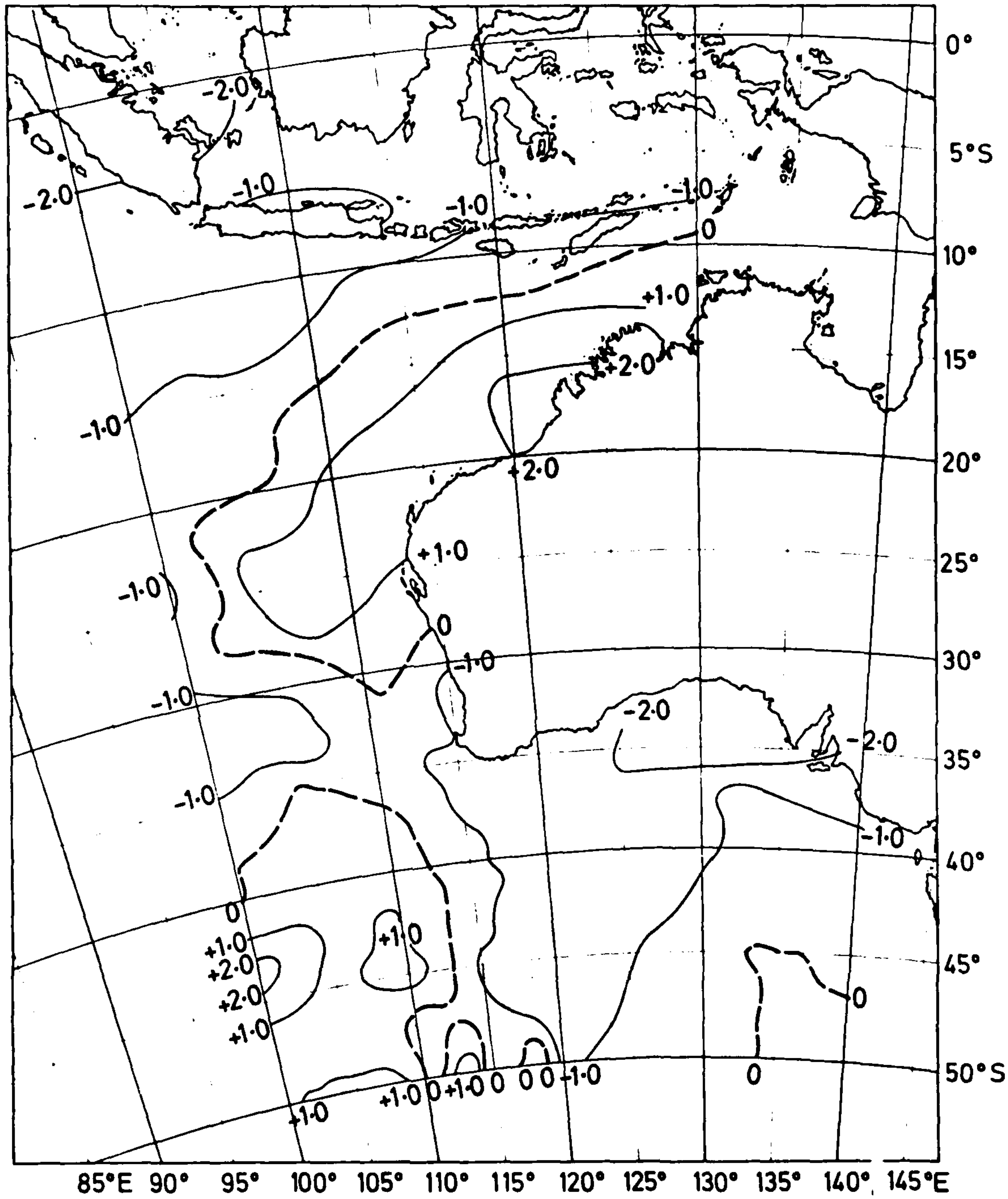

Fig. 5 (b) August 1978 SST anomaly.