COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION

DIVISION of FISHERIES and OCEANOGRAPHY

Report No. 84

THE SURFACE SALINITY REGIME OF THE TASMAN AND CORAL SEAS

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Reprint No. 940

Marine Laboratory
Cronulla, Sydney
1977

ISBN 0 643 02052 7

Printed by CSIRO, Melbourne

77.208-600

THE SURFACE SALINITY REGIME OF THE TASMAN AND CORAL SEAS

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Abstract

From the monthly changes in the mean surface salinity patterns of the Tasman and Coral Seas (1966-1974) in relation to evaporation precipitation characteristics, the annual balance of surface salinity appears to be largely maintained by:-

(a) advective exchange of high and low salinity waters into and out of regions of excess precipitation or evaporation;

(b) localized runoff from eastern Australia and south-western New Zealand into coastal waters

(c) winter convective overturn in the middle and southern regions of the Tasman Sea

These advective exchanges occur along well defined salinity plumes in the Coral Sea and in the western Tasman Sea. The central Tasman Sea is the major source of high salinity water which by advection into the Coral Sea compensates in part for the excess precipitation in this region.

INTRODUCTION

Donguy *et al* (1970) used surface salinity of the northern Coral Sea to identify and trace paths of west and east flowing currents and counter currents of this region. Rochford (1957) had earlier made use of surface salinity as a tracer of water types.

However little consideration had been given in these papers to the effect of the precipitation-evaporation (P-E) balance upon the seasonal changes in the surface salinity.

Surface temperature-salinity data collected by CSIRO from ships of opportunity in the Tasman and Coral Seas since 1966 provide an adequate time-space data record to examine this relationship.

DATA AND METHODS

The salinity data used have been lodged with World Data Centre A, Washington D.C. The rainfall values (Fig. 1) for the years 1966-1974 have been supplied by the Bureau of Meteorology, Melbourne. Use has also been made of the longer term data in Taylor (1973) to complete the mean rainfall coverage (Fig. 1). Evaporation values for the Tasman and Coral Seas have been taken from Privett (1960).

The methods of collection and analysis of the samples from the ships of opportunity have been described by Piip (1974).

The surface salinity data have been reduced to mean monthly 1^{o} square values, and for some comparisons to 5^{o} square means, covering the period 1966-74. The longer term mean has been used in preference to individual years because of the considerable changes in surface temperatures and salinities in evidence since 1966 (Rochford 1973). The salinity values have been contoured at 0.1‰ intervals. However the standard deviation of random variability of individual values about the monthly mean within each 1^{o} square, although mostly less than 0.1‰ , was on occasions as high as 0.2‰. Thus any feature of scale less than 1^{o} square or which did not persist over at least three 0.1‰ contour intervals may not be significant.

Rainfall values have been reduced to mean 1966-74 monthly values and charts of the mean monthly rainfall prepared. From these charts averaged values for 5^o squares have been estimated (Table 1).

Evaporation values in Table 1 for 5^o squares are taken direct from Privett. These values, although for years prior to 1966, are based upon a long enough series of years to be considered adequately representative of the 1966-74 period for the purpose of this paper.

RESULTS

Precipitation-Evaporation Balance

The distribution within the Coral and Tasman Seas of the annual P-E balance (Table 1) is shown in Figure 2.

The sparseness of the rainfall data over the open sea situation is clearly a limitation on the reliability of these P-E estimates. In contouring Figure 1 the assumption has been made that the land based rainfall values are too high for the adjoining open sea situation. Contouring therefore has deliberately limited the areas of high precipitation to sea areas immediately adjoining the region of recorded high rainfall values.

Within these limitations it is considered that Figure 2 delineates the three areas of interest:

(a) An area north of around 20^oS in the east and 15^oS in the west can be delineated where annual precipitation exceeds annual evaporation. Maximum of this precipitation excess occurs in a zonal band centred around 15^oS in the east and 8^oS in the west.

(b) In an area west of New Zealand, P on average exceeds E each year. However the P-E difference there is not large enough to be free of the limitations of the rainfall data, and there could be a slight net annual evaporation loss.

(c) Elsewhere in the southern Coral Sea and the Tasman Sea E exceeds P especially in the western half of the region. Two cells of maximum net evaporation loss per year are located around 22°S and 37°S.

Seasonal Changes in the Surface Salinity

Comparing Figures 3-14 with Figure 2, it is seen that the monthly surface salinities follow a general pattern dictated by the overall anti-cyclonic circulation. Thus lower salinity waters predominately move southward, away from the region of positive P-E along the western margin, and higher salinity waters predominately move north away from the region of negative P-E along the eastern margin of the Coral and Tasman Seas.

However, closer inspection of the monthly changes in surface salinity in this region reveals subsidiary patterns that indicate possible mechanisms for the maintenance of the overall salinity balance. These subsidiary patterns are considered in the following part of this section.

A. The Tropical Zone

The tropical zone is characterized by waters less than 35.0‰. It occurs north of a meridional gradient around 17-22°S, and is best developed in April (Fig. 3). This salinity gradient is located in the eastern Coral Sea in the same zone as the Tropical Front, (Stanton 1973). These low salinity waters form annually by dilution of surface waters during the north west Monsoon (December-March) with a maximum of rainfall during March. Three distinct regions of accumulation of such diluted waters occur:

I. An eastern region east of around 163°E in the north and east of the New Hebrides to the Fijian Is. in the south (Fig. 4).

II. A central region from around 162^{O}E extending along the chain of the Solomon Is. to New Britain and northern Papua-New Guinea with a southern limit around 13^{O}S and a western limit around 150^{O}E (Fig. 4).

III. A western region bounded on the west by the coast of Queensland northward at 20^{O}S, eastward by around 150^{O}E and northward by Papua-New Guinea (Fig. 4).

The meridional boundaries of the three regions are delineated by zones of higher salinity water extending northward from the subtropical high salinity central waters of the Tasman Sea in the case of the separation of Zones II and III, and from the northern Tasman Sea in the case of the separation of Zones I and II (Fig. 4).

These low salinity tropical waters extend southward of 22^{O}S from Areas I-III as low salinity plumes between February and April. From Area III this low salinity plume is best developed in February-March (Figs. 5 and 4), from Area II in March (Fig. 4) and from Area I in April (Fig. 3).

By April, with the disappearance of the two high salinity meridional corridors, the three regions I-III have merged into a single low salinity zone of less than 34.7‰, between 8 and 15^{O}S. Southward escapement of tropical low salinity water from this zone occurred in April principally between New Caledonia and Fiji (Fig. 3).

By May however (Fig.6) the southward stress of the Monsoon has been replaced by the northward stress of the south east Trades and high salinity water accumulates northward along the two corridors originally found in March. In June the northward drift of high salinity water and the southward drift of low salinity water are clearly shown as two tongues aligned in north-west to south-east directions (Fig. 7).

Further north in June the northern limit of the tropical low salinity waters of region I can be seen at around $3^{o}S$ along $168-170^{o}E$ where a zone of the highest salinity for these latitudes occurred in this month.

In July, the southward extension of the low salinity plume from Zone II has retreated northward but that from Zone III has advanced almost to the region off Brisbane. However the western Coral Sea north of around $12^{o}S$ is increasing in salinity and is no longer the source of the low salinity tropical water of region III (Fig. 8).

In August the western higher salinity corridor extends to the south east coast of Papua New Guinea and the low salinity tropical water has receded beyond $14^{o}S$. The central higher salinity corridor has shifted westward and weakened. The northern boundary of region I has also moved southward as the area of the low salinity tropical water decreases in winter and spring (Fig. 9).

By September, however, the higher salinity corridors separating Zones I-III have almost disappeared north of $17^{o}S$ (Fig. 10), although salinities within the Barrier Reef and off the Queensland coast continue to increase.

The salinities in October indicate that a westward reversal of drift of low salinity water from region I towards II and perhaps III is responsible for this disappearance of the high salinity corridor (Fig. 11).

From November onwards the north west Monsoon provides a brake on this westward flow of low salinity water from region I and the high salinity corridor in the west is recreated almost to the south-east coast of Papua New Guinea (Fig. 12).

In December the initial monsoonal diluted tropical waters spread southward from region II around 158°E and from region III largely from the Gulf of Papua, to around 23°S (Fig. 13).

By January the two plumes of low salinity water from regions II and III have merged to the north of Brisbane and, augmented by localized runoff from the eastern Australian coastal rivers, contribute to the generally lowered salinity of the East Australian Current in this month (Fig. 14).

In February, the southward spread of water of low salinity from inside the Great Barrier Reef and some augmentation from localized runoff contribute most of the low salinity water of the East Australian Current in this month (Fig. 5). Escapement from region II however is much reduced. From region I escapement begins to increase in this month reaching a maximum in April (Fig. 3).

B. The Sub-Tropical Zone

I. The high salinity central Tasman Sea water

In a region centred at around 28-30°S and extending eastward from around 160-162°E, there is found in every month a body of water of salinity greater than 35.70‰. The area occupied by this water to the west of 170°E varies throughout the year with the maximum area and peak salinities of greater than 35.80‰ encountered in January-March (Figs 14, 5 & 4) and with minimum area and salinities less than 35.80‰ in the winter months July-September (Figs 8-10). There is also a seasonal shift in the meridional extent of this Central Tasman water with southernmost occurrence in February-March (Figs 5 & 4) and northernmost in August-January (Figs 9-14).

II. Low salinity (35.40‰) waters of the southern Tasman Sea.

Low salinity water appears seasonally off the New South Wales coast (Figs 14, 5 & 4) and throughout the year from eastern Tasmania to westward of New Zealand.

The northern extent of these waters varies seasonally with minimum northward extent in January-March.

Minimum salinities in the south-east occur in the period August onward.

The Annual Salinity Balance

In regions where P exceeds E each year, an influx of high salinity water by horizontal or vertical advection or by horizontal diffusion is required to maintain the annual salinity balance. In regions where E exceeds P each year, an influx of low salinity water is correspondingly required. Figure 15, based upon the positioning of the major low and high salinity plumes in Figs 3-14 and the location of regions of maximum P > E and E > P (Fig. 2), indicates the extent that displacement of low and high salinity waters contributes to the annual salinity balance of the Tasman and Coral Seas.

South of a boundary (shown as the northern limit of winter convection overturn in Fig. 15) the decrease in temperature to a minimum in winter-spring is always accompanied by a sharp drop in salinity. This is thought to be caused by convective overturn and mixing with deeper cooler and lower salinity waters. Such convective overturn provides a further mechanism for maintaining the annual salinity balance in this region of annual evaporation each year.

North of the boundary in Fig. 15 whilst convective overturn still occurs it will increase rather than decrease surface salinity because a sub-tropical lower layer (Wyrtki 1962) of high salinity occurs below the surface.

In the extreme north convective overturn is inhibited by the very strong vertical density gradient and also in general the sub-tropical lower layer occurs at too great a depth to influence surface salinity by vertical mixing within the shallow mixed layer.

DISCUSSION AND CONCLUSIONS

Donguy *et al* (1970) have postulated that a series of near zonal flows in the Coral Sea transports low salinity waters eastward and high salinity waters westward. The evidence given in the present paper suggests that high and low salinity waters move into and out of the Coral Sea to the north of 20°S in a series of gyres (I-III Fig. 15). Continuity of low salinity waters across the Coral Sea, suggestive of zonal flow was found only in April (Fig. 3).

These gyres are probably the result of the channelling by land masses of the inflow of low salinity waters during the north west Monsoon, predominatly along the paths (1) to the east of the Solomon Islands and the New Hebrides (Gyre I, Fig. 15); (2) between the Solomon Islands and eastern New Guinea (Gyre II, Fig. 15); and (3) north west Coral Sea from the Gulf of Papua and the Fly River discharge and eastward through Torres Strait (Gyre III, Fig. 15). South of 20°S low salinity water spreads into the Tasman Sea along two major pathways:

(a) One pathway is situated along the eastern Queensland-New South Wales coastal margin. Low salinity water augmented by local river discharge, spreads southward along this pathway predominately in the period December to April.

Plumes of low salinity water indicating a drift eastward out of this pathway occur in the north in December and in the south in March. A large gyre that could carry these waters from the western Tasman Sea eastward and northward has been demonstrated by satellite-tracked buoys (Cresswell 1976,

(b) The other pathway is situated to the west of Fiji and terminates in the region between Norfolk Island and New Caledonia. Low salinity waters penetrate further south along the pathway in February-March (Fig. 15).

The annual salinity balance in surface waters is maintained in:

(a) the Coral Sea (high nett precipitation excess) by egress of the surplus low salinity waters after the north-west Monsoon and entry of high salinity waters during the south-east Trades;

(b) the northern Tasman Sea (high nett evaporative loss) by entry of low salinity waters from the western Coral Sea and coastal margins of east Australia. There is also some entry of low salinity waters from the eastern Coral Sea, in the first four months of the year. In other months there is egress of high salinity waters into the Coral Sea;

(c) the southern Tasman Sea (low nett evaporative loss) by limited entry of low salinity waters from the sub-Antarctic region south of the Tasman Sea. The area off south western New Zealand is seasonally diluted by local river discharge. In winter-spring convective overturn also lowers surface salinity in this region of the Tasman Sea.

Added to the effect on surface S‰ caused by advective redistribution of low and high salinity waters is a much slower effect caused by horizontal diffusion (Bowden 1955). However no account of this process has been taken in this paper.

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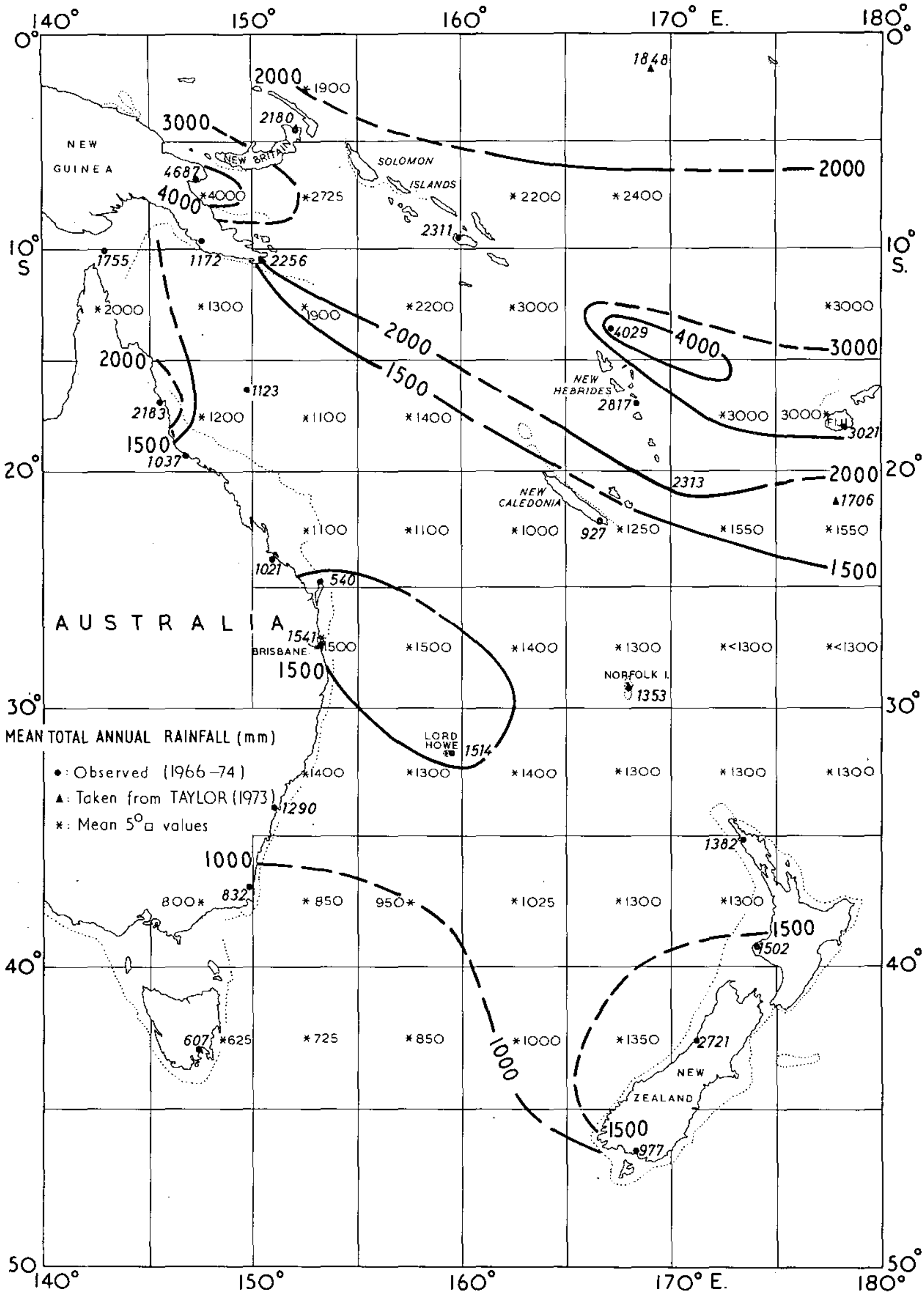


Fig. 1. Mean total annual precipitation (1966–'74) in mm based upon coastal and island records.

* Mean interpolated 5° square total rainfall within those 5° squares for which evaporation values have been calculated (Table 1).

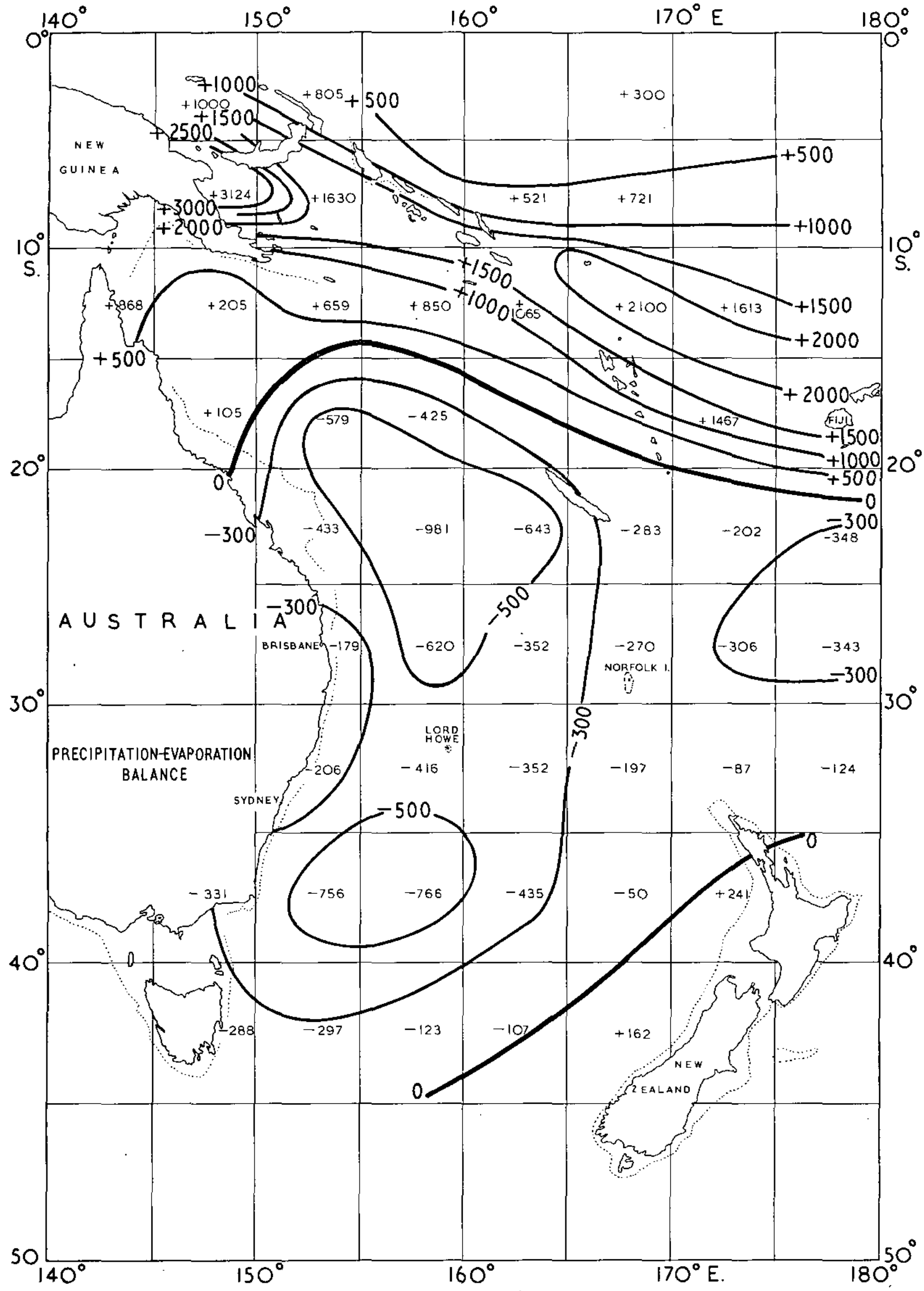


Fig. 2. Mean annual nett Precipitation-Evaporation balance of the Tasman and Coral Seas (in mm) based upon precipitation and evaporative data from Table 1.

+ = P > E   – = E > P

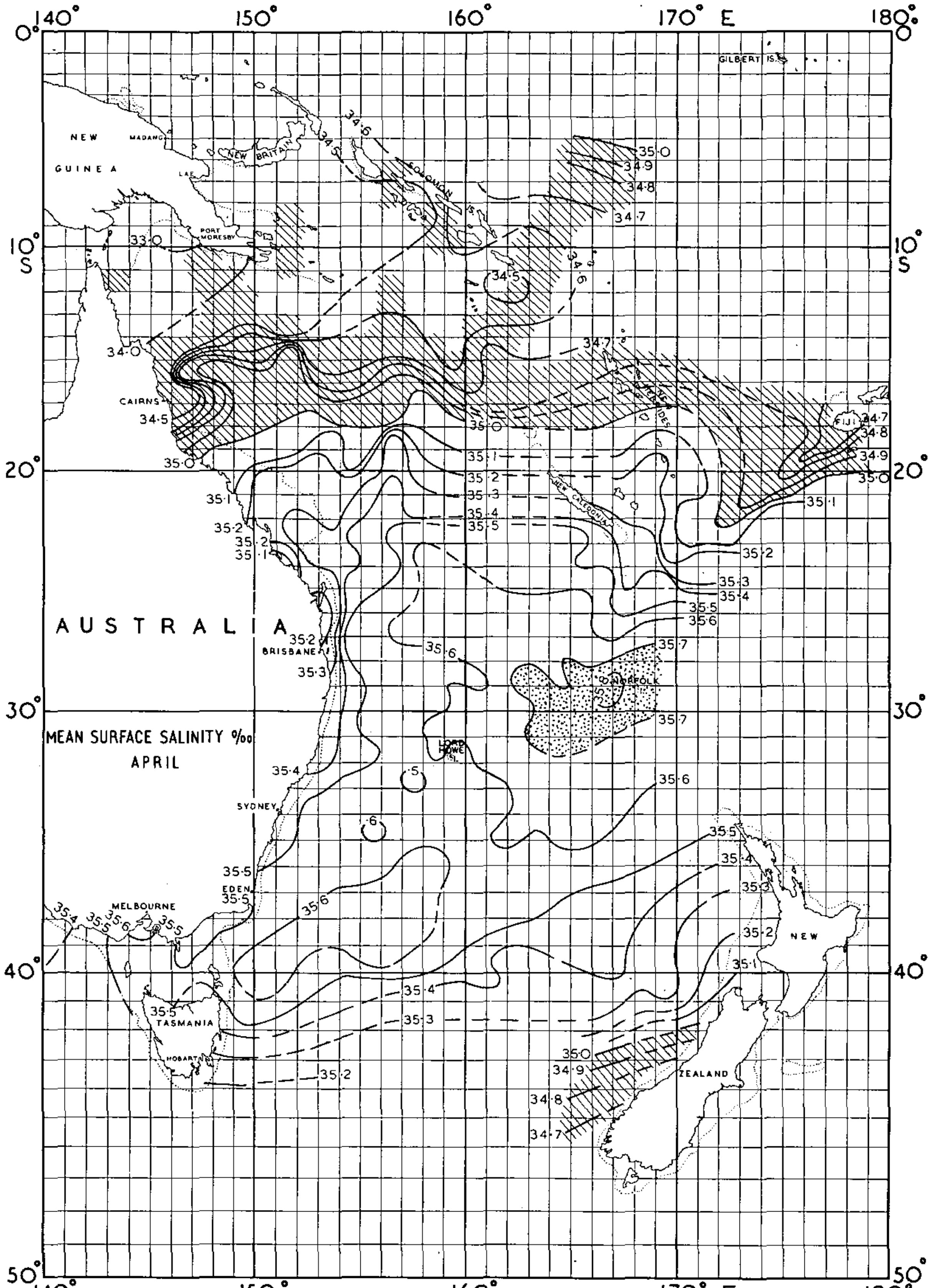
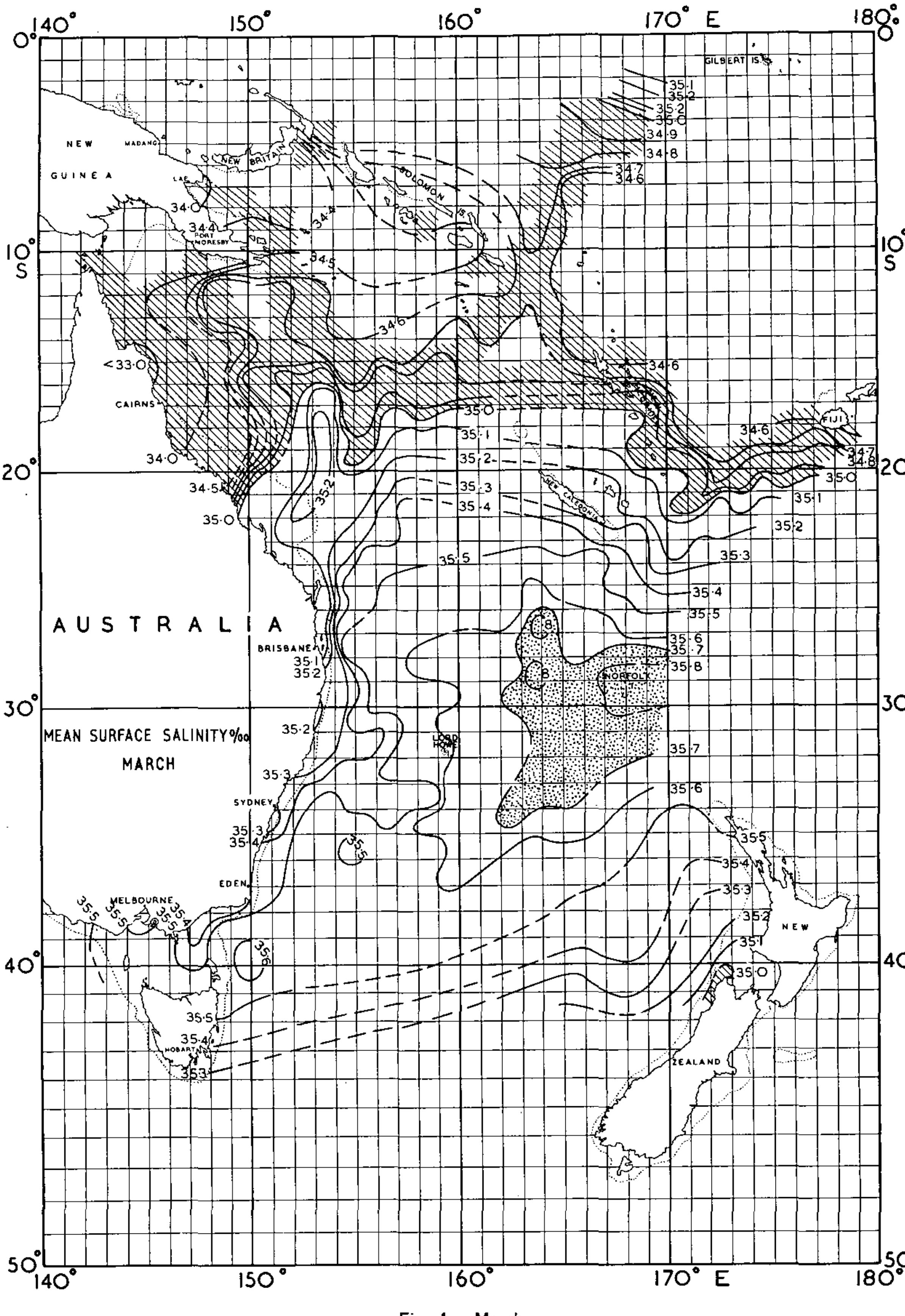


Fig. 3. April

Figs 3 to 14. Charts of the mean (1966–'74) monthly surface salinity of the Tasman and Coral Seas. Above 34.5‰ contour intervals at 0.1‰. Between 34.0–34.9‰ intervals at 0.5‰. Less than 34.0‰ intervals at 1.0‰.


MEAN SURFACE SALINITY ‰
MARCH
AUSTRALIA
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SYDNEY
EDEN
MELBOURNE
HOBART
NEW CALEDONIA
NORFOLK
LORD HOWE
FIJI
NEW ZEALAND
PORT MORESBY
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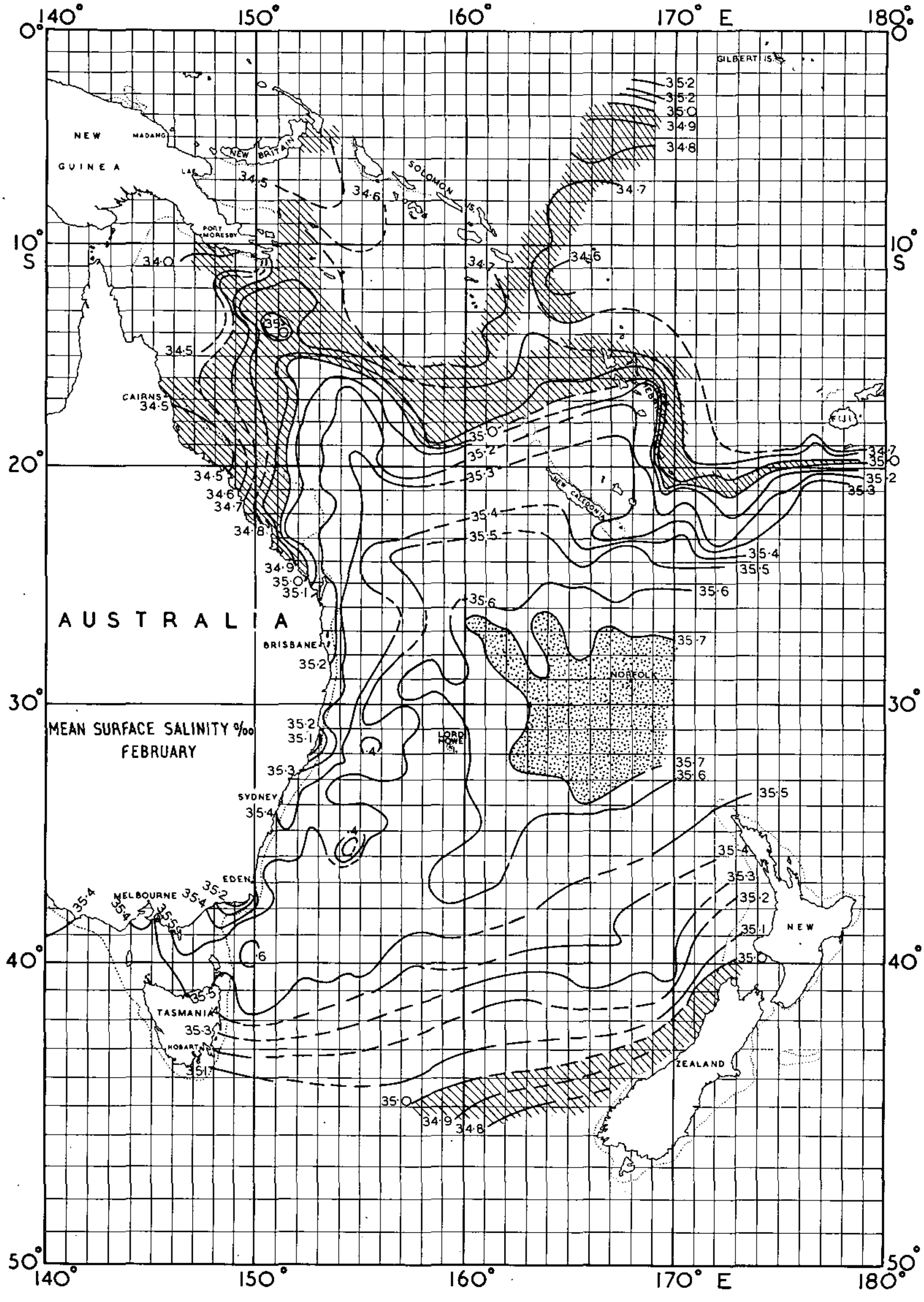
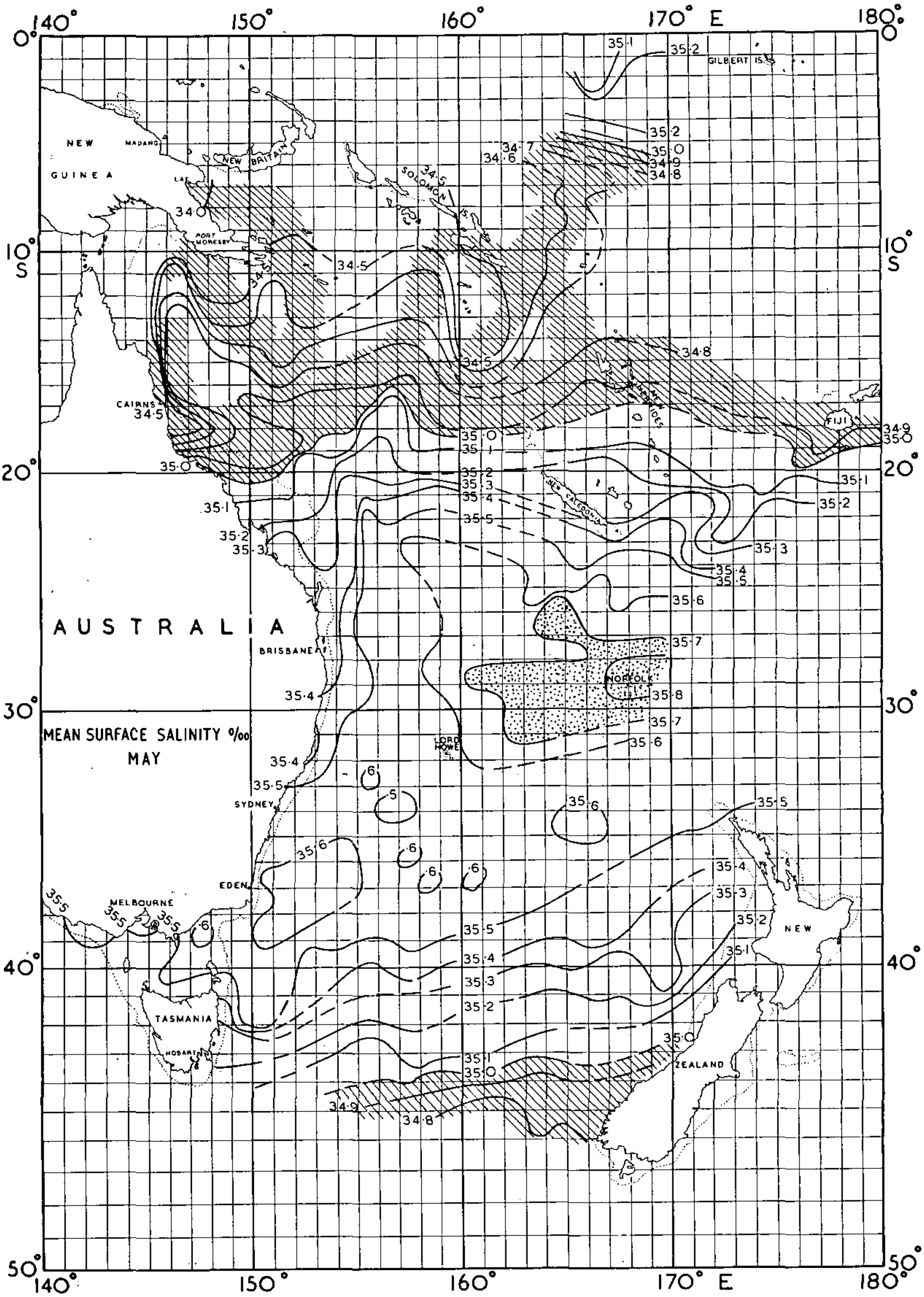
Fig. 4. March



·Fig. 5. February



MEAN SURFACE SALINITY ‰
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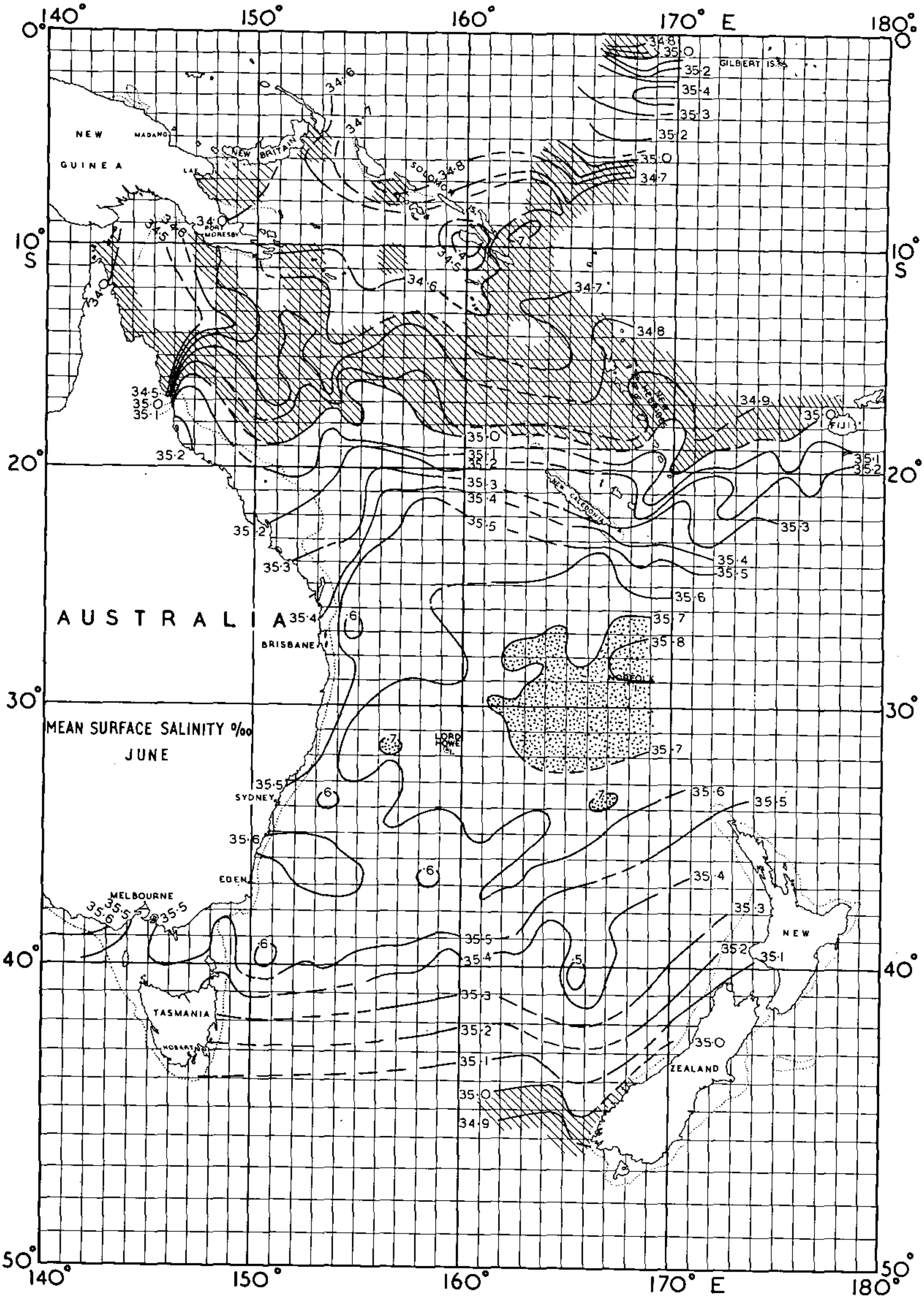
Fig. 6. May



MEAN SURFACE SALINITY ‰
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Fig. 7. June

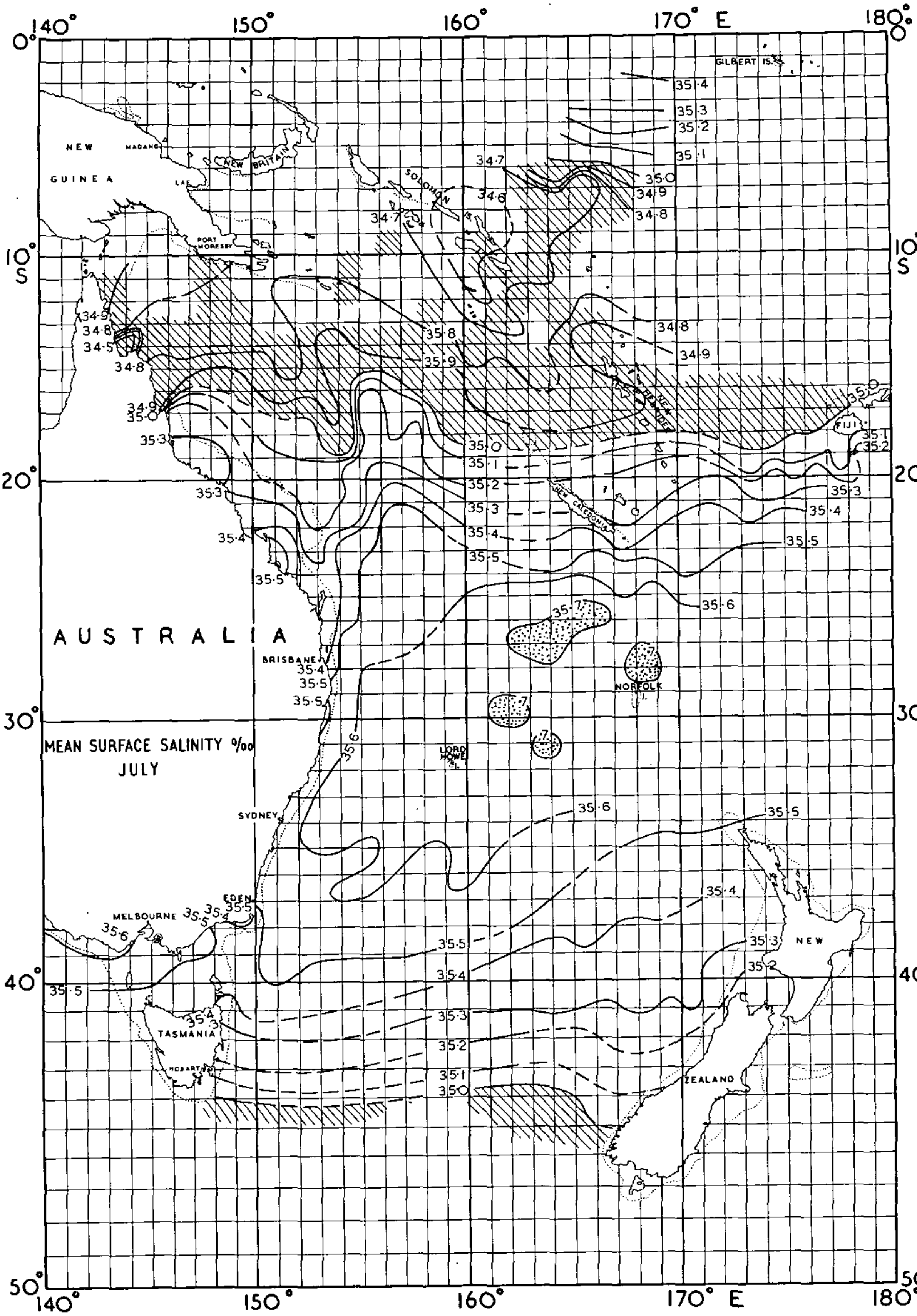
MEAN SURFACE SALINITY ‰
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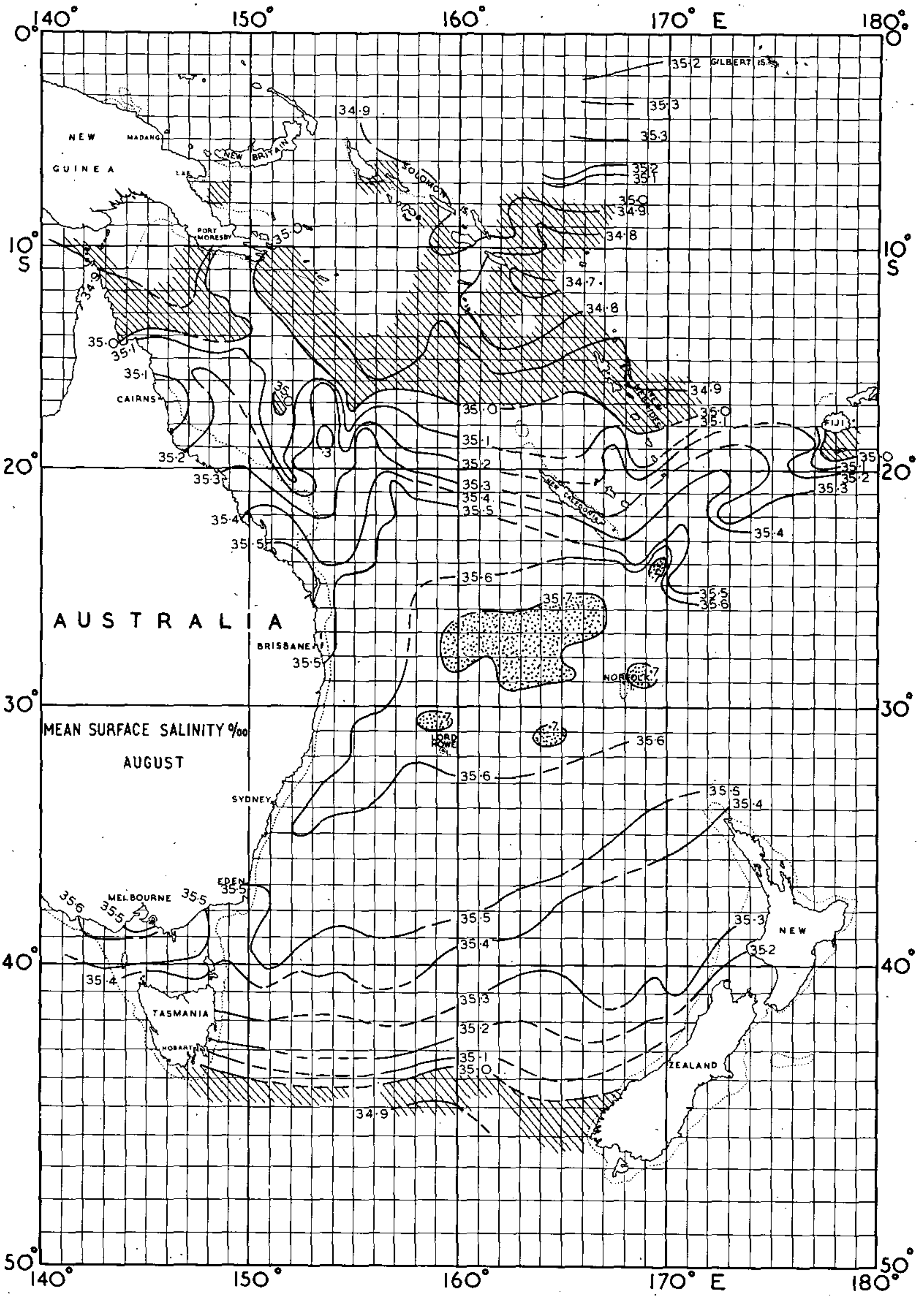
Fig. 8. July



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TASMANIA
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NEW ZEALAND
MEAN SURFACE SALINITY ‰
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34·7
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35·5
35·6
35·7

Fig. 9. August

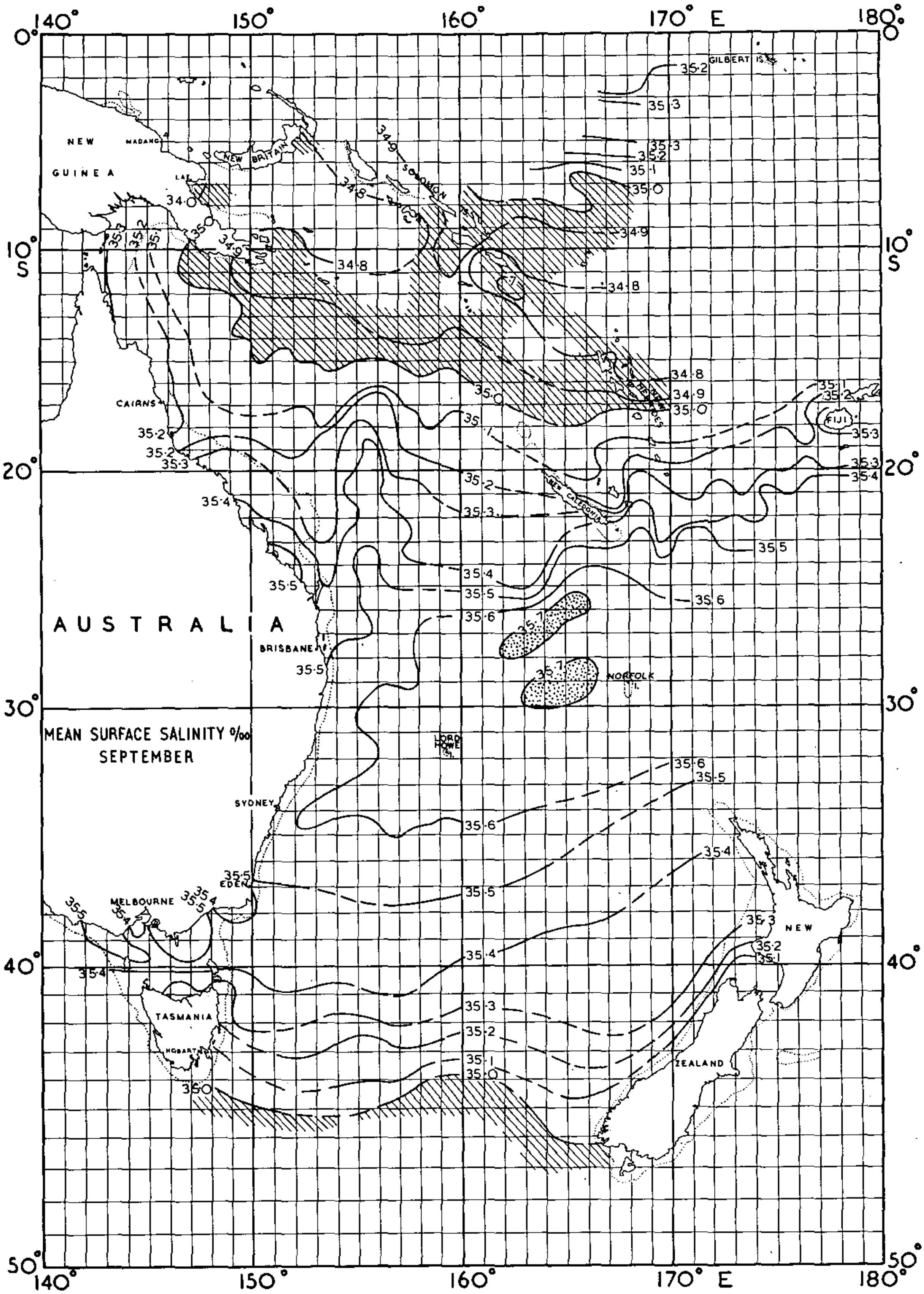

Fig. 10. September

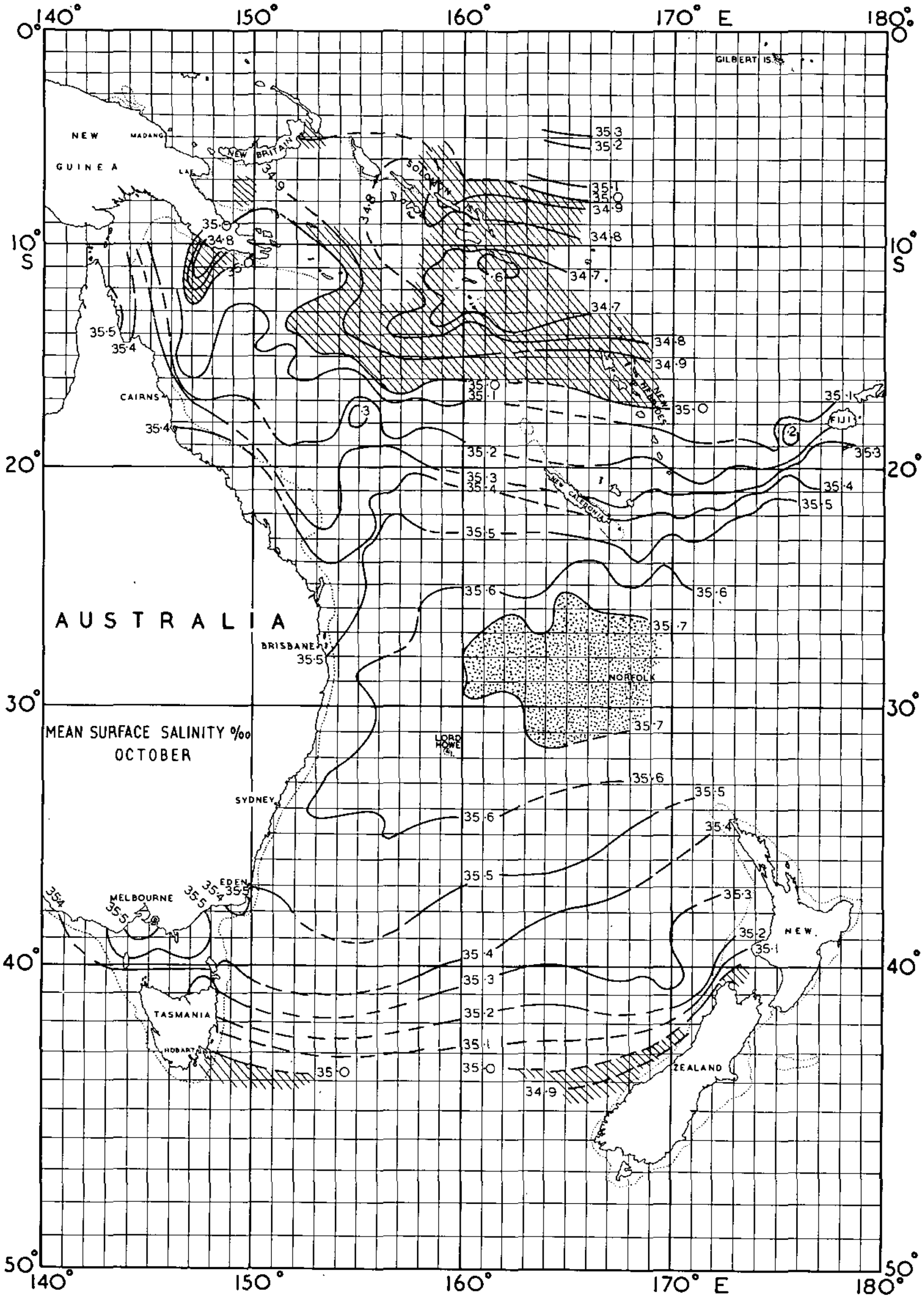

Fig. 11. October

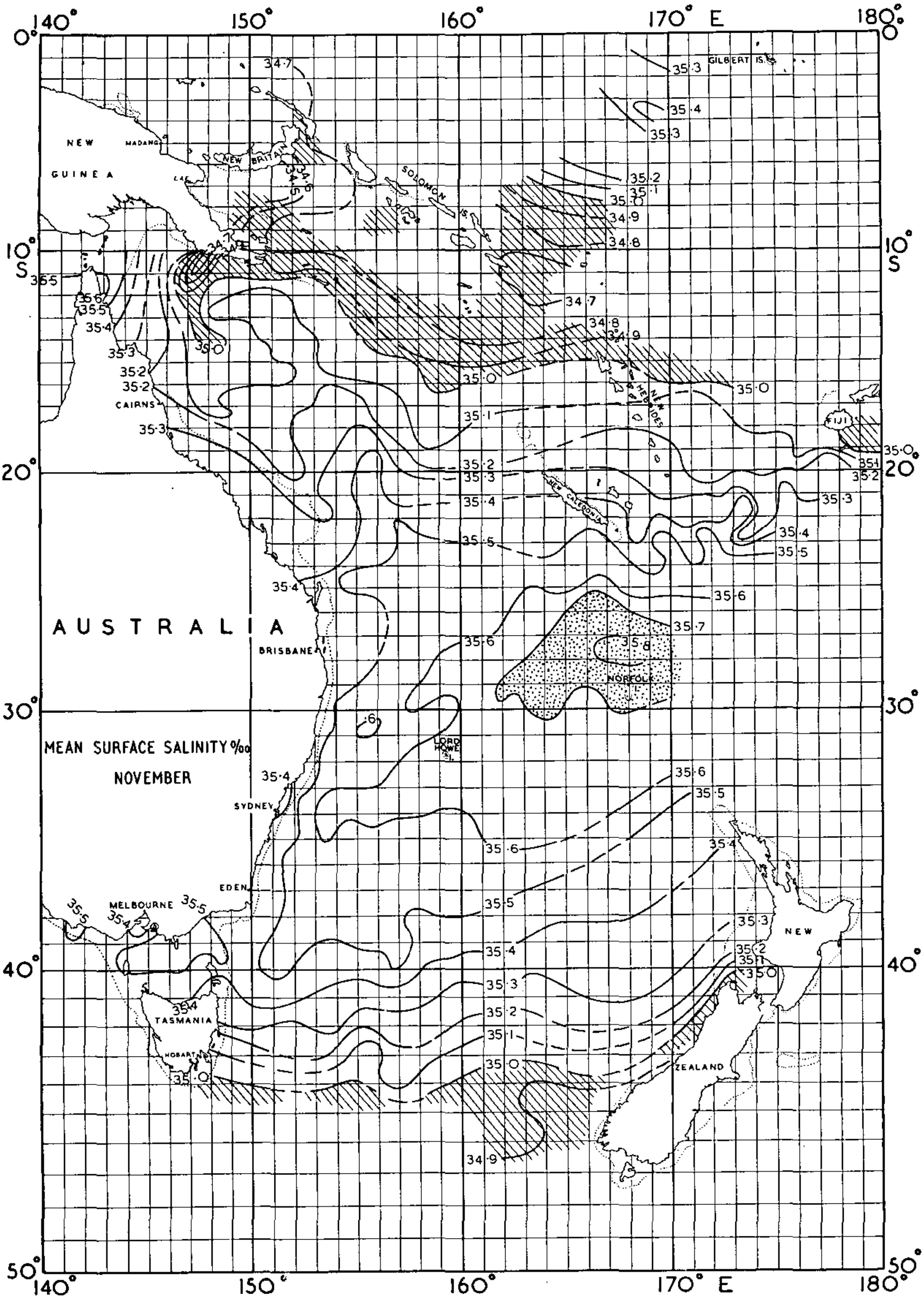

Fig. 12. November

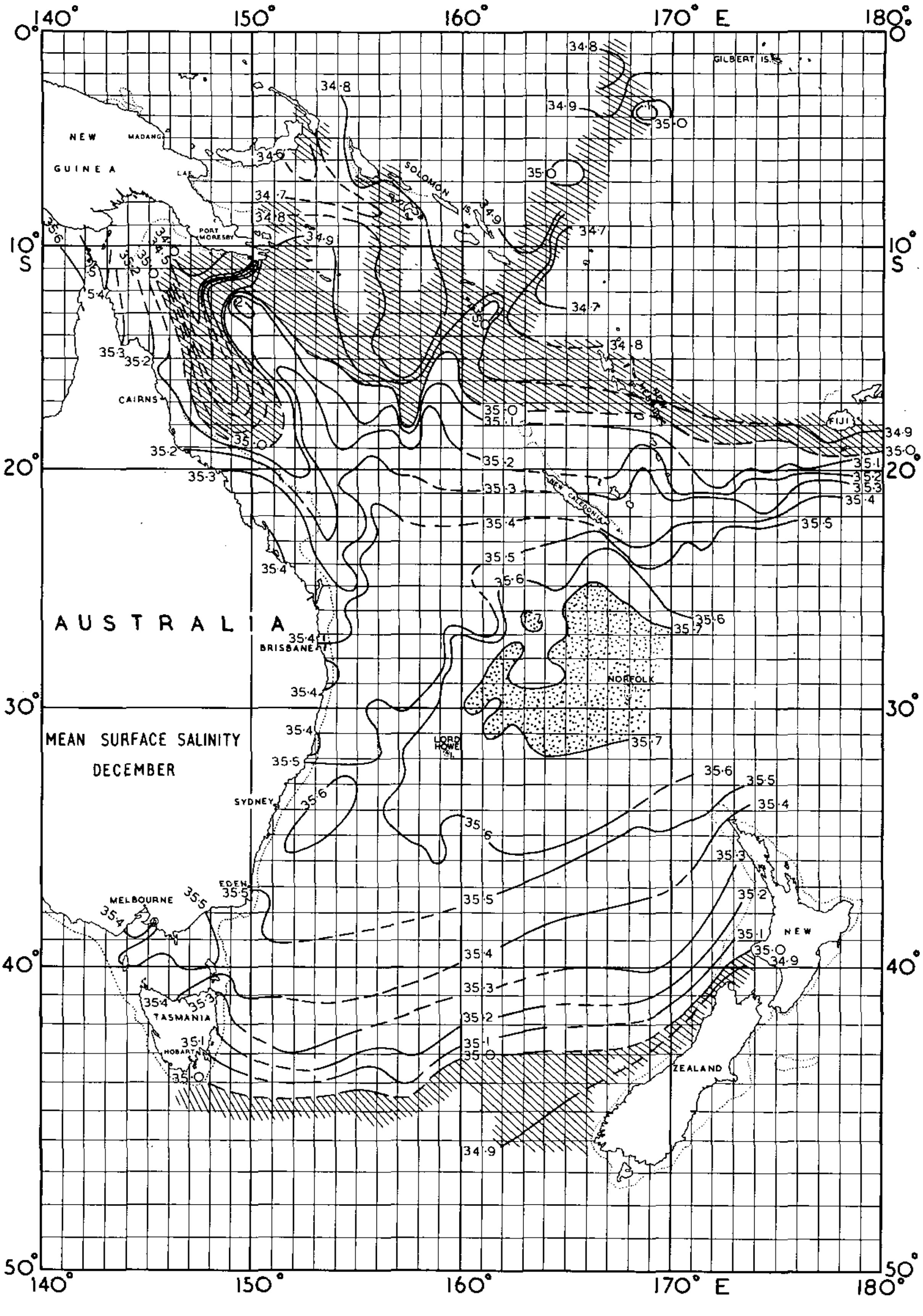

Fig. 13. December

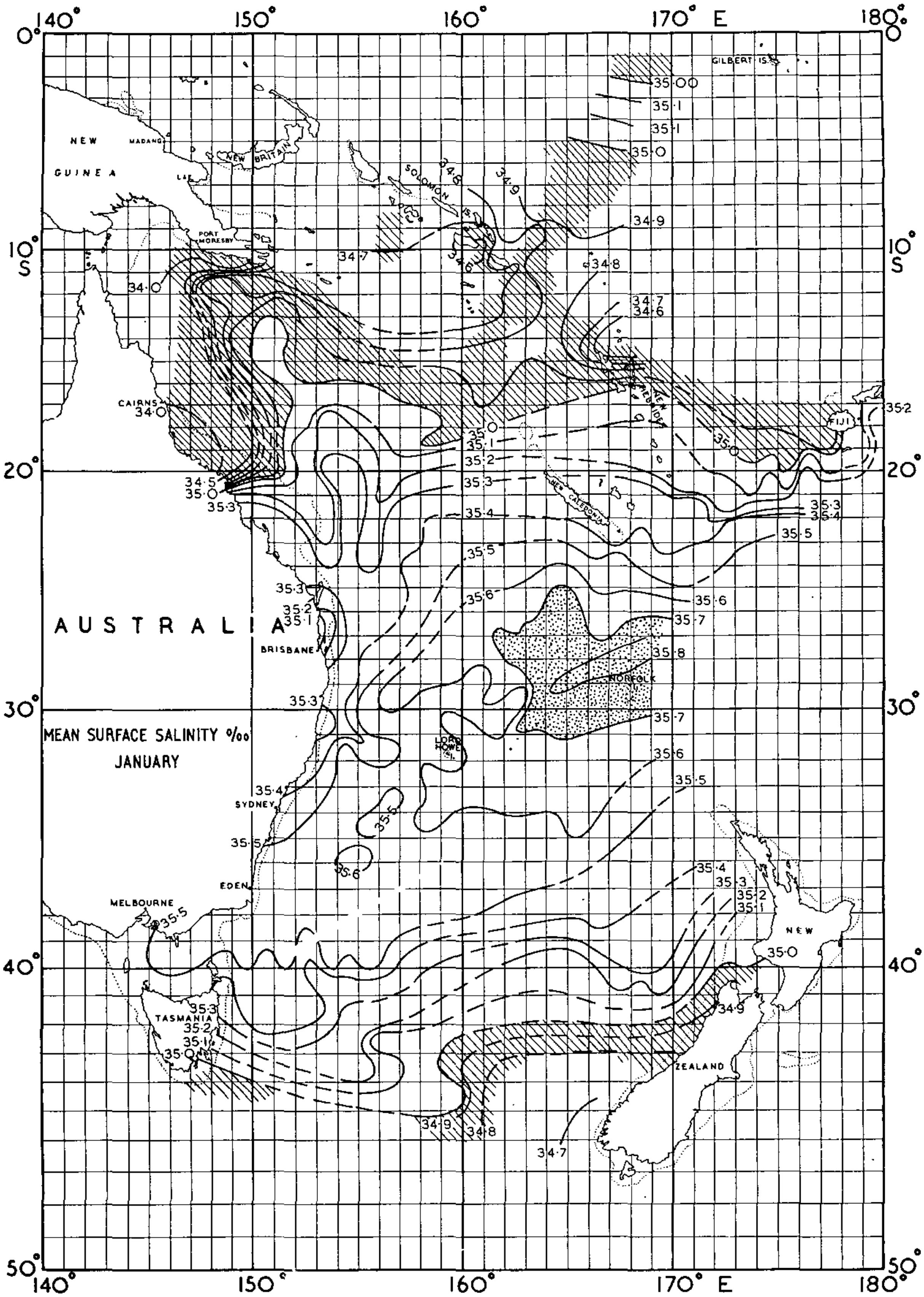

Fig. 14. January

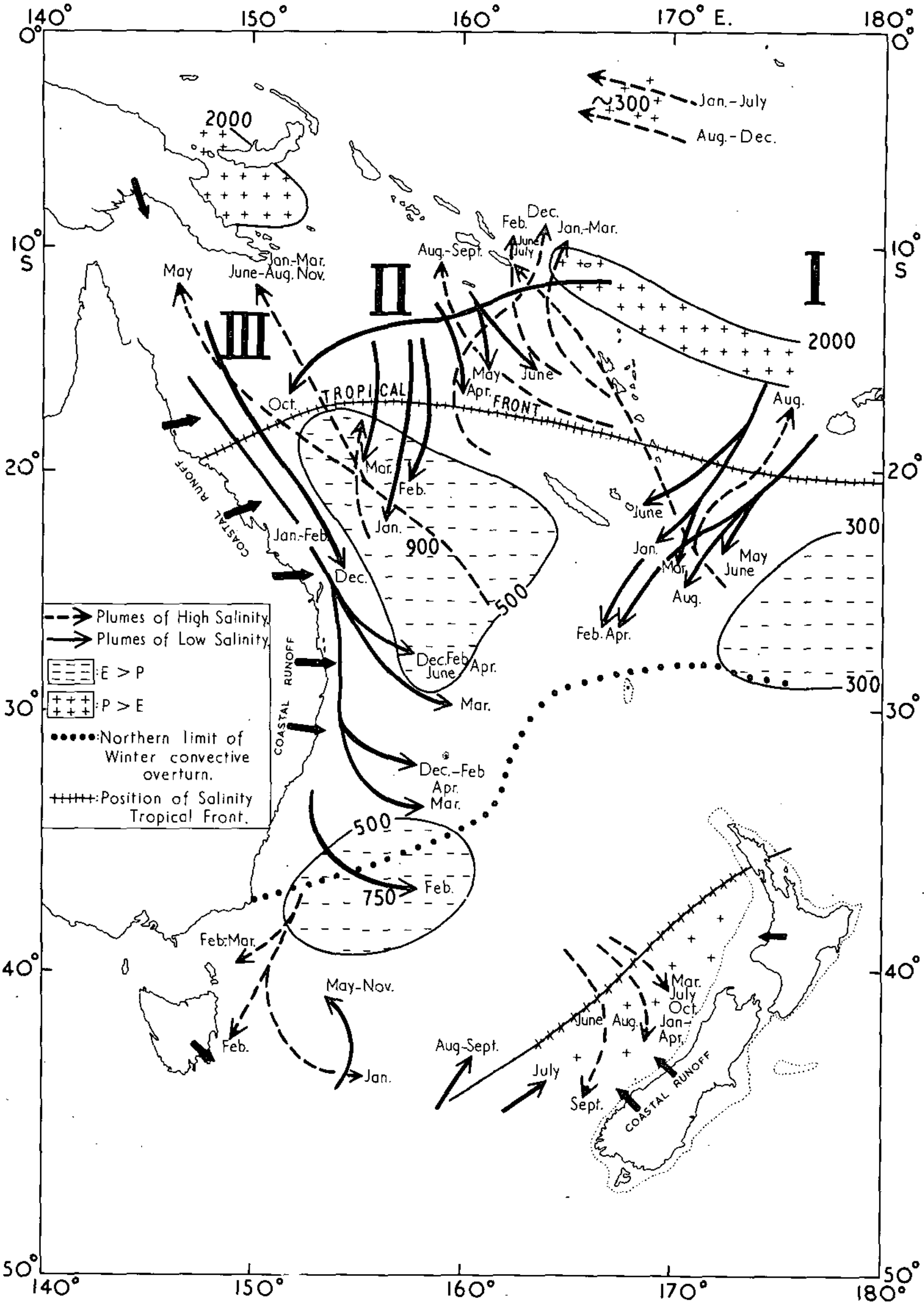

Fig. 15. Chart summarising:—

(a) Regions of major nett precipitation excess each year +++
(b) Regions of major nett evaporative loss each year - - -
(c) Principal plumes of low salinity water, their direction of flow (increasing salinity values) and their month or months of occurrence ——→
(d) Principal plumes of high salinity water, their direction of flow (decreasing salinity values) and their month or months of occurrence - - -→
(e) Northern limit of winter convective overturn ooooo
(f) Position of salinity tropical front ++++++

TABLE (1)

THE MEAN (1966-1974) ANNUAL AND QUARTERLY TOTALS OF PRECIPITATION AND EVAPORATION AND OF THE P-E DIFFERENCE WITHIN 5° SQUARES OF THE TASMAN AND CORAL SEAS

	Annual total (mm)			Dec.-Feb. total (mm)			March-May total (mm)			June-Aug. total (mm)			Sept.-Nov total (mm)		
5° □	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E
0-5°S 150-155°E	1900	1095	805	750	243	507	575	285	290	329	331	-2	375	246	129
5-10°S 145-150°E	4000	876	3124	850	189	661	1000	248	752	1150	258	892	1000	191	819
5-10°S 150-155°E	2725	1095	1630	825	243	582	850	276	574	525	313	212	525	237	318
5-10°S 160-165°E	2200	1679	521	825	486	339	600	313	287	375	340	35	400	519	-119
5-10°S 165-170°E	2400	1679	721	875	540	335	575	313	262	450	423	27	500	391	109
10-15°S 140-145°E	2000	1132	868	1050	315	735	745	248	497	120	294	-174	80	291	-211
10-15°S 145-150°E	1300	1095	205	670	288	382	455	294	161	100	304	-204	75	218	-143
10-15°S 150-155°E	1900	1241	659	550	315	235	675	359	316	400	340	60	475	246	229
10-15°S 155-160°E	2200	1350	850	600	279	321	725	386	339	400	350	50	475	346	129

5° ☐	Annual total (mm)			Dec.-Feb. total (mm)			March-May total (mm)			June-Aug. total (mm)			Sept.-Nov. total (mm)		
	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E
10-15°S 160-165°E	3000	1935	1065	900	342	<u>558</u>	950	423	<u>527</u>	500	589	-89	650	573	77
10-15°S 175-180°E	3000	1387	1613	925	324	<u>601</u>	825	478	347	550	331	219	700	273	427
15- 20°S 150-155°E	1100	1679	-579	475	342	133	350	497	-147	175	432	-<u>257</u>	100	382	-<u>282</u>
15- 20°S 155-160°E	1400	1825	-425	400	360	40	450	432	18	270	534	-<u>264</u>	280	482	-<u>202</u>
15- 20°S 170-175°E	3000	1533	1467	895	333	<u>562</u>	935	469	<u>466</u>	520	313	207	650	437	213
15- 20°S 175-180°E	3000	1460	1540	900	360	540	925	451	474	500	340	160	675	319	356
20- 25°S 150-155°E	1100	1533	-433	550	351	199	220	478	-258	190	386	-196	140	337	-197
20- 25°S 155-160°E	1100	2081	-981	350	396	-46	325	580	-255	250	543	-293	175	537	-362
20- 25°S 160-165°E	1000	1643	-643	335	306	29	255	534	-279	255	469	-214	155	328	-173

5° □	Annual total (mm)			Dec.-Feb. total (mm)			March-May total(mm)			June-Aug. total (mm)			Sept.-Nov. total (mm)		
	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E
20-25°S 165-170°E	1250	1533	-283	450	351	99	300	405	-105	300	300	0	200	319	-119
20- 25°S 170-175°E	1550	1752	-202	525	378	147	475	543	- 68	300	451	-151	250	391	-141
20- 25°S 175-180°E	1550	1898	-348	550	405	145	425	552	-127	275	543	-268	300	382	- 82
25- 30°E 150-155°S	1500	1679	-179	475	414	61	425	506	- 81	350	442	- 92	250	337	- 87
25- 30°S 155-160°E	1500	2120	-620	425	486	- 61	400	580	-180	425	580	-155	250	464	-214
25- 30°S 160-165°E	1400	1752	-352	300	378	- 78	350	534	-184	450	460	- 10	300	391	- 91
25- 30°S 165-170°E	1300	1570	-270	275	351	- 76	350	460	-110	425	423	2	250	346	- 96
25- 30°S 170-175°E	1300	1606	-306	275	315	- 40	400	524	-124	375	497	-122	250	273	- 23
25- 30°S 175-180°E	1300	1643	-343	325	333	- 8	375	497	-122	350	515	-165	250	300	- 50

5° ☐	Annual total (mm)			Dec.-Feb total (mm)			March-May total (mm)			June-Aug. total (mm)			Sept.-Nov. total (mm)		
	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E
30-35°S 150-155°E	1400	1606	-206	450	333	117	350	515	-165	350	497	-147	250	391	-141
30- 35°S 155-160°E	1300	1716	-416	275	423	-148	375	570	-195	375	552	-177	275	460	-185
30- 35°S 160-165°E	1400	1752	-352	275	369	- 94	325	524	-199	500	524	- 24	300	346	- 46
30- 35°S 165-170°E	1300	1497	-197	225	297	- 72	350	442	- 92	450	442	8	275	319	- 44
30- 35°S 170-175°E	1300	1387	- 87	250	270	- 20	325	377	- 52	450	442	8	275	273	2
30- 35°S 175-180°E	1300	1424	- 124	275	306	- 31	325	377	- 52	400	400	0	300	300	0
35- 40°S 150-155°E	850	1606	-756	225	288	- 63	200	497	- 297	225	497	-272	200	309	-109
35- 40°S 155-160°E	950	1716	-766	200	306	-106	250	570	-320	300	497	-197	200	346	-146
35- 40°S 160-165°E	1025	1460	-435	200	297	- 97	275	432	-157	325	368	-43	225	282	- 57

5° □	Annual total (mm)			Dec.-Feb. total (mm)			March-May total (mm)			June-Aug. total (mm)			Sept.-Nov. total (mm)		
	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E	Ppt.	Evap.	P-E
35- 40°S 165-170°E	1300	1350	- 50	250	234	16	325	359	- 34	425	451	- 26	300	291	- 9
35- 40°S 170-175°E	1300	1059	241	275	230	45	300	276	24	375	322	53	350	218	132
40- 45°S 145-150°E	625	913	-288	154	189	- 35	161	161	0	163	193	- 30	147	237	- 90
40- 45°S 150-155°E	725	1022	-297	175	288	-113	175	184	- 9	200	313	-113	175	237	- 62
40- 45°S 155-160°E	850	973	-123	175	230	- 55	225	239	- 14	250	267	- 17	200	237	- 37
40-45°S 160-165°E	1000	1107	107	200	171	29	290	386	- 96	260	322	- 62	250	228	22
40- 45°E 165-170°E	1350	1188	162	275	243	32	300	294	6	375	396	- 21	400	255	145